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# **Business Intelligence Analytics of the Inbound Materials Inventory's Planning Methods**

A case study in a Swedish provider of automotive  
technology

Master's thesis in MSc Quality and Operations Management

Hala Ahmed  
Marcus Bergqvist

DEPARTMENT OF TECHNOLOGY MANAGEMENT AND ECONOMICS  
DIVISION OF SUPPLY AND OPERATIONS MANAGEMENT

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# Business Intelligence Analytics of the Inbound Materials Inventory's Planning Methods

Hala Ahmed, Marcus Bergqvist

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Examiner and Supervisor: Patrik Jonsson, Department of Technology Management and Economics

Report no E2022:070  
Department of Technology Management and Economics  
Division of Supply and Operations Management  
Chalmers University of Technology  
SE-412 96 Gothenburg  
Telephone +46 31 772 1000

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## **Abstract**

Material planning is a dynamic activity-dependent on company-specific conditions; therefore, matching the planning method with the planning environment can support achieving good planning performance. Survey studies performed in the Swedish industry have indicated a need to investigate further how companies are using the methods, how parameters are set, and how often these are reviewed. The literature on material planning is well established; however, there is a lack of empirical evidence incorporating practical experiences and quantifiable data. This study aims to contribute to this area by analyzing quantitative data from a case company's ERP system to assess method-environment fit and how the case company sets and updates the parameters.

A mixed-method approach was used to address the research questions, where the quantitative data was used to identify general relationship patterns, while the qualitative data helped explain and interpret those patterns. Cluster analysis was utilized to establish a connection between the planning environment and the suitable method to support the case company in assessing the method environment fit. General empirical findings indicate the use of MRP and that the case company sets and updates the planning parameters manually based on experience or agreements with suppliers. Additionally, the case company has not identified an approach to link important environmental characteristics to the planning method used by the case company.

The main contribution of this thesis is a systematic six-steps process to categorize items based on different environmental characteristics, which can support assessing the method-environment fit, thus contributing to better inbound inventory planning performance. The results of performing this process on the case company's data included five clusters with different environmental characteristics. One group of items, for example, included items with environmental characteristics that make reorder point methods more suitable than MRP. Another group included items needing more attention due to high variation in weekly consumption patterns by updating the parameters more frequently or having more stock to account for this high variation.

Additional recommendations are presented in this study to support the case company in improving its materials planning performance. These included recommendations concerning measuring the method input and output performance, reviewing and updating parameters regularly, and taking a more structured approach to selecting a safety mechanism are also suggested for the case company to improve its materials planning practices.

**Keywords:** Inventory management, material planning methods, planning environment, planning parameters, item categorization, cluster analysis.

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Hala Ahmed and Marcus Bergqvist, Gothenburg, May 2022



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# 1. Introduction

*This chapter describes the background behind the issue investigated, followed by the research project's aim. Furthermore, a set of research questions are outlined to fulfil the research project's purpose. Additionally, the last section covers the delimitations.*

## 1.1 Background

A company's success depends on its ability to provide services to its customers, which often translates to having suitable products available at an acceptable price within a reasonable timescale (Wild, 2002). Inventory control can be seen as balancing conflicting requirements within the company. Consequently, it is a dynamic activity dependent on company-specific conditions where planning methods should be continuously revised to reflect changes in the environment (Ziukov, 2015). Furthermore, Wild (2002) argues that inventory control has a central role in supporting business activities to optimize three specific targets: customer service, inventory cost, and operating cost. However, the most profitable policy is not to create sub-optimizations in any of these areas; thus, the focus of inventory control is to secure an optimal balance between these (Wild, 2002).

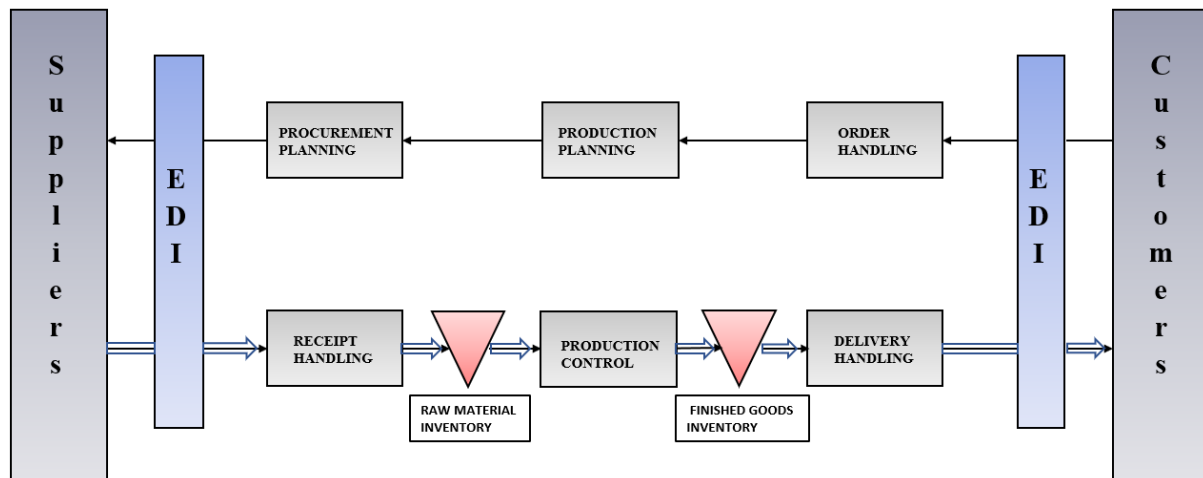
The primary purpose of the inventory is a buffering, decoupling function, where it acts as a shock-absorber between the company's manufacturing capabilities and customer demand and between component availability and finished assembly requirements (Fogarty et al., 1991). Material planning is a central part of inventory management at the tactical and operative level to balance supply and demand to keep the material flow and the value-adding activities in manufacturing going without interruptions (Jonsson and Mattson, 2002). Deciding order quantities and delivery times for replenishing the inventory most efficiently is considered the main problem within inventory management (Wild, 2002). Throughout the years, survey studies performed in the Swedish industry have informed about discrepancies in the fit between different planning methods and the environmental context (Jonsson and Mattson, 2014). Consequently, this affects other parts of the organization since many activities are dependent on the correct level of stock being held (Wild, 2020).

The use of specific planning methods often depends on the current planning environment in which the company operates, where forecast accuracy and variations in outbound volumes seem to aggravate environmental factors. Therefore, it becomes crucial to investigate practical experiences from which the methods are used, how they are used, how the usability is perceived, and what circumstances affect how they work practically (Jonsson and Mattson, 2014). That is because these factors, in addition to how the parameters are determined, the frequency of their review, and the frequency of planning, may affect the planning performance (Jonsson and Mattsson, 2008).

Many planning methods were developed many years ago, but their use and applicability are still valid from a theoretical point of view (Mattson, 2007). However, the decision models inherent in the methods are built on a set of simplifying assumptions, and the effectiveness of the methods is thus dependent on the extent to which these assumptions are reasonable in the planning environment in which they are used (Mattson, 2007). Consequently, the method must reflect the planning environment to be helpful as a decision support tool. Theories on inventory management and the planning method are well established; however, there has been a lack of adequate empirical analysis of the performance of the material planning methods and the impacts on the planning environment (Jonsson and Mattsson, 2008). This thesis targets to contribute to this underexplored area by analyzing empirical data from a case company.

This research is conducted in collaboration with Meridion AB, a business management consultancy specializing in consulting services for Infor M3 and Qlik sense. Infor M3 is a cloud-based ERP system for manufacturing and distribution that provides analytics features for users (Infor, 2022). Qlik sense, on the other side, is a data visualization tool that supports the users in understanding and using their data more effectively (Qlik, 2022). The case company is one of Merdion AB's clients, and it is a supplier for the automotive industry and mainly provides safety components for autonomous vehicles and advanced driving assistance systems. The company has had a previous collaboration with Chalmers, and several theses have been conducted in different areas within **Figure 1**. The thesis focuses on the raw materials inventory triangle and the demand and environment related to it.

Figure 1 Example of the information and material flow in a production company



**Figure 1** illustrates a production company's information and material flow from a supply chain perspective (Meridion, 2022). It is a general model used to describe the process from customer order to delivery. The thin black arrows in the Figure illustrate the flow of information, whereas the blue arrows illustrate the material flow.

## 1.2 Aim

This project was carried out in collaboration with Meridion AB to investigate one of their clients' inbound inventory management methods. The aim of the project was to investigate the method-environment fit and how the case company sets and updates safety stocks, lead times, and order quantities. This was facilitated using data and Business Intelligence (BI) visualization tools to identify planning environment characteristics and how these relate to the chosen planning method.

The outcome of the thesis can be divided into three different levels. The first is to assess the method-environment fit and the case company's way of using the planning methods, the second is to outline a way for the case company to set the inventory management parameters, and the third is to manage the update of these parameters over time. This is facilitated by a six-steps process that enables the case company to identify different environmental characteristics and match these with a suitable planning method. The process also supports determining purchased items that might need more frequent updates of the parameters.

### **1.3 Specification of the issue under investigation**

Three research questions were formulated based on the aim of the project. Initially, it was essential to understand how the planning environment was related to what planning methods and parameters were used and whether some specific methods and parameters are better suited depending on the environmental context.

- *Research question 1 - What are the different possible materials planning methods for the case company's inbound inventory management?*

Secondly, to understand the environmental context in which the case company operates and how the planning methods are matched accordingly, it was necessary to examine whether the case company uses a suitable planning method given the current environmental characteristics. Additionally, a central part was to look into how the parameters are set and how frequently these are updated.

- *Research question 2 - How does the case company currently work with their planning methods in terms of interpreting the data, setting, and updating the parameters, and how does the current setup and planning environment affect the inventory management performance?*

Lastly, the thesis also explored possible approaches to improve the inbound inventory materials planning performance

- *Research question 3 - How can the case company improve its inbound inventory materials planning performance and establish a fit between the used planning method and the planning environments?*

## **1.4 Delimitations**

The project was limited to addressing inventory management regarding purchased goods, where the focus was on inbound inventory management. Additionally, the study was limited to one company to allow for an in-depth analysis of the topic. Furthermore, the project mostly used existing data from the case company's Enterprise Resource Planning (ERP) system, namely Infor M3, and did not involve the generation of new quantitative data. However, qualitative data was gathered through interviews to increase the understanding of the secondary quantitative data from the system.

Additionally, the focus was limited to the internal planning environment, where no further analysis was conducted regarding the macro environment, i.e., external aggravating factors. Lastly, this study only considered the most widely used materials planning methods, which are, according to (Jonsson and Mattsson, 2006), reorder point systems, run-out time planning, Kanban, periodic review system, and Material Requirements Planning (MRP).



## 2. Literature Review

*This chapter covers theories on the most common materials planning methods, and various factors related to the planning environment are discussed and related to each planning method's applicability in different environmental contexts. Moreover, all planning methods' most common parameters are explained and discussed. Lastly, item categorization and the role of the ERP system are also reviewed in the chapter.*

### 2.1 Material Planning methods

Material planning aims to establish quantities and points in time for every product and item to initiate material flows and satisfy existing requirements (Jonsson and Mattsson, 2009). Therefore, material planning can be considered by answering four basic questions: (1) which item should the new orders be planned for? (2) what is the order quantity for each item? (3) when should the order for each item be delivered? And (4) when should the order be placed with the supplier or started in internal manufacture? (Jonsson and Mattsson, 2009). Material planning methods mainly answer the first question and provide a basis for making decisions regarding the three other questions; however, the bases for decisions are generated differently in the different methods (Jonsson and Mattsson, 2009).

#### 2.1.1 Reorder point system

In this method, materials are ordered based on a reference quantity called the reorder point, whereas when the inventory level falls below the reorder point, the stocks are replenished, and re-ordering takes place (Jonsson and Mattsson, 2009). The reorder point -when to place the order- is determined based on the actual inventory balance, while the reorder quantity is determined based on the average expected demand (Thomas E. Vollmann et al., 2005). The reorder point quantity is calculated as the expected usage during lead time added to the safety stock quantity (Jonsson and Mattsson, 2009). The reorder point is calculated excluding safety stock to ensure that the quantity available in stock would be sufficient to cover requirements when the stock falls below the reorder point quantity during the replenishment lead time (Jonsson and Mattsson, 2009).

$$ROP = SS + D \cdot L$$

Where: ROP = reorder point, SS = safety stock, D = demand per time unit, and L = lead time

Based on the survey data (Jonsson and Mattsson, 2014), the reorder point system and the MRP are the most common materials planning methods used in the Swedish industry. However, the reorder point system is used as the primary method in distribution companies (Jonsson and Mattsson, 2014).

Several material planning methods are considered variants of the reorder point method, and there are also different applications for this method. The material planning based on this method is usually built on accumulated future demand; thus, the method is considered more suitable for controlling items with independent demand and is not intended for items with dependent demand. However, some consideration can be taken to dependent demand, and it is possible to use the reorder point system for items with dependent demand. (Jonsson and Mattsson, 2009).

### **2.1.2 Periodic review system**

The logic behind this method is to have planned deliveries with fixed intervals and fixed delivery quantities to reduce the transaction cost. In this method, the reference level for the order is calculated by adding the expected consumption during the replenishment interval and the lead time plus a safety stock (Jonsson and Mattsson, 2009).

$$T = D \cdot (R + L) + SS \qquad Q = T - S$$

Where: Q = order quantity, T = target level, D = demand per time unit, R = reordering interval, L = lead time, SS = safety stock, S = stock on hand

The periodic ordering method is similar to the reorder point system, and they share many characteristics. The main difference between the two methods is that the period between the consecutive inbound deliveries is constant, and the order quantities vary in the periodic ordering method. While in the reorder point system, the time between deliveries varies, and the order quantities are fixed. (Jonsson and Mattsson, 2009).

### **2.1.3 Run-out time planning**

The run-out time planning method is closely related to the reorder point method. However, in this method, the requirements to cover are expressed as a period of time, in contrast to the reorder point method, which is described as a quantity. Therefore, run out time refers to the available time in stock and how long the stock is expected to last, i.e., cover time. Run-out time is equal to the stock on hand divided by the anticipated demand per time, and the decision rule is that the order should be placed if the run-out time is shorter than the summation of the safety lead time and the replenishment lead time. (Jonsson and Mattsson, 2009).

### **2.1.4 Rate-based (Kanban) planning**

The rate-based planning is a reorder point method based on the use of kanban cards (Jonsson and Mattsson, 2009). Kanban is considered by Oden et al. (1993) as the simplest method to control inventories since it does not require any formal planning or record keeping. It follows a basic principle illustrated in the following steps according to Jonsson and Mattsson (2009):

- Step 1: The attached Kanban card is released when removing the first item from a ballet or when a pallet becomes empty at the consuming unit
- Step 2: This released Kanban card is then sent to the supplying unit
- Step 3: The supplying unit is authorized via the card to transfer a full standard pallet to the consuming unit
- Step 4: Before sending the Kanban card to the downstream consuming unit, the received card at the upstream stock unit is attached to the pallet

### **2.1.5 Material Requirements Planning (MRP)**

MRP calculates when additional material requirements are needed, and based on this, the method determines and schedules new deliveries at points in time (Jonsson and Mattsson, 2009). MRP develops planned purchase orders for inbound inventory materials, i.e., raw materials, components, and subassemblies required to fulfil the Master Production Schedule (Oden et al., 1993).

The basic principle for the MRP method is only to schedule a new purchase order when there is a net requirement at a specific point in time. This point for order release is calculated by deducting the lead time for an item from the delivery time (Jonsson and Mattsson, 2009). MRP uses inputs from the Master Production Schedule, Bills of Material (BOM), and inventory data (Oden et al., 1993) and then applies simple-straightforward calculations and a common-sense approach to material planning (Landvater, 1997). The starting point for MRP is the master production schedule, which provides the requirements of the items. MRP then obtains information based on the BOM file from the ERP system to link the master production schedule for a finished product to the requirements of the components used in this finished product (Jonsson and Mattsson, 2009). Based on this, required order quantities for raw materials and components are calculated, along with the points in time when these requirements occur (Jonsson and Mattsson, 2009).

#### *2.1.5.1 MRP nervousness*

MRP nervousness can be defined as “*significant changes in MRP plans, which occur even with only minor changes in the higher-level records or the master production schedule*” (Jacobs et al., 2011, p. 300). Such changes can cause variations in delivery schedules further down in the value chain, and there are many ways in which minor changes in the MRP system can create nervousness or instability in the MRP plans. Moreover, shifts in MRP parameter settings such as safety stock, safety lead time, and planned lead time values and the use of some lot-sizing techniques are common contributors to the general MRP performance and can thus cause instability in the system (Enns, 2001). Instability caused by these changes is, according to Jacobs et al. (2011), more damaging to the MRP performance in systems with many levels in the product structure. Furthermore, there are several ways to mitigate nervousness in the system outlined by Jacobs et al. (2011). First, it is crucial to carefully alter the parameter settings since it can dampen the nervousness and be a trigger for it. It is also suggested to select different lot-sizing techniques for the various levels in the product structure. However, lot sizing is generally not relevant when manufacturing is customer-order initiated (Jonsson and Mattsson, 2009).

## **2.2 The planning environment**

The planning environment is often referred to as specific conditions that characterize the product, production process, and material flows, each associated with different variables which constitute the essential prerequisites for planning (Jonsson and Mattsson, 2003). The selection of materials planning methods should be based on the existing planning environment and thus support prioritized company goals (Jonsson and Mattsson, 2009; Spenhoff, Semini, and Alfnes, 2014).

### **2.2.1 Product related variables**

As one of the influencing areas, product-related variables will impact the application of the planning method of choice (Jonsson and Mattsson, 2003). In a manufacturing process, many products must be controlled simultaneously where several products are related to each other in that one product is required to manufacture another; thus, there is a dependent demand between different components (Van Veen and Wortmann, 1992). The bill of material (BOM) will ultimately impact the material planning performance regarding the inherent complexity that follows when the number of levels and items on each level increases (Jonsson and Mattsson, 2003). Moreover, Jonsson and Mattsson (2003) further state that the accuracy of the product data, i.e., detailed component information, is another variable that will have implications for the choice of material planning method. Additionally, the product variety will consequently be significant from a material planning perspective.

### **2.2.2 Material flow variables**

Material flow conditions are another set of variables influencing which material planning method is the most suitable. Compared to the product variables, these variables are more related to the consumption patterns of the different materials. A central part here is the material flow to production, where the volume and frequency of a specific material are crucial to consider when applying different material planning methods (Jonsson and Mattsson, 2003). Moreover, the nature of the demand is another variable that is essential to consider and will thus have implications on the planning performance.

Zuikov (2015) classifies demand as either deterministic or probabilistic, where the first type constitutes known demand and the second type unknown demand. Based on this classification, the deterministic environment can be divided into either dynamic -varies over time- or static -the same over time-. On the other hand, the probabilistic environment can be divided into stationary and non-stationary, which refers to whether the demand follows a probability distribution or is entirely random. Moreover, whether a material has a dependent or independent demand is another important variable that needs to be considered (Jonsson and Mattsson, 2003). Dependent demand refers to the demand for a specific component or item assembled into the final product, while independent demand refers to the demand for a finished product (Mentzer et al., 2007). Additionally, Jonsson and Mattsson (2003) further state considerations regarding the procurement ordering type and the source of the demand, i.e., whether it is a replenishment order or a custom order. Furthermore, Mattsson (2007) notes that the lead time from suppliers has been reduced substantially over the years, which has led to more frequent replenishments of materials. According to Mattsson (2007), this has changed the dynamics in the planning environment in terms of the timing of replenishments, which consequently affects the application of the material planning methods.

### **2.3 Method-environment fit**

The different materials planning methods provide fundamentally the same type of support. However, these methods vary in applicability, whereas the environment plays a central role in determining how these planning methods can be used efficiently and effectively (Jonsson and Mattsson, 2006). For example, reorder point methods, e.g., reorder point system, periodic review system, and run out time planning, are mainly designed for independent demand items, and they work better when the product components are more standardized, have longer life cycles, and have a more stable demand (Jonsson and Mattsson, 2006). In contrast, Kanban is most suited for items with steady and regular demand, simple BOM, short lead times, and small order quantities (Jonsson and Mattsson, 2006). On the other hand, MRP works acceptably well in all manufacturing environments, but it has a specific strength in planning items with dependent demand. (Jonsson and Mattsson, 2006).

**Table 1** summarizes the primary application environments for the selected planning methods and their limitations. This thesis focuses on inbound inventory items, and the demand for such items can be traced to the demand for the finished goods through the Bill of Materials (BOM), thus, making it a dependent demand. Dependent demand items are usually managed best by an MRP type system (Fogarty et al., 1991). However, using reorder point methods for such items unavoidably causes backorders and constant shortages and expediting (Oden et al., 1993). Therefore, to manage dependent demand items effectively and efficiently, accurate inventory status, BOM files, and an MRP system are required (Fogarty et al., 1991). Nevertheless, reorder point methods can be useful for controlling dependent demand items in some instances, such as standard low-value items or those incorporated in many different BOMs where the total demand tends to be smoothed out (Jonsson and Mattsson, 2009).

*Table 1 Main application environments for the materials planning methods*

Method	Main application environment	Limitations
<b>Reorder point system</b>	Items with independent demand Low-value items Large variation in demand Frequent requirements Small order quantities and short lead times	Not possible to generate delivery schedules Future requirements cannot be planned
<b>Periodic review system</b>	Items with independent demand Frequent requirements Coordination of items Small order quantities and short lead times	
<b>Run-out time planning</b>	Items with independent demand Frequent requirements Seasonality in demand Access to capacity is not a significant issue	
<b>Kanban</b>	Items with independent demand Small order quantities Simple BOM Regular and steady demand	
<b>MRP</b>	Dependent demand Known and long lead times Predictable variation in demand Complex standardized products or product options Uneven demand	Nervousness to changes

## **2.4 Materials Planning Parameters**

There are specific mechanisms connected to the materials planning methods to determine or address the time and quantity-related questions and different uncertainty considerations related to balancing supply and demand. According to Jonsson and Mattsson (2006), the quantity mechanisms for the different planning methods are the same, but each method's mechanisms for timing are specific. Therefore, the main parameters can be related to lot sizing, safety mechanisms, lead times, and planning frequency (Jonsson and Mattsson, 2006).

### **2.4.1 Lot size determination**

The concept of lot sizing is considered one of the most important in supply chain management due to its impact on critical areas of an organization's performance concerning the flow and storage of materials (Roettig, 2016). Lot sizing decisions must be made in widely varying circumstances where objectives on a multidimensional level need to be considered (Dolgui and Prodhon, 2007). Therefore, extensive research on the subject has led to the development of a variety of lot-sizing techniques, each trying to deal with the increasing complexity in different practical situations (Kuik, Salomon, and Wassenhove, 1994; Axsäter, 1986).

Conceptually, lot sizing methods deal with the quantity aspect of material planning, where the motives for lot sizing can, according to Jonsson and Mattsson (2009), be divided into financial and non-financial. The financial aspect of lot-sizing deals with the balance between ordering cost and carrying cost, where lot sizes should be determined as efficiently as possible regarding tied-up capital (Jonsson and Mattsson, 2009; Toomey, 2000). Moreover, non-financial elements of lot-sizing are often based on the necessity to produce or procure larger quantities than needed due to, e.g., production constraints or other external environmental factors (Jonsson and Mattsson, 2009). Furthermore, the accuracy of the lot sizing methods is dependent on several environmental factors, which has led researchers to categorize the methods based on different variables (Kuik et al., 1994).

Since a model is only an abstraction of reality, it is challenging to obtain realistic input values for the different methods, making it challenging to find an optimal method (Ziukov, 2015; Dolgui and Prodhon, 2007). According to Jonsson and Mattsson (2009), lot sizing methods can be classified based on whether the order quantity is fixed or variable or if the expected run-out-time is fixed or variable see **Figure 2**. Based on this categorization, it is possible to determine three groups of methods where each group performs differently under specific conditions (Jonsson and Mattsson, 2009).

*Figure 2 Example of lot-sizing methods*

Quantity	Fixed		<ul style="list-style-type: none"> <li>- Estimated order quantity</li> <li>- Economic order quantity</li> </ul>
	Variable	<ul style="list-style-type: none"> <li>- Lot for Lot</li> <li>- Estimated run-out-time</li> <li>- Economic run-out-time</li> </ul>	Dynamic lot sizing methods
		Fixed	Variable

Run-out time period

Regardless of which method is used, the general objective is to minimize the cost per unit of time; however, the main difference lies in how each method translates activities and system accomplishments into costs (Kuik et al., 1994).

## 2.4.2 Safety mechanism determination

Implementing safety mechanisms protects the material flow from disruptions due to demand and supply uncertainty (Jonsson and Mattsson, 2006). Therefore, it is necessary to deploy different buffer mechanisms to secure desired service levels, reduce the risk of stockouts, and handle uncertainty (Roettig, 2016). There are two main ways of doing this depending on the circumstances, i.e., by either adding safety stocks or safety lead times (Jonsson and Mattsson, 2009). Safety lead time should be used when there are uncertainties in lead time and safety stocks during uncertainties in supply and demand quantity (Whybark and Williams, 1976). However, sometimes it is possible to use quantity buffers during time uncertainties when the demand for each period is small compared to the annual demand because quantity buffers can cover several planning periods (Jonsson and Mattsson, 2009).

Generally, the traditional methods of calculating safety stocks are a function of the service levels, replenishment lead time, demand uncertainty, and lead time uncertainty (Chopra, Reinhardt, and Dada, 2004). Based on these variables, multiple methods for dimensioning safety stocks have been developed (Barros, Cortez, and Carvalho, 2021). According to Silver, Pyke, and Peterson (1998), these can be divided into three groups: simple-minded approach, customer service levels, and cost optimization. The number-of-days method, commonly used in the first group, is considered the simplest to calculate safety stocks (Jonsson and Mattson, 2019). However, this method has been given limited attention in the literature and is often criticized for not considering demand and lead time variation. According to Barros et al. (2021), these are two essential parameters for establishing adequate safety stock levels. Despite the criticism, close to 50 % of medium- and large-sized companies in the Swedish industry use this method (Jonsson and Mattsson, 2014).

Furthermore, the second group of safety stock methods is based on a targeted service level where the corresponding safety stock is calculated with an assumed demand distribution (Jonsson and Mattson, 2019). According to Axsäter (2006), cycle service and demand fill rate are two prominent methods included in this category. The cycle service is defined as *“the probability of being able to deliver directly from the stock during one inventory cycle, i.e., between two successive inventory replenishments”* (Jonsson and Mattsson, 2009, p.271), and the demand fill- rate can be defined as *“the proportion of demand that can be delivered directly from stock”* (Jonsson and Mattsson, 2009, p.271). Jonsson and Mattsson (2019) note that the demand fill rate is the most scientifically favoured method used in practice. One reason is that the cycle service method has been criticized for not considering replenishment order quantities or the number of shortage risk occurrences (Axsäter, 2006). In addition, Vandepuut (2020) argues that the demand fill rate is more relevant when the order cycles are long. However, according to Barros et al. (2021), the cycle service level method is easier to optimize mathematically.

### **2.4.3 Lead-time determination**

The accurate estimation of lead times is crucial for all material planning methods (Jonsson and Mattson, 2006). A critical factor in any planning system is to trust that the materials will be available on time. Thus changes in the total replenishment lead time need to be closely monitored and updated to ensure desirable planning performance (Roettig, 2016). Companies use different approaches to determine lead times, i.e., based on experience, monitoring actual lead time, or using calculations in the ERP system (Jonsson and Mattson, 2006). However, determining lead times based on experience may harm the planning performance (Jonsson and Mattsson, 2008). Another drawback with experience-based lead times is that lead times must be updated manually and are thus more costly to review.

Furthermore, the replenishment lead time is often subject to uncertainties, which can provoke shortages or surplus in inventories and nervousness in the system (Dolgui and Prodhon, 2007). Therefore, it is suggested to calculate the lead time analytically to ensure more accurate estimates of the total lead time (Jonsson and Mattsson, 2006). Frequently, lead times are rarely constant due to unpredictable events that can cause random delays in the system (Hnaïen, Dolgui, and Ould Louly, 2008). The authors agree that fluctuations in lead times can negatively affect the system's performance; however, it is possible to ignore these fluctuations in some instances. Usually, random factors that cause delays in the system are often mitigated by implementing safety stocks (Hnaïen et al., 2008). However, changes in replenishment lead time need to be adjusted, especially when using dynamic safety stock calculations to reduce the risk of either shortage or excess safety stock levels (Roettig, 2016).

### **2.4.4 Planning frequency and parameter review**

The planning frequency is closely connected to perceived planning performance, especially in environments characterized by uncertain demand (Jonsson and Mattsson, 2008). The authors argue that more frequent planning will result in more accurate and updated plans, whereas less frequent planning implies longer planning intervals, which from a planning perspective can increase uncertainty. However, shorter planning periods can cause instability in the system, often referred to as systems nervousness (Blackburn, Kropp, and Millen, 1986).

Additionally, Jonsson and Mattsson (2006) showed that an increasing number of companies had developed a re-planning capability in their Enterprise Resource Planning system. However, only a few of these companies do this automatically. Furthermore, the quality of the planning parameters also impacts the performance of the material planning method in terms of how accurately they represent reality (Sheu and Wacker, 2001).

#### *2.4.4.1 Planning horizon*

Planning is done on mainly three levels in a company: strategic, tactical, and operative, where each of these levels requires different planning time horizons (Jonsson and Mattsson, 2009). Generally, the planning horizon is the interval on which assumptions and decisions are made concerning the demand (Kuik et al., 1994). Material planning is related to the operative decision level, on which the planning horizon is often determined based on how precise decisions can be made with the available information (Jonsson and Mattsson, 2009). Kuik et al. (1994) state that the planning horizon can be either finite, i.e., a defined timeline, or infinite, i.e., no specifically defined timeline, and these are usually accompanied by dynamic or stationary demand, respectively. Essentially, the required length of the planning horizon is related to the required level of detail in the planning (Jonsson and Mattsson, 2009).

## **2.5 Item categorization**

A common method for categorizing items is the ABC classification, where two of the most common ranking criteria used are demand value and demand volume (Teunter, Babai, and Syntetos, 2010). In addition, other criteria such as lead time and item criticality are sometimes more important than solely using financial measures (Flores, Olson, and Dorai, 1992). Based on the criteria used, items will then be classified into different groups, labelled A, B and C, depending on how many groups are suitable to use for the current situation (Teunter et al., 2010). Furthermore, the method is used for classifying items and can also be used to group customers, suppliers, and other objects into different classes based on the most suitable ranking criteria to aid inventory management decision-making (Jonsson, 2008). In its practical use, ABC analysis applies the minority principle, which means that every group of objects has a small number that accounts for a large portion of the value (Jonsson, 2008).

Depending on the company's nature and context, the number and type of criteria and the relative impact of each may vary (Flores et al., 1992). However, adopting a multicriteria approach when using the ABC classification can, according to Flores et al. (1992), be increasingly more complex to analyze and make practical use of it for decision making. To handle multi-criteria scenarios, the authors suggest using the analytic hierarchy process (AHP), which provides a way to combine multiple criteria by generating a consistent measure that can be used in combination with the classical ABC structure. However, this approach requires more information about each item, requiring increased managerial attention to find key criteria to group with (Flores et al. 1992). Additionally, Huiskonen, Neimi, and Pirttilä (2003) further discuss the importance of using multiple criteria to classify inventory items but adds the importance of linking customer characteristics to inventory decision-making. They propose a four-step process consisting of the following steps: (1) Classify the products based on specific criteria, (2) analyze customers to find their importance from a supplier perspective, (3) Identify customer groups and segments, and (4) combine the product and customer characteristics.

## **2.6 Role of ERP system in materials planning**

Enterprise resource planning (ERP) is a framework for organizing, defining, and standardizing essential business processes to enable effective planning and control to facilitate internal knowledge sharing between functional units (Jacobs and Weston Jr, 2006). Most ERP systems offer practical support for effective material planning using various planning methods (Jonsson and Mattson, 2006). The complexity of ERP systems puts specific requirements on the individual user and the organization as a whole (Umble, Haft, and Umble, 2002). Due to the ERP systems' integrated nature, data accuracy is a central part of an ERP system to function appropriately, whereas wrongly entered data inputs can have detrimental effects on the system's performance (Umble et al., 2002). Moreover, to mitigate such mistakes, extensive education and training among users are necessary to take advantage of the different functionalities provided by the system (Umble et al., 2002).

Jonsson (2008) elaborates on the importance of providing sufficient training and states that it is even more critical in larger organizations since employees need a better understanding of their role and how their actions impact downstream users. Thus, the general focus should be to develop an organization where the planner has the knowledge, authority, and the time to manage the planning parameters effectively to facilitate the use of the different material planning methods (Jonsson, 2008). Additionally, Jonsson and Mattsson (2006) further emphasized the importance of frequently reviewing the parameters to increase the operative performance of the material planning.

## **2.7 Framework connected to the project**

**Table 2** outlines the theoretical frame connected to each research question. **Section 2.1** summarizes some of the most commonly used materials planning methods, which provides the reader with a general understanding of the characteristics of the methods. **Section 2.2** provides a theoretical explanation of what constitutes the planning environment and the most common characteristics that need to be considered when choosing the planning method. Moreover, **section 2.3** connects the environmental characteristics to each planning method to give the reader an understanding of which method is best suited for the different planning environments. Additionally, **section 2.4** discusses some of the most important parameters which are central to all planning methods. These sections will primarily aid in addressing RQ1 and RQ2. Lastly, **sections 2.5** discuss the importance of categorizing items to match the planning method to the planning environment, and **section 2.6** outlines the general role of the ERP system in materials planning. **Sections 2.6** and **2.5** are relevant to answer RQ2 and RQ3.

*Table 2 Theoretical frame connected to the project*

Theoretical framework	RQ1	RQ2	RQ3
2.1 Material planning methods	<b>X</b>	<b>X</b>	
2.2 The planning environment	<b>X</b>	<b>X</b>	
2.3 The effect of the planning environment on the planning method performance	<b>X</b>	<b>X</b>	
2.4 Material planning parameters		<b>X</b>	
2.5 Item categorization		<b>X</b>	<b>X</b>
2.6 Role of the ERP system in materials planning		<b>X</b>	<b>X</b>



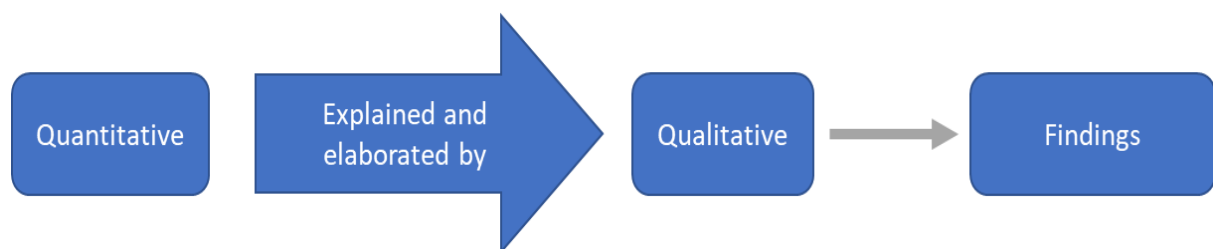
## 3. Methodology

*This chapter covers the methodology used in the project. It describes the research strategy, design, and process. It also explains how researchers collected data and decided on the sampling technique. Furthermore, a detailed description of how the data analysis was carried out is provided. The chapter also critically assesses and discusses important quality aspects related to the used approaches and reflects on the relevant ethical aspects of the research.*

### 3.1. Research strategy

The thesis examined current methods used by the case company for determining parameters related to raw materials inventory management and performance. The study followed a mixed-method approach with an explanatory sequential design to investigate the research problem and answer the research questions, as illustrated in **Figure 3**. In this design, quantitative data were collected and analyzed. Afterwards, qualitative data were collected and analyzed to explain the quantitative findings. This approach is considered a good fit when the quantitative data uncover general relationship patterns that cannot be explained with quantitative data alone, and further insights need to be generated (Bell et al., 2019). The study takes on a deductive approach, whereas it started with theory to develop a hypothesis and then collected and analyzed data to test the hypothesis (Bell et al., 2019).

*Figure 3 Explanatory sequential mixed-method design, adopted from Bell et al. (2019)*



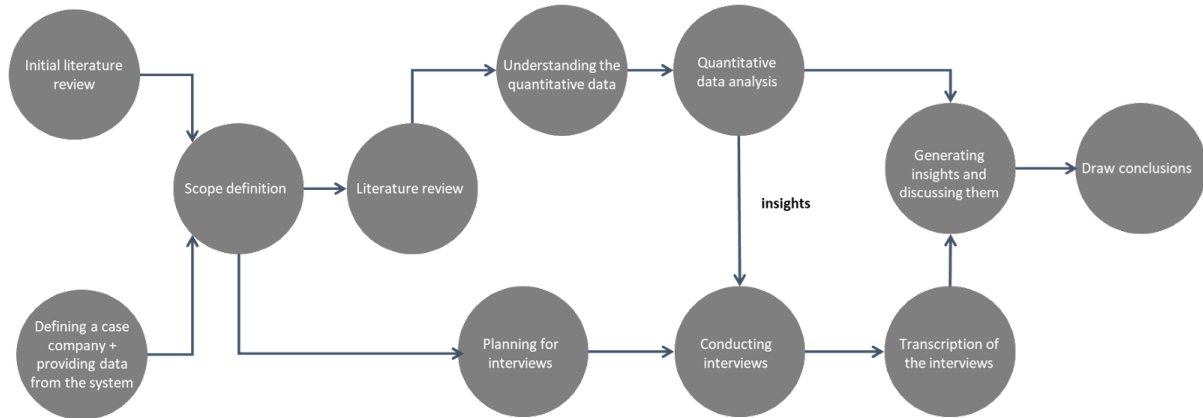
## 3.2 Research design and process

The research design was a case study for a single company because case studies are believed to be more appropriate when an in-depth understanding of a specific topic is required (Noor, 2008). In addition, the replicability aspect of the research quality was given a high focus to allow Meridion AB to expand on the research later and conduct comparative research at other companies. In a comparative design, identical methods are used in two or more cases to compare and contrast them (Bell et al., 2019). **Figure 4** illustrates the process followed throughout the thesis.

The process started by performing an initial literature review on academic books and journal articles by searching for keywords such as “inventory management,” “Materials replenishment planning,” “inventory control,” and “inventory forecast performance.” This step aimed to explore how existing theory applies to the case study and facilitate a better understanding of the topic. Next, Meridion AB decided on a case company from their clients and provided the quantitative dataset. These two steps facilitated a good initial understanding of the issue under study and enabled the student to fine-tune the scope definition. Once the scope was defined, a more in-depth literature review was performed, after which a set of hypotheses were made, and the research questions were formulated. The primary databases used for literature search include Google Scholar, Scopus, Web of Science, Wiley Online Library, and Emerald. The following steps were to understand the quantitative data better and analyze the dataset.

The interviews were planned in parallel, and insights generated from the quantitative dataset were used to formulate the interview guides (See **A. Appendix 1, 2, 3, and 4**). Once the interviews were conducted and transcribed, the authors brainstormed, continuously discussed, and analyzed the quantitative and qualitative data to draw meaningful conclusions. Even though the process might seem sequential here, it is essential to note that it was somewhat iterative, and the authors constantly went back and forth between the different steps.

Figure 4 The process followed in conducting the thesis



### 3.3 Data collection method and sampling technique

The data collection process started in parallel with the literature review by collecting secondary data generated by the ERP system of the case company within a period between December 2020 to April 2022. Secondary data allows further analysis to reach additional knowledge, explanations, or conclusions (Saunders et al., 2016). Three basic data Tables were extracted by Meridion AB from Infor M3, the case company's ERP system, and made into the quantitative dataset. These included: MITMAS, which had all component information, MITBAL, which included planning settings and parameters; and MITPLO, with all recorded transactions in the ERP system. In addition, during the interviews stage, an additional quantitative document in an Excel format was shared by the case company, which contained safety stock calculations and data on items' values. Therefore, the period considered for the analysis has been March 2021 to December 2021.

After the initial quantitative analysis, three semi-structured interviews with key staff within Meridion AB and the case company were held between March 2022 and April 2022 to gain a more in-depth understanding of discovered knowledge or conclusions based on the secondary data analysis. In addition, semi-structured interviews were used to allow for flexibility in the interview direction to facilitate more prosperous and detailed answers (Bell et al., 2019).

Additional data was retrieved from interviews held in 2020 to conduct a previous master thesis completed for the supply chain at the same case company (Hansen and Sveide, 2020). The data from these interviews were validated again with the case company before using it.

### 3.3.1 Sampling technique

The Interviewees were chosen based on purposeful sampling technique. In this method, the sample is selected based on its relevance to the research question (Bell et al., 2019). The first interview was held with a Meridion AB employee (interviewee 1, 2022) who has previous knowledge about the case company’s supply chain. The second interview was conducted with the strategic planner of the case company (Interviewee 2, 2022), who referred to a materials planner (Interviewee 3, 2022) to get more details on the method and the planning process for the purchased items.

### 3.4 Data analysis

A Mixed-Method approach was followed to analyze the data, whereas both quantitative and qualitative data were collected and analyzed to gain needed knowledge and insights to answer the first two research questions. Additionally, cluster analysis was used to develop an approach that can support the case company in improving its planning method, thus, addressing the third research question. **Table 3** describes how the different analysis steps contribute to answering the research questions.

*Table 3 Analysis steps connected to the project*

	RQ1	RQ2	RQ3
<b>Data analysis steps</b>	Initial quantitative analysis	Initial quantitative analysis	Cluster analysis
		Qualitative data analysis	

### 3.4.1 Initial quantitative analysis

To understand how the case company works with its inventory planning method, an initial quantitative data analysis was conducted on the three basic Tables extracted by Meridion AB. The analysis included demand analysis and safety stock analysis, where authors looked for patterns and trends from the data and documented these. This fundamental understanding of the quantitative dataset was needed to facilitate the formation of the first interview guide, which was used in the first round of interviews (See **A. Appendix 1**). Excel and Qlik sense were the main tools to capture initial relevant insights from the quantitative dataset. At first, Qlik sense was meant to be used as the primary method. However, due to some issues with the built-in model that affected the data, basic Tables were extracted by Meridion and provided in a CSV format to be used in Excel.

To start the analysis in Excel, the three Tables were merged into one Table by linking the columns with the unique item number. Afterwards, a pivot Table was created using all the relevant factors, namely, were: item number, item description, item status, item type, on-hand balance, ABC class volume, ABC class frequency, lead time, safety stock, safety time, annual demand, order quantity, planning date, and order category, and transaction quantity. The dataset contained complete data from March 2021 until December 2021. Therefore, when estimating values for the entire year, the summation from March to December was multiplied by a factor of 1.167 to compensate for January and February. When consolidating the different tables, the standard deviation for some items was not possible to calculate due to only having one transaction in the selected period. These data points were thus considered outliers and excluded from the dataset. Additionally, item values data for some items were not possible to retrieve; those were also excluded. Therefore, the total purchased items considered for the analysis have become only 792 items instead of the full range of 1100 items.

### 3.4.2 Qualitative data analysis

The qualitative data were analyzed to explain the phenomenon in the study. The qualitative data analysis started after completing the initial quantitative analysis. Qualitative data were continuously gathered and analyzed to aid the understanding of data quantitative data extracted from the case company's ERP system. The observations and insights gained from the quantitative dataset were used as input for the first interview guide. Initially, general broader questions were formulated for the first round of interviews to capture available insights regarding the different aspects of materials planning (see **A. Appendix 1**). The semi-structured interviews were considered a means to gain a deeper understanding and had some clarifications and validations about the knowledge of the quantitative dataset. Afterwards, the relevant person was interviewed, a strategic supply planner at the case company. The interview guide was formulated using both the initial quantitative analysis and the outcome from the first interview as an output (see **A. Appendix 2**). Afterwards, the process was repeated, and the authors were referred to a materials planner who worked more with the operational activities as the following person to interview, and the collected data up to this point was used as input for the step (**A. Appendix 3**). During this third interview, the case company provided additional quantitative data in the format of an excel sheet, and this was also consolidated into the original dataset as previously mentioned. The fourth and final interview took place during a site visit after most of the analysis was performed. The purpose was to clarify and validate the alignment with the case company (see **A. Appendix 4** for the interview guide).

The collected data was broken down into categories, which were derived from the general discussion topics during the interviews, combined with the insights from the quantitative dataset. The four main categories that resulted were the general planning settings, planning method and parameters setup, planning environment, and inbound inventory management performance. Those four were further broken down by subdividing them into different areas (used as subheadings in chapter 4), which were then saturated with relevant data. In the following step, the relationship between two main categories, the planning method, parameters setup, and the planning environment, was explored through cluster analysis.

### 3.4.3 Cluster analysis

*To address the third research question*, items' categorization was explored to improve the case company's materials planning method performance. This was because item categorization using multiple criteria can bring several advantages, as highlighted by different scholars (Flores, Olson, and Dorai, 1992; Huiskonen, Neimi, and Pirttilä, 2003). Therefore, the different purchased items were categorized through cluster analysis by using multiple criteria that included factors that can describe the planning environment characteristics. These factors included lead times, items' values, weekly consumption variations, and requirements frequency. This is mainly because those factors support describing the suitable planning environment for the varied materials planning methods as highlighted in **Table 1**.

Three different methods were used to conduct the cluster analysis, and their outcome was then compared to validate the results. The first method used the IBM software tool, SPSS Statistics, using the two-cluster analysis option. The second approach was through using K-Means clustering in Python. Lastly, in the third method, the student coded the different parameters' values for each item with "high, medium, or low" based on reference values and used a formula in Excel to categorize the items accordingly. The analysis outcome was different items' clusters, with each cluster having distinct characteristics based on the environment parameters, to then match these groups with the suitable planning method.

## 3.5 Quality of the Research

Bell et al. (2019) state three of the most common criteria for evaluating business research; reliability, replicability, and validity. To increase the reliability and replicability of the study, a structured approach was followed, and each step was documented. Furthermore, these two aspects were given a particular focus, that is, to allow Meridion AB to repeat and replicate the study for other case companies in the future. To increase the validity, the research followed a systematic way throughout the different stages, using well-established theories and logical sequence. Moreover, the authors aimed to increase the validity by using different methods to perform the cluster analysis and then contrasting the results obtained from each method.

This contrast showed that the outputs from the three methods are considerably similar in many aspects.

When critically assessing quantitative data collection and analysis, several issues can be brought up. Firstly, all the quantitative aspect of the research was initially planned to be carried out using Qlik sense. The analysis was started in the Qlik sense application; however, several issues appeared with the model. For example, when connecting the different dates to see patterns or filtering on years, many data points disappeared, and the student ended up with the wrong dataset. The authors suspected the issue only when verifying the initial analysis results with Meridion AB and the case company. Meridion later confirmed the issue with the model. Therefore, to mitigate the risk of using the wrong dataset, it was decided to conduct the analysis using Microsoft Excel using raw data -basic Tables- instead. An important note here is that the basic data Tables, i.e., MITMAS and MITBAL are a snapshot of the system, which means that the planning settings corresponded to a specific date when the data was extracted from the system. However, the content of the Tables was still relevant and validated by the case company. The second issue arose when the standard deviation was used to measure weekly production demand (weekly consumption) stability.

In contrast, items with typically high consumption ended up with high standard deviation quantities and incorrectly indicated which items have a more stable consumption trend. An adjusted deviation was calculated by dividing the standard deviation quantity by the average weekly consumption for each item to mitigate this. An additional issue was related when conducting the coding in Excel, whereas it was difficult to know what the case company would consider the high, low, or medium value of parameters. This was solved by estimating values based on the distribution curves for the parameters and then communicating and validating the suggested reference value with the case company. Lastly, the K-means clustering in Python with five clusters resulted in a group with only one data point, i.e., one item, which can be problematic. For this cluster -cluster 4-, the item's characteristics were checked in detail, and it was added to the cluster with the closest attributes, cluster 2.

Looking at the qualitative approach, increasing the sample size might have made the results more credible since only two persons were interviewed. However, the two Interviewees were selected due to their vast knowledge in the area, which is believed to add a good level of credibility to the results. Furthermore, All the interviews were recorded and transcribed afterwards to allow a repeated and detailed examination (Bell et al., 2019). The recording and transcription of the interviews ensured that no information was lost. Another aspect that can potentially affect the quality of the research, in general, is that some external factors affect the normal conditions in which the case company used to operate. For example, it was brought up by Interviewee 2 (2022) and Interviewee 3 (2022) several times that the current supply chain disruptions are affecting different aspects of the business by causing, for example, long lead times and higher uncertainties for almost all items.

### **3.6 Ethical aspects of the research**

Bell et al. (2019) list four ethical principles to be considered by researchers, including avoidance of harm to participants, confidentiality and privacy protection, informed consent, and preventing deception. Due to the nature of the research, the highest risk is expected to be in the protection of confidentiality and privacy since the study used business-sensitive data. Therefore, a Non-Disclosure Agreement was signed with the company that limits the usage of the accessed data to only the master thesis and obliges the researchers to get consent from both Meridion and the case company before publishing any data. Other measures when conducting interviews were also taken; for example, consent from participants was always asked before recording. Anonymity is also used to protect the participants from any type of harm. Additionally, sensitive or confidential information about either Meridion AB or the case company was either removed or masked. Lastly, the interviews' transcriptions were only used to analyze the data but are not enclosed.



## 4. Empirical findings

*This chapter describes the empirical findings from the qualitative and quantitative concerning the planning settings and the planning environment. It outlines insights gained from the dataset extracted from the case company's ERP system and interviews with material planners from the case company and generates insights from analyzing the data.*

### 4.1. General parameters settings

To understand the commonly used terms in the different Tables (MITMAS, MITBAL, and MITPLO), **Table 4** explains the various terms and parameters' settings.

*Table 4 Examples of planning parameters and ERP settings*

Headline	Description
<b>Item number</b>	A unique reference number for each item
<b>Item description</b>	A brief description of the item
<b>Item status</b>	Indicates the item status 10: Preliminary 20: Released, active items 30: Alternate items available 40: Item is released but has a low turnover 50: Item is to be used and then removed from the assortment. 80: Items are no longer stocked, but returns are possible 90: Item no longer stocked 99: Item no longer stocked due to item number change
<b>Item type</b>	16 different groups that the case company use as a mean of categorization, alongside the ABC categorization
<b>On-hand balance</b>	Inventory balance at the moment of extracting the data
<b>ABC class volume</b>	Volume * item value, where the volume is the total annual usage.
<b>ABC class frequency</b>	Movement frequency (number of transactions/movements) Unit frequency (number of basic U/Ms) Volume frequency (number of cubic meters).
<b>Lead time</b>	This is the time needed to meet a requirement, from the point in time when acquisition activities are started to the point in time when the requirement is fulfilled.
<b>Safety stock</b>	A buffer quantity is only used during unexpected circumstances such as increased demand, difficulties in delivery, etc.
<b>Safety time</b>	Safety time is how many days before the actual need date a planned order should be available in stock. The purpose is to protect the scheduling from any fluctuations in the item's delivery time.
<b>Annual demand</b>	It is the annual demand per warehouse/item. The annual demand can be calculated automatically or manually.
<b>Order quantity</b>	The quantity determines the amount of an item to be purchased or manufactured at one time.
<b>Order category</b>	110: Released manufacturing order 250: Planned purchase order 251: Released purchase order
<b>Transaction quantity</b>	The quantity of a specific item reported in the ERP system.

To provide an overview of how the case company works with their planning method and the current parameters set in the system, some general parameter settings that the case company uses for materials planning are displayed in **Table 5**. The information in the second column is extracted from the ERP system, and the third and fourth columns indicate the item distribution for the different parameter settings. In addition, there is a code in the ERP system for some parameter settings that indicate which setting is used for that parameter. Thus, these settings impact the outcome of the materials planning for each item.

*Table 5 General planning settings at the case company*

Planning settings	Information from ERP	# of items	% of items
<b>Planning method</b>	0 – Manually planned	1	0.1%
	1 - MRP	791	99.9%
<b>Order policy</b>	0 – Manually entered quantity	8	1%
	11 - Discrete order quantity	10	1%
	12 – Manually entered run-out time	774	98%
<b>Annual demand method</b>	1 – Calculated automatically	792	100%
<b>Safety stock method</b>	0 – Manually calculated	792	100%
<b>Re-order point method</b>	0 – Manually calculated	792	100%
<b>Multiple supply</b>	1 – Single supply	1	0.1%
	2 – Multiple supply	613	77.4%
	4 – Multiple supply	178	22.5%
<b>Lead time</b>	0 – 21 days	472	59.6%
	21 – 50 days	126	15.9%
	>50 days	194	24.5%
<b>Safety time</b>	0 days	23	2.9%
	1 days	725	91.5%
	2 days	1	0.1%
	3 days	1	0.1%
	5 days	4	0.5%
	15 days	38	4.8%
<b>Status</b>	Status 20	769	97.1%
	Status 50	23	2.9%

It can be seen from **Table 4** that all items are planned using MRP. The case company also uses three types of order policies (lot sizing method), which are all used in combination with the MRP to convert expected requirements into one or several replenishment orders. There are multiple other options for order policies in the ERP system, where each method belongs to a specific group. Namely, three groups based on whether the quantity or period is fixed or variable. For most items, the order quantity is determined according to the “manually entered

run-out-time” method, which means that the order quantity is calculated dynamically according to the same logic used in MRP. As requirements arise, orders are placed to cover the number of days that are entered manually as the run-out time. The order quantity is selected to cover a set number of planning periods, where the number of periods is selected manually based on the materials’ planner’s experience of what is considered a suitable time interval to cover needs. Usually, these estimations are based on factors such as estimated annual demand, item value, and the cost of the ordering process. This alternative belongs to the group with variable quantity combined with a fixed period, which means that the run-out time does not change between the orders; however, the quantity varies to cover for variation in demand between the planning periods. An explanation of the remaining methods can be found in **B. Appendix 1**.

When looking at the annual demand method, the case company updates it automatically for all items, and it can either be integrated with the forecasting or based solely on the results of the demand calculations. The value 0 for both the safety stock and reorder point method indicates that these parameters are determined and calculated manually. Additionally, the case company uses primarily one day of safety time for all purchased items. The dataset also indicates that the case company uses both single and multiple sourcing, where most of the items have two different settings for multiple supply in the ERP system. The value 2 informs that the supplier or warehouse set for the item is defaulted, and if not, the main supplier with a valid agreement is found, and a second supplier with a valid agreement will be used instead. The value 4 also informs that multiple supply is used for the item, but the implication is that the required quantity supplied is done according to different supply methods which are specified in the ERP system.

An additional setting observed from the dataset was that almost all items had 610 days set as the planning horizon, which indicates how many days are covered by the requirements planning. However, there may be requirements beyond the planning horizon, but these are not considered when orders are planned. Additionally, none of the items is master scheduled items. The different settings in Infor M3 for planning method, safety stock method, planning, and stock parameter settings are displayed in **B. Appendix 2, 3, 4, 5**.

## **4.2 Planning method and parameters setup**

As previously reflected in the quantitative dataset, the case company only uses MRP for purchased items. This was further emphasized by Interviewee 1 (2022) and also mentioned by Interviewee 2 (2022). Through MRP, the company places delivery schedules to their suppliers, including firm orders and forecasts for a period of 18 months in the form of Electronic Data Interchanges (EDIs). When it comes to the execution, the case company uses Kanban as the planning method in production. However, this is considered outside the scope of this thesis.

### **4.2.1 Orders initiation**

Purchase orders (POs) are generated automatically by the system based on production planning (Interviewee 2, 2022). The POs are either sent automatically or modified by a material planner depending on the supplier's relationship with the case company and their flexibility in changing the POs after they are sent. For example, when the supplier is flexible in handling pull-in and push-out orders in the forecast, the orders are sent automatically without going through all the details. However, for some suppliers where this flexibility is not offered, a material planner must do an extra check before sending the orders (Interviewee 2, 2022). Nevertheless, all the planning is done automatically by the system, and no manual planning is performed, but the planner performs a check before sending the orders to ensure accuracy (Interviewee 2, 2022).

### **4.2.2 Items categorization**

When looking at the quantitative dataset, it is observed that the case company uses ABC classification on all their purchased items. Interviewee 1 (2022) mentioned that it was recently implemented at the case company. This might be why Interviewee 2 (2022) responded that the ABC categorization is set up in the system but is not being used. However, Interviewee 3 (2022) corrected this information and said that they are using ABC classification; however, the company has not been able to automate the process. The material planner, Interviewee 3 (2022), performs manual steps in the system on a monthly basis to update the ABC classification based on volume for the coming year and purchasing frequency in the last three months. This process is described as time-consuming by both Interviewee 2 (2022) and Interviewee 3 (2022).

In addition to the ABC Categorization, the company has other types of item groups mentioned by Interviewee 2 (2022). These groups are mainly by the item type and lead times (Interviewee 2, 2022). Another aspect investigated was if the case company has more critical items than others. However, Interviewee 2 (2022) responded by explaining that all the items are considered equally crucial since all the BOM items are needed to deliver the finished goods to the customers.

### **4.2.3 Parameters setup and update**

When it comes to parameters set up and update, the case company sets up different safety stocks and lead times depending on the item type and the supplier's agreement regarding the lead time (Interviewee 2, 2022). Every month, the safety stock is updated based on item value, lead time changes, weekly demand, and quantities per reel (Interviewee 3, 2022). This is also another time-consuming process. Nevertheless, the safety stocks are not updated or reviewed for all items every time; instead, the team goes through the list to make adjustments where needed based on specific triggers such as changes in lead times, demand, adding a new production line, or changing a supplier (Interviewee 2, 2022). However, even though suppliers sometimes ask for longer lead times, the lead time set in the system is not always updated at the request of the supplier. Whether the lead time will be updated depends on, e.g., agreements with suppliers or item type (Interviewee 2, 2022). Another aspect of the parameters set and updated is that the case company is not working with lot sizing to optimize order quantities. Instead, when determining order quantities, interviewee 2 (2022) explained that they consider the reel size, agreements with suppliers, and packaging size. Since the packaging and reel sizes are predetermined, optimizing order quantities is impossible (Interviewee 2, 2022).

Even though the company uses MRP solely, they match the environment by having different setups within MRP. For example, for new items or items planned to be phased out, the case company sets the safety stock at zero and works with safety time instead (Interviewee 3, 2022). Interviewee 2 (2022) also said, “We use MRP for all purchased items. The production plan is the input for some items, while manual forecasts are added to the system instead for the items generally needed for producing the different components, such as glue. However, it is still the

MRP generating purchase orders based on the forecast from production, the stock levels, safety stocks, and everything. So, there are different demand pictures in some cases, but it is still the MRP that generates the order.”

It was observed from the quantitative dataset that some items in 2021 had a stock on hand which was below the safety stock, which can be problematic. This is described in detail in **section 4.4.1**. Additionally, for some items, it was noticed that the difference is quite significant between the annual demand calculated in the system and the estimated actual demand based on production orders. The steps of these calculations are explained in **section 4.4.2**.

#### **4.2.4 Pull-in and push out orders**

Deviation on the original EDIs sent to the supplier can generally happen due to changes in production plans. The MRP is handling these deviations by suggesting new delivery dates for orders. This is referred to as pull-in when the order delivery date is changed to arrive sooner than the original date, and a push-out is when the planned delivery of the order is delayed. The material planners then usually follow what the system says; however, the decision on manual intervention also depends on whether the demand for the item is high or low. As explained in **section 4.2.1**, purchase orders are generated automatically by the MRP, but sometimes manual interventions are necessary when pulling in or pushing out orders within the lead time due to changes in the production plan. This, however, is something that has to be agreed upon with the supplier. For instance, some suppliers want delivery schedules or quantity changes before the EDIs are sent to allow the suppliers’ system to start working on the agreed modifications. According to Interviewee 2 (2022), this is one of the reasons why the case company does not change the lead time for some suppliers.

Regarding pull-ins, the case company does not always need to get an OK from the supplier compared to when they want to push out frozen orders. When pushing out orders, the supplier will remove the order from the system and create a new one with the lead time. According to Interviewee 2 (2022), this is sometimes not desirable, depending on how many weeks they want to push out the order. If the lead time on the item is very long, it can be problematic to only push out the order a few weeks due to the risk of not getting the material in time.

## 4.3 Planning environment

This section describes the different characteristics of the planning environment in which the case company operates. It covers the following areas: item and product characteristics, lead time characteristics, demand characteristics, and production characteristics.

### 4.3.1 Item groups and product characteristics

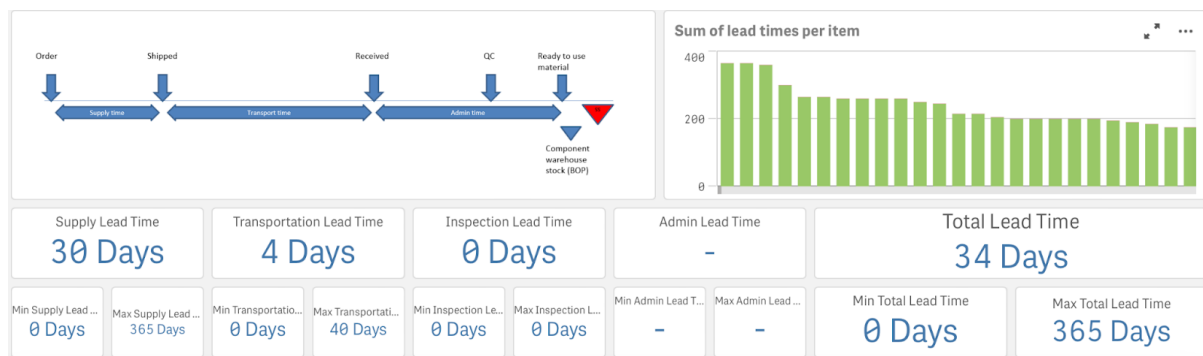
Items seem to be grouped according to different criteria, e.g., item type or lead time; however, the number of groups seems to differ between what is seen in the dataset and the insights from Interviewee 2 (2022) and Interviewee 3 (2022). From the dataset extracted from the case company's ERP system, it is possible to distinguish 16 item groups. However, Interviewee 3 (2022) explained that they currently have 34 item groups, but some might be outdated. Moreover, each item group can contain both items, semi-finished and finished products, and if a component is placed in a particular group, it means that the total volume of that item is needed for the specific semi-finished or finished product in the same group. In addition, Interviewee 3 (2022) explained that all the purchased items are used in at least one or several Bill of materials.

### 4.3.2 Lead time characteristics

The dataset indicates a variation in lead time between the different components ranging from only a few days to almost a year for some components (See **Figure 3**). It is also noted by Interviewee 3 (2022) that an increasing number of suppliers are asking for longer lead times. However, an important note here is that the most prominent reason is the semiconductor crisis, among other supply chain disruptions. In addition, an important distinction is being made between transportation lead time and what the case company themselves define as lead time, i.e., the lead time for firm orders which is usually a part of the logistics agreement with their suppliers. For most components, this lead time is set to 20 working days; however, some suppliers are now asking for 100 days up to 1 year lead time for firm orders. This is problematic because if the case company gives a supplier 52 weeks of firm orders, i.e., no change agreements, they will have high stock levels at the end of the year (Interviewee 3, 2022). On the other hand, interviewee 2 (2022) explains that they use EDI lead time with their suppliers,

which means that they are not only purchasing materials on production lead times but rather on the EDI lead time for call-offs. However, there is a production lead time, but they are not ordering based on this since they are sending forecasts and call-offs to their suppliers. Additionally, it can also be noted from the Qlik application, where data is extracted from the case company's ERP system, that the total lead time can be divided into different groups (see **Figure 6**).

Figure 5 Lead times in the Qlik sense application.



It can also be noted that they do not set transportation lead time for all items and thus mostly use supply lead time. According to Interviewee 2 (2022), Transportation lead time is only used when the case company owns the transport; otherwise, the transport lead time is combined with the total lead time, which is displayed in Figure 3. According to the dataset, the average total lead time is 34 days, and the average transportation lead time is four days. Moreover, to adjust for lead-time variation, the case company works with early warnings towards their suppliers when they cannot deliver according to the delivery schedule, but each supplier is responsible for notifying if they cannot meet the demand.

### 4.3.3 Demand characteristics

From the same dataset, it can be noted that there is variation in demand, both between the different purchased items and on a monthly and weekly basis for the same item throughout 2021. For example, interviewee 3 (2022) states that the daily demand can vary from 10 to 10 million pieces. The variations are both prevalent on the consumption side, i.e., the quantity and frequency of production calls for materials, and on the purchasing side, i.e., purchasing quantity and frequency. There are many reasons for this, and Interviewee 2 (2022) described different

demand pictures, e.g., production plans, stock levels, and safety stocks, potentially affecting the variation shown in the dataset. However, the most common demand type is production orders derived from customer delivery schedules, including firm orders and forecasts. Insights from Interviewee 1 (2022) indicated that some customers are changing the delivery schedules on concise notice, which causes variations in the production plans, which will profoundly affect the materials planning. The effect of this is that the MRP has to either pull in or push out orders within the lead time, and sometimes adjustments have to be made manually by the materials planner. However, depending on when the changes happen, it can be challenging to acquire the correct quantity of materials due to long lead times from suppliers.

Moreover, further insights from Interviewee 2 (2022) indicated that some purchased items are not dependent on customer orders. For these items, the material planner must look into historical data and do manual forecasts to estimate the future demand. An example of such an item is glue, where it is sometimes difficult to know the correct stock levels exactly. Commonly, these cans of glue get thrown away even though they are half full, which will also affect the performance of the MRP since it will produce fewer purchase orders than what is needed.

#### **4.3.4 Production characteristics**

According to Interviewee 1 (2022), variation in production plans is prevalent due to late changes in delivery schedules from customers, especially among large car manufacturers. EDIs from the customers are most often sent for three months with firm orders, but they can vary quite a lot every week even though the total volume for a period of 3 months is fixed. The case company works with 8-week production plans when production runs smoothly, and the rest is forecasted. However, according to Interviewee 1 (2022), this is rarely the case. Ideally, the first two weeks entail signing contracts and ensuring that production has the available information from the customer delivery plans. The production plan should usually be locked during week three, but it is relatively common for customers to make last-minute changes.

According to Interviewee 1 (2022), Variation in production plans is difficult to handle from a material planning perspective. A reason for that is that lead times from suppliers heavily affect the possibility of adjusting for occurring changes in the production plan. Moreover, Interviewee 3 (2022) discussed the SMT (Surface-mount technology) production lines, more specifically the reel quantity for each machine, as a limiting factor in material planning. A reel is a role of tape where small electric components are attached to and then fed into the automated machines building the circuit boards. According to Interviewee 3 (2022), the reel quantity varies depending on the size, type of component, and machine. However, changes in reel quantities do affect safety stocks and order quantities.

## **4.4 Inbound inventory management performance**

Two questions were examined to understand how the current setup and planning environment affect inventory management performance in general. These two factors are: (1) do the inventory levels fall below the safety stock, and if so, how significantly? (2) does the annual demand calculated in the system match the consumption patterns?

### **4.4.1 Inventory levels compared to safety stock**

A part of the analysis was to compare the safety stock set for an item with the actual on-hand stock levels to indicate the performance of the MRP. An important note here is that the content of the basic data tables, i.e., MITBAL and MITMAS, is a snapshot of the settings currently set in the ERP system when the data was extracted. The basic data tables were extracted on October 10th, 2021. When combining the tables, it was noted that the actual on-hand stock levels when the data was extracted were significantly below the safety stock for some items, which can potentially indicate either coming shortages or delayed deliveries. **Table 6** illustrates the deviation between the safety stock and the on-hand stock set in the system. However, since this is a snapshot of the system, it is not possible to estimate the overall performance according to this measure, but these items might need extra attention if it is a reoccurring situation.

Table 6 Safety stock and on-hand stock

Item number	Safety stock	On-hand stock	Deviation percentage
1	6,000	13	-46054%
2	12,000	2,596	-362%
3	1,000	246	-307%
4	126,000	31,731	-297%
5	18,000	4,561	-295%
6	8,250	2,458	-236%
7	18,000	8,338	-116%
8	12,000	6,062	-98%
9	30,000	15,257	-97%
10	21,440	13,024	-65%
11	40,000	25,564	-56%
12	20,000	12,894	-55%
13	60,000	39,047	-54%
14	600,000	434,864	-38%
15	1,500	1,146	-31%
16	17,000	13,250	-28%
17	16,000	12,836	-25%
18	4,000	3,313	-21%
19	60,000	49,889	-20%
20	1,200	999	-20%
21	8,000	6,919	-16%
22	12,000	11,042	-9%
23	50,000	46,851	-7%
24	4,000	3,869	-3%

#### 4.4.2 Calculated demand compared to actual consumption

From the transactions Table, it was possible to identify the consumption patterns for the different items used to calculate the total consumption for a specific item and establish any potential variation in demand by calculating the standard deviation. Insights from the interviews indicated that it is more common that the demand varies weekly; therefore, the weekly standard deviation was calculated. Additionally, in the same table, there is a planning date connected to each item every time there is a registered transaction in the ERP system, where each transaction is described with a specific order category. To determine the consumption for each item, it was necessary to look at items with the order category 110, i.e., released manufacturing orders.

The quantities connected to a specific planning date were summed using a pivot table in excel to capture the total quantity used for a specific item per week to get the weekly consumption patterns. In addition, the transactions were limited to include 2021 since it was the only full-year included in the dataset. However, during both January and February, the consumption volumes were almost non-existent for most items, which means that most of the consumption occurred between weeks 9 to 52. Therefore, when estimating the weekly variation, the standard deviation was only calculated from March to December 2021 to get a more accurate estimate of the variation. In addition, to get a better measure of the weekly variation, the average weekly quantity was divided by the standard deviation to get the adjusted weekly variation seen in **Table 5**. In this way, it was possible to view the variation as a percentage of the average weekly consumption compared to the calculated standard deviation, which shows the variation as a quantity. An example of the weekly consumption patterns for some items is illustrated in **Table 7**.

*Table 7 Example of items with actual consumption combined with weekly variation*

Item number	Total consumption Mar-Dec	Weekly standard deviation	Average Weekly consumption	Adjusted weekly variation
1	-7,238,219	24,789	-168,331	0.15
2	-20,898	389	-498	0.78
3	-7,145,228	44,451	-166,168	0.27
4	-686,555	5,948	-15,966	0.37
5	-241,226	8,600	-11,487	0.75
6	-661,843	3,395	-15,392	0.22
7	-2,119,847	10,947	-49,299	0.22

The exact process was followed to estimate the weekly manufacturing and purchasing orders. From the transaction (MITPLO) Table, this was possible by counting the number of planning dates for each item number and order category, 110, 250, and 251. Doing this made it possible to view the number of weekly manufacturing and purchasing orders. **Table 8** illustrates the outcome of counting the number of manufacturing orders, and **Table 9** presents the outcome for the number of purchasing orders.

Table 8 Manufacturing order frequency for random items

Item number	Total manufacturing orders Mar-Dec	Weekly standard deviation	Average weekly number of manufacturing orders	Adjusted weekly variation
1	77	2.71	3.67	0.739
2	2398	9.57	55.77	0.172
3	754	2.91	17.53	0.166
4	1996	5.16	46.42	0.111
5	1529	5.85	35.56	0.165
6	699	3.24	16.26	0.199

Worth mentioning is that the Tables are not displaying manufacturing and purchasing data for the same items. Later in the cluster analysis, the manufacturing and purchasing orders count will be used as factors.

Table 9 Purchasing order frequency for random items

Item number	Total purchasing orders Mar-Dec	Weekly standard deviation	Average weekly number of purchasing orders	Adjusted weekly variation
1	200	1.36	4.65	0.29
2	207	1.42	4.81	0.29
3	39	0.32	1.11	0.29
4	16	0.65	1.33	0.49
5	51	0.52	1.21	0.43
6	118	0.78	2.95	0.27

Furthermore, after mapping out the weekly consumption pattern, a comparison between the actual annual consumption and the annual demand set in the system showed notable deviations; see **Table 10** for details. The second column shows that almost 20 % of the items have a variation where the actual consumption is smaller than the annual demand calculated in the system. The third column shows that 72 % of the items have a deviation where the actual consumption is more significant than the annual demand set in the system. Additionally, 66 items had 0 annual calculated demand in the system, even though these items are purchased and used in manufacturing; see **Table 11** for an example of such items. A multiplier was used to accommodate the excluded months in the actual consumption calculation for March to December to allow a more accurate comparison.

Table 10 Actual consumption deviation from calculated annual demand in the system for the different items

Deviation	Items with actual consumption less than annual demand	Items with actual consumption more than annual demand
<b>0 - 25 %</b>	91	213
<b>26 - 50 %</b>	24	277
<b>51 - 75 %</b>	2	79
<b>76 - 100 %</b>	1	6
<b>More than 100 %</b>	33	0

Table 11 Example of items with 0 demand set in the system

Item number	Consumption Mar-Dec 2021	Adjusted actual annual consumption	Annual demand set in the system
<b>1</b>	-1,925,808	2,118,389	0
<b>2</b>	-395,533	435,086	0
<b>3</b>	-320,978	353,076	0
<b>4</b>	-275,698	303,268	0
<b>5</b>	-274,176	301,594	0
<b>6</b>	-212,687	233,956	0

## 4.5 Cluster analysis

To conduct the cluster analysis, the criteria used were first selected out of the different factors that the dataset included. The factors considered had to reflect and describe the item's planning environment, which is needed to match the expected resulting groups with the suitable materials planning method. The materials planning methods considered are MRP and the reorder point methods, mainly due to the nature of the purchased items for having dependent demand. After discussing the different possibilities with the thesis supervisor, four key factors were considered for the cluster analysis. These were: lead time, frequency (count of consumption orders and purchase orders), weekly consumption standard deviation, and item value. After agreeing on these four factors, the second step was to combine the data in a simple Table and have it in CSV format. This dataset was then analyzed using different tools, namely, IBM SPSS, a Python Algorithm, and Microsoft Excel. **Table 12** illustrates the used data set using an example of a few randomly selected items.

Table 12 Dataset illustrated by a few selected random items

Item number	Adjusted variation	count of consumption orders	count of purchase orders	Lead time	Item value (SEK)
1	0.115	4,161	42	8	0.011
2	0.162	1,250	46	20	0.008
3	0.269	591	207	40	0.008
4	0.178	2,047	43	8	0.016
5	0.160	1,425	52	8	0.021
6	0.217	551	39	8	0.038
7	0.272	871	45	80	0.022

### 4.5.1 Two steps clustering in IBM SPSS

The dataset was imported to IBM SPSS software, and two cluster analysis was selected as the classification method to analyze the data. The numbers of clusters were automatically set up by the software using the Bayesian Information Criterion (BIC) / Schwarz Criterion. BIC is a model selection method that adds the number of parameters multiplied by the log's sample size to penalize -2 log-likelihood (Jones, 2011). The outcome results are illustrated in **Figure 7** and **Figure 8**. From **Figure 7**, it can be seen that the resulted cluster quality was considered good, and in **Figure 8**, the different clusters' sizes are visualized.

Figure 6 Cluster sizes

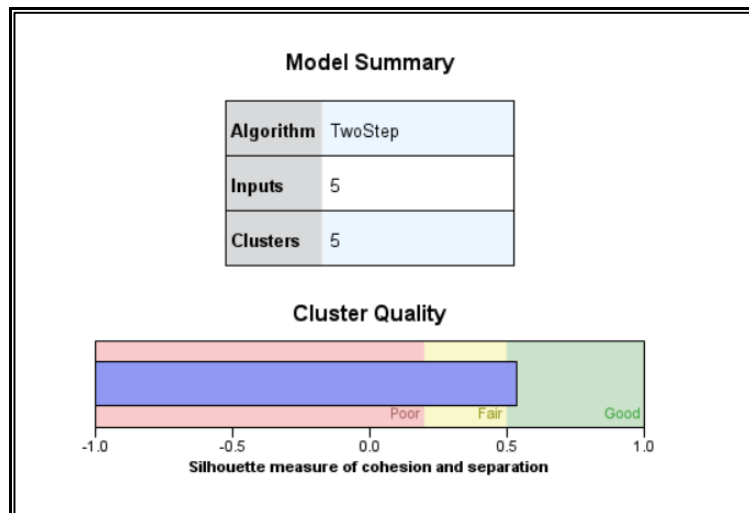
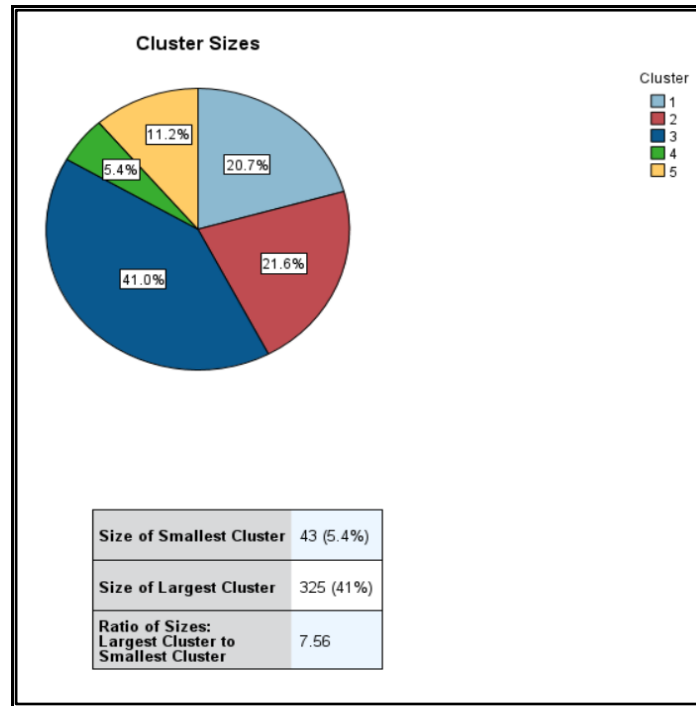


Figure 7 Model summary and cluster quality



The resulting five clusters had the following characteristics, presented in **Table 13**. Based on this approach, the largest cluster (cluster 3) contained 325 items and had a relatively medium adjusted weekly consumption standard deviation, relatively short lead-time, medium frequency in both consumption orders and purchase orders, and relatively small item values. The second-largest cluster was cluster 2, and it also had a relatively medium-adjusted deviation and medium frequency. However, items' values were higher for cluster three, and the lead time was rather long. Cluster 1, on the other hand, had the highest adjusted deviation, indicating that the consumption patterns for these items vary a lot every week. Other characteristics for this cluster included a medium lead time and low order frequency of both purchase and consumption orders. Looking at Cluster 5, the items within this cluster had the lowest consumption deviations, the highest order and consumption frequencies, the shortest lead times, and the lowest item values. With this environment, items within Cluster 5 would make suitable candidates for a re-order point method. Lastly, Cluster 4 was the smallest cluster, with items within this cluster also showing characteristics of high order and consumption frequency, medium consumption deviation, and medium lead times, but this cluster also had the items with the highest values.

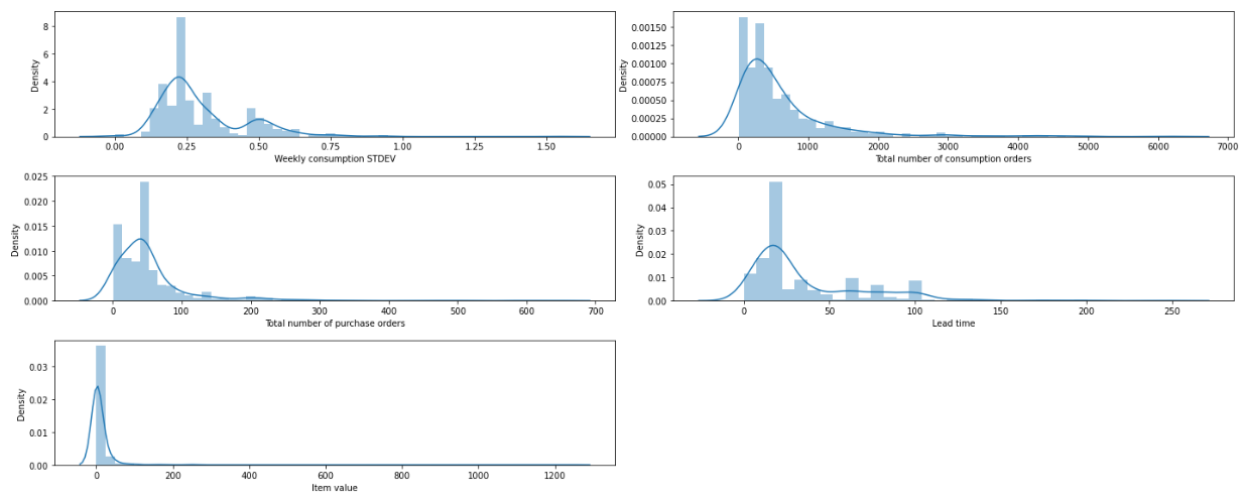
Table 13 The characteristics of the clusters

Cluster	1	2	3	4	5
<b>Size (number of items)</b>	164	171	325	43	89
<b>Mean adjusted weekly consumption STDEV</b>	0.55	0.25	0.24	0.24	0.16
<b>Mean lead time</b>	29.4	83.7	18.2	32.0	16.5
<b>Mean count of consumption orders</b>	112	496	465	742	2,114
<b>Mean count of purchase orders</b>	14	62	44	58	232
<b>Mean item values</b>	6.1	11.7	4.2	95.0	0.9

### 4.5.2 K-means clustering in Python

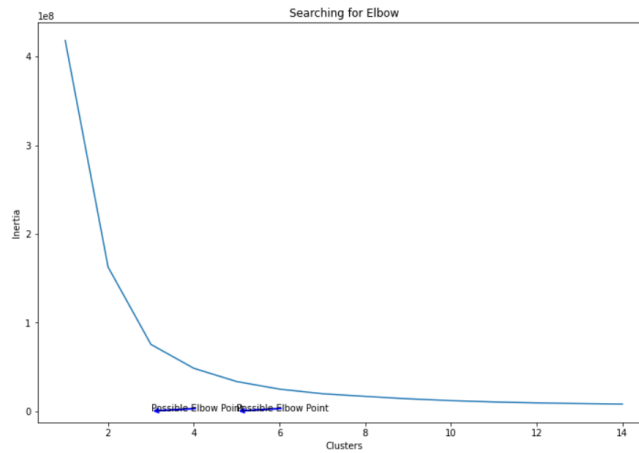
Another tool explored for clustering the data was through a K-means clustering algorithm. According to Syakur et al. (2018), the K-means method is the most common and simplest clustering method, and it can group large datasets with efficient computation time. The python algorithm was developed and run in Jupiter Notebook; an open-source application used to create and share live codes. The distribution plots for the data were visualized to understand better how the different data are distributed. This is also used later when conducting the semi-manual coding in Microsoft Excel to set up the high-medium-low limits. This is illustrated in **Figure 9**, where the different graphs indicate the distribution of items based on the five factors used in the clustering.

Figure 8 Distribution plots for the different factors



The number of clusters was determined using the elbow point method, which improves the efficiency and effectiveness of K-means clustering (Syakur et al., 2018). See **Figure 10**.

Figure 9 Elbow point method to determine a suitable cluster size



Based on this, two different sizes of clusters were plotted, and the trial was with three groups. The outcome is illustrated in **Figure 11**. However, when looking at the swarm plots to understand the distribution for the different values of the considered factors, it was apparent that the three clusters analysis did not provide valuable insights since none of the clusters had environmental characteristics that can be said to be more suitable for a method and not the other (see **Figure 12**). For example, looking at Cluster 1, the average values for the different factors make it the cluster with the lowest item values, lowest adjusted consumption variation, highest order, and consumption frequency. However, these characteristics did not hold for all the items within the cluster due to the wide distribution of the different factors.

Figure 10 K-Means with three clusters

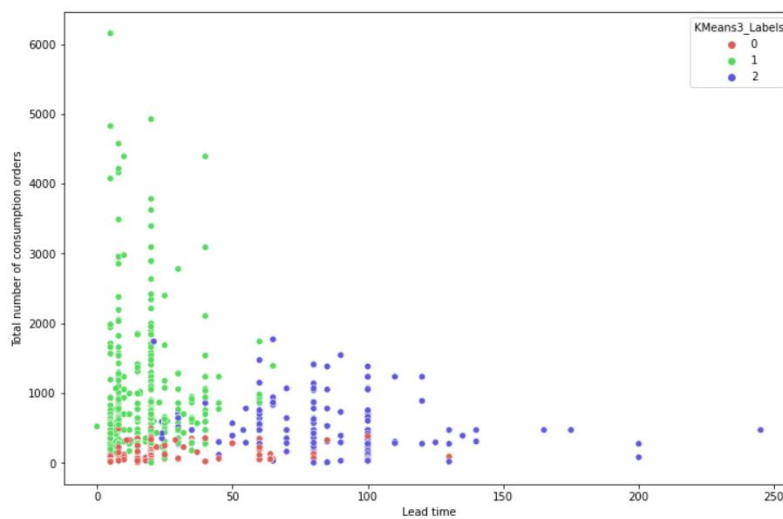
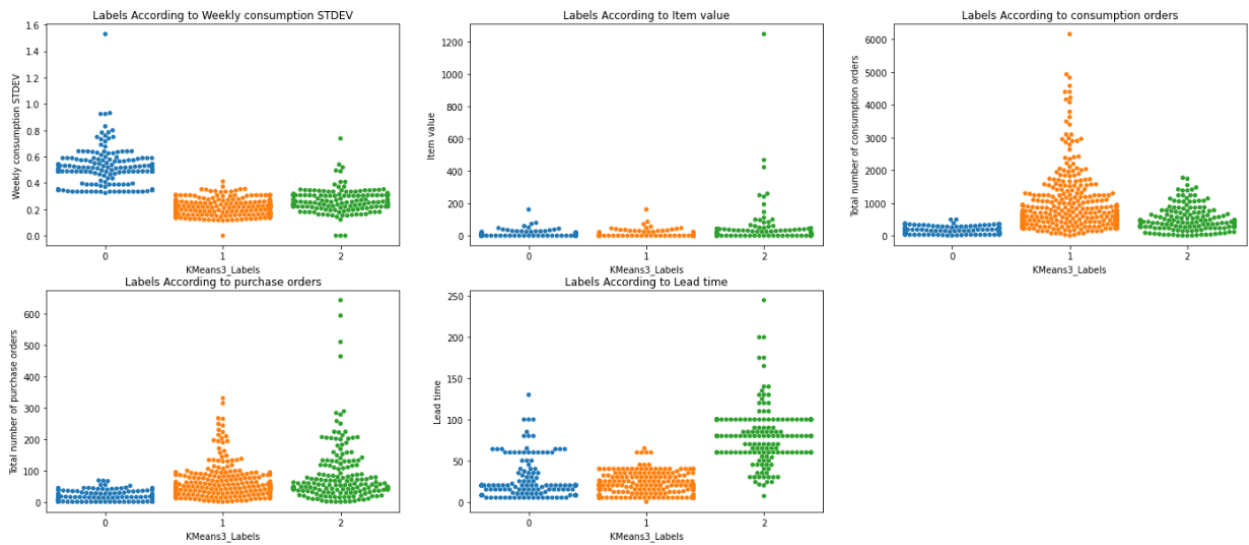


Figure 11 Swarm plots for the three clusters



Since the three clusters analysis did not provide the needed insights, K-means clustering with five clusters was motivated by IBM SPSS to reach a high-quality classification using the same number of clusters. The outcome of this is illustrated in **Figure 13**. The five clusters did indeed provide a better distribution between the clusters since each cluster had different environmental characteristics with significantly less overlap. This was reflected in the distribution of the attributes as visualized in the swarm plot in **Figure 14**. However, one quality issue noticed here was that cluster 4 had only one data point. For this data point, the characteristics looked similar to those for cluster 2. An intriguing cluster that was zoomed in was cluster 2, whereas items within this cluster had the highest order and consumption frequencies, low lead times, low item values, and the lowest weekly consumption standard deviation. Based on these characteristics, items within Cluster 2 make potential candidates for a reorder-point method. Cluster 3 also provides relative insights since the items within this cluster had a high weekly consumption standard deviation with longer lead times than cluster 3. An increased consumption deviation is problematic regardless of the materials planning method used; this might indicate that even if MRP is still the suitable method for items within this cluster, more attention needs to be paid to either have a more regular parameters update or increase the buffer in inventory.

Figure 12 K-means with five clusters

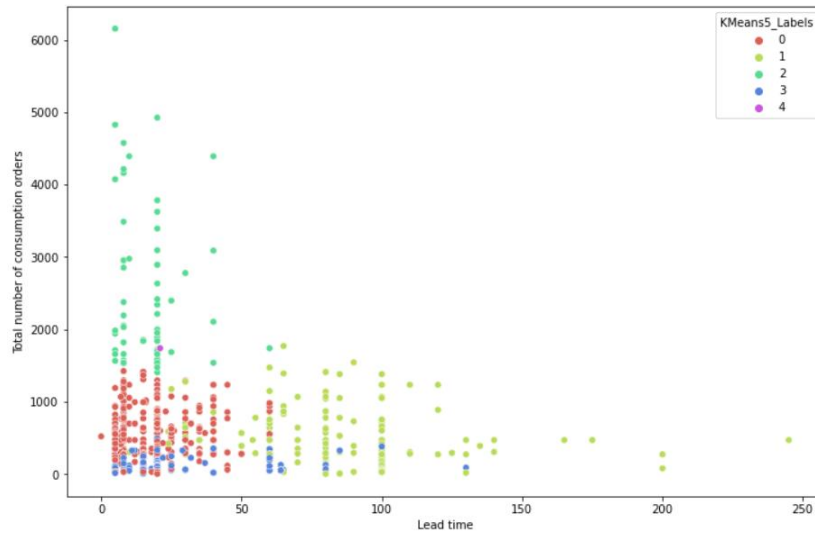
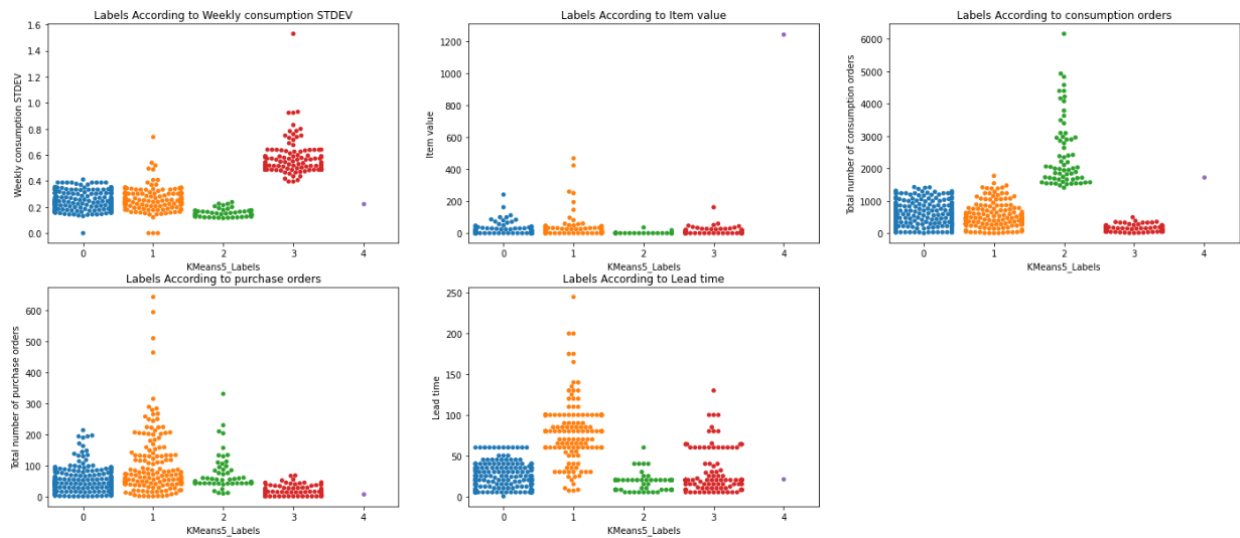


Figure 13 Swarm plots for the five clusters



### 4.5.3 Coding-based clustering in Microsoft Excel

Microsoft Excel was also used to code the different factors or attributes for each item. Each attribute was given a low, medium, or high code based on its value and a set criterion (see **Table 14**). These criteria were derived from the distribution graphs plotted by the algorithm and further discussed with the case company to validate them. The student decided to use one measure for frequency to simplify the coding. The frequency used here was derived from the ABC classification that the company already had.

Table 14 Coding criteria for the different attributes

Attribute	Low	Medium	High
Frequency	C	B	A
Lead time	less than 21 days	21 - 50 days	50+ days
Item value	less than 1 SEK	1 - 20 SEK	20+ SEK
Adjusted deviation	less than 15%	15% - 30%	30%+

Afterwards, the method fit was determined based on how the item behaved in these four attributes. For example, low lead time items with low weekly consumption SDTEV, high frequency, and low item value were considered very likely candidates for reorder point methods (reorder\_point\_candidate1). This would mean that items in this category have environmental characteristics that match the primary application environment for the reorder point methods -except that they are items with dependent demand-. Thus, those items could benefit from having a more straightforward planning method, a variant of the reorder point methods, instead of MRP. Items with the same criteria as items in the reorder\_point\_candidate1 category, except for the SDTEV being medium, are considered second best candidates for reorder point method (reorder\_point\_candidate2). A third group for reorder point was selected mainly due to item value below 20 SEK being considered still relatively low. Therefore, items with the same criteria as reorder\_point\_candidate2 but with medium item values are grouped as reorder\_point\_candidate3. Items in both categories reorder\_point\_candidate2 and reorder\_point\_candidate3 can benefit from using the reorder point methods, however, those items will need to be further explored, and perhaps more criteria will need to be added. Such criteria can, for example, include examining how many BOMs the items are used in. Purchased items used in many BOMs would make the reorder point methods more favourable since this can support making the demand more even.

Finally, the items that do not fall within the three reorder point groups are grouped as MRP suitable since those items match the primary application environment for MRP by, for example, having longer lead times and uneven demand (consumption patterns). Items with high weekly consumption STDEV, labelled as MRP\_More\_Attention, being matched with MRP as the method, are labelled differently since more attention will need to be paid to these items due to the high uncertainty caused by the high variation in the weekly consumption patterns. **Table 15** illustrates a random sample for ten items.

Table 15 Excel coding for a sample of random items

Item number	Adjusted variation	ABC-Frequency	Lead time	Item value	Suggested planning method
1	low	A	low	low	reoder_point_candidate1
2	medium	A	low	low	reoder_point_candidate2
3	low	A	low	low	reoder_point_candidate1
4	medium	C	High	High	MRP
5	medium	A	High	low	MRP
6	high	B	low	low	MRP_More_Attention
7	low	A	low	low	reoder_point_candidate1
8	medium	A	medium	medium	MRP
9	medium	A	medium	High	MRP
10	medium	A	low	medium	reoder_point_candidate3

This analysis resulted in five clusters, with each cluster having different environmental characteristics. The clusters' sizes and features are described in **Table 16**.

Table 16 Clusters' sizes and characteristics

Suggested planning methods	No. of items	Adjusted STDEV	Avg LT	Avg value
<b>MRP</b>	404	0.265	37	16.15
<b>MRP_More_attention</b>	231	0.444	46	8.00
<b>reoder_point_candidate1</b>	44	0.136	13	0.09
<b>reoder_point_candidate2</b>	87	0.196	13	0.09
<b>reoder_point_candidate3</b>	26	0.196	16	5.2

#### 4.5.4 Cluster comparison

A last step in the cluster analysis was to compare the different clusters determined by the different methods concerning the clusters of items that are potential candidates for the reorder point method. The goal here was to validate whether the same items appear in the different clusters with similar characteristics. With the current setting that the case company has, all items are planned using MRP as a method. Therefore, the student decided to validate the clusters that contain items that are potential candidates for the reorder point method. From the manual coding, three groups of items were considered potential candidates and used as a reference compared to the clusters determined with SPSS and the python algorithm. Cluster 5 generated by SPSS showed similar characteristics as the reorder point candidate group 1, 2, and 3. Therefore, the item numbers were compared to validate the relevancy of cluster 5 with the groups coded manually.

The results showed that 87 % of the items in cluster 5 from the two-step clustering in SPSS appeared in the three groups labelled as candidates for reorder point method in the Excel coding. On the other hand, when looking at the clusters generated by the python algorithm, it was found that 67% of the items in cluster 2 match the items in the “reorder point candidate 1” group determined by Excel. These results indicate significant similarities in the outcome, especially between SPSS two steps clusters and the manual coding in Microsoft Excel. While the output from the K-means clustering in python was less similar, Cluster 2 still matched 67% of the items that the manual coding in Excel indicated as the best potential candidates for using a reorder point method.



## 5. Discussion

*This chapter discusses the main areas of the formulated research questions. Section 5.1 addresses and examines the method-environment fit by synthesizing the literature with the empirical findings. Additionally, the section covers the most central parameters of all materials planning methods. Lastly, section 5.3 outlines recommendations for the case company and provides a detailed process of categorizing items based on environmental characteristics.*

### 5.1. Method-environment fit

The planning method's effectiveness depends on whether a set of simplifying assumptions is reasonable to the planning environment in which the company operates in (Ziukov, 2015; Mattsson, 2007; Spenhoff et al., 2014). From a theoretical standpoint, there are five possible alternative materials planning methods. However, their primary application environment varies, which ultimately will affect the accuracy of the materials planning; see **Table 1**. It is difficult to find items with precisely the ideal environmental characteristics required to work optimally for different planning methods.

#### 5.1.1 The case company's materials planning method

The case company uses MRP for all purchased items regardless of the different planning environment characteristics for the purchased items. Mainly because MRP is the only planning method that can generate future delivery schedules. Another finding indicates that all purchased items have a dependent demand, which means that every item appears in at least one or several BOM structures. These are, according to Fogarty et al. (1991), usually best managed by MRP type systems, but in some circumstances, such as for standard, low-value items which are apparent in many different BOM structures, the reorder point method can also be useful for controlling dependent demand (Jonsson and Mattsson, 2009). On the other hand, Kanban is excluded as a possible material planning method for the purchased items for the case company because it cannot be customized for items with dependent demand. Also, when looking at item characteristics and product BOM structures, it was found that the BOMs were relatively complex, and order quantities were rather large.

### **5.1.2. The case company's planning environment characteristics**

As mentioned in **section 4.3.2**, the quality of some parameters is affected by the recent supply chain disruptions, namely lead time. Whereas the high uncertainty affects the quality of the parameters set in the system. The case company has already classified their different purchased items based on lead time and item types. Based on this, some item groups, such as those used in production, can benefit from having a simpler material planning method.

It was possible to distinguish different environmental characteristics related to the case company and the different purchased items based on the cluster analysis in **section 4.5**. It is noted that there is a variation in consumption patterns, i.e., volume and frequency of requirements between the different items, both on a weekly basis for the same item and between the various items. Some items have more stable demand regarding volume and frequency, whereas others have a significant weekly variation. One reason for this variation is late changes in delivery schedules from customers, which require adjustments in the production plan. From a material planning perspective, orders must be pulled in or pushed out within the lead time, mainly handled by the MRP. However, manual interventions from the material planner are sometimes necessary. Variation in demand is a prominent environmental factor that will imply the performance of the planning method, and methods such as Kanban generally prefer more stable demand patterns (Jonsson and Mattsson, 2003; Zuikov, 2015; Jonsson and Mattson, 2006). MRP can, however, handle uneven demand in a good way, but these items might need more attention than others to ensure that the parameters are set correctly.

## **5.2. Parameters setting and update**

The quality of the planning parameters in terms of how accurately they represent reality will impact the performance of the material planning method (Sheu and Wacker, 2001). Shifts in parameter settings can cause instability in the system; therefore, careful considerations have to be made when altering the parameter settings (Enns, 2001; Jonsson and Mattsson, 2008; Jacobs et al., 2011). Moreover, parameters' accuracy would affect the ERP system's performance as a whole due to its integrated nature (Umble et al., 2002). The following section discusses the main types of parameters.

### **5.2.1 Lot size determination**

Decisions regarding order quantities are considered a crucial aspect of materials planning, and they are usually made under widely varying circumstances; therefore, many different aspects have to be considered (Roettig, 2016; Dolgui and Prodhon, 2007). Ultimately, lot sizing aims to minimize the cost per unit; however, motives for lot sizing can be financial and non-financial (Kuik et al., 1994; Jonsson and Mattsson, 2009). Insights from the empirical findings indicate that the case company mostly has non-financial motives for determining order quantities. The reason is that there are limitations in terms of reel sizes and packaging constraints that limit the possibility of optimizing order quantities regarding financial measures. This means that the order quantities must correspond to the reel size since splitting the reels is impossible to find the optimal order quantity.

From the quantitative dataset, it is possible to distinguish three different lot sizing methods used by the case company to determine order quantities. The first is manually entering run-out-time is almost exclusively used for all purchased items. The second method is manually entering the order quantity in the system. Lastly, for the remaining items, orders are created for each requirement, and the method is called in the ERP system “discrete order quantity” however, it uses the same logic as the lot for lot method. However, the Lot for lot is not performing any lot-sizing due the order quantity is solely based on each unique requirement that arises, and it does not involve any storage or tied-up capital (Jonsson and Mattsson, 2009). Therefore, using this method can sometimes result in small order quantities and many ordering occasions (Jonsson and Mattsson, 2009), which potentially can cause instability in the system depending on the demand patterns for the different items. Therefore, if the ordering cost is high, this is possibly not a suitable method to use.

On the other hand, the run-out time method has a more dynamic way of calculating order quantities that correspond with the demand variations within a fixed time interval (Jonsson and Mattsson, 2009). Since the order quantity is based on the demand during a fixed period, the input values must have high quality to ensure that order quantities match the estimated demand for the specified time interval. This means that when assessing how long the run-out time

period should be, careful considerations have to be made concerning how accurate the demand can be estimated for the set period. The case company estimates the length of the run-out time based on experience. Most items had a significantly different annual consumption than the system's calculated annual demand based on the analysis performed. Therefore, this would be expected to affect this method negatively. Shorter planning intervals are preferable from a planning accuracy perspective, whereas more extended periods can increase uncertainty (Jonsson and Mattsson, 2008). However, experience base methods are generally not as accurate as the more analytically complex ways (Jonsson and Mattsson, 2009).

### **5.2.2 Lead time determination**

Two points might negatively affect the materials planning performance regarding lead time setting and update. Firstly, the case company sets the lead times based on agreements with the suppliers, not by monitoring the actual lead time or performing calculations in the ERP system. Researchers have criticized this approach (Jonsson and Mattson, 2006; Dolgui and Prodhon, 2007) as it might harm the planning performance and lead to shortages, excess inventories, or create nervousness in the system. A more analytical approach to calculating lead times is a better alternative to providing more accurate lead times estimates (Jonsson and Mattson, 2006).

Secondly, the case company does not closely monitor lead times to measure the variation between actual lead times and what is in the system. Roettig (2016) regarded monitoring actual lead times as one of the most critical factors in a planning system to secure the accurate timing for replenishing materials. Consequently, the lead time is not updated based on the actual situation but based on experience (agreements with the suppliers). Interviewee 2 (2022) mentioned that this worked quite well for the case company before all the recent supply chain disruptions, whereas the lead times did not vary from those in the system. However, the recent supply chain disruptions are causing higher uncertainties and longer lead times for almost all items. This is also reflected in that many suppliers are requesting longer lead times. Nonetheless, those requests are not matched with lead times updates in the system and are handled for each order separately. It is only updated in the system when the requests trigger an update in the agreement with the supplier.

### **5.2.3 Safety mechanism determination**

The case company works with both safety stock and safety time, depending on where in the life cycle the item is. For example, the company sets zero safety stock and works with safety time for newly introduced parts or those about to be phased out. While for the remaining items, the safety stock level is set and updated regularly. Using safety lead time for newly introduced items would match with dealing with uncertainties in lead time, as suggested by Whybark and Williams (1976). However, for phased-out items that have already been used for some time, which indicates a relatively known lead time, safety stocks would be more suitable due to uncertainties in supply and demand quantity (Whybark and Williams, 1976).

The regular update for the safety stock levels is regarded as a time-consuming process for the material planner. However, the added value of this process would be that it allows the company to adjust to the different variables. This is specifically important as the industry is faced with higher uncertainties and longer lead times, as previously mentioned. Common reasons for when the safety stocks are adjusted for the items include significant changes in an item's lead time, change in demand, adding a new production line, or when the supplier for an item has been changed to a new supplier. Those common reasons for updating safety stocks match to some extent with the traditional method for calculating safety stocks, as presented by Chopra et al. (2004), being a function of demand and lead time uncertainties, service levels, and replenishment lead time.

The company works well on frequently updating the safety stock levels. However, from the quantitative data analysis, it was found that twenty-four items had an on-hand inventory below the safety stock levels set in the system. Out of the total purchased items that the company has, this is a relatively small proportion; however, it was mentioned by Interviewee 2 (2022) that all items used in the BOM are needed to deliver the finished products to the end customer. Nevertheless, this can also be attributed to external factors, and it cannot be certainly attributed to the performance of the materials planning per se.

### **5.3. Recommendations to improve the materials planning performance**

The following chapter outlines three general recommendations for the case company to consider regarding materials planning. Namely, measuring the materials planning method performance, reviewing and updating the different parameters regularly, and having a more structured approach for selecting the suitable safety mechanism. Possible approaches to implement these three recommendations are presented in **Table 17**. Additionally, a sequential process for how the case company can categorize the items based on environmental characteristics to match the method with the environment.

#### **5.3.1. General recommendations**

A first step to improve the materials planning performance at the case company would be to *measure the performance* of the materials planning method. According to (Solberg et al., 1997), when looking into process improvement, measurement plays a vital role in three different areas; when deciding which improvement opportunities or issues need attention when obtaining measurements baseline and after an improvement has been executed. Therefore, to improve the performance of the planning method, the case company should start measuring the performance of both input and output of the materials planning method. Input being the accuracy of the parameters set in the system. When it comes to measuring input, the following aspects are suggested:

- 1) Lead time deviation: To improve the overall planning performance, it is suggested that the case company starts to measure the actual lead time and update the lead time set in the system based on calculations that consider the actual lead time. This is expected to provide more accurate estimates and result in better materials planning in terms of setting inventory levels, providing better control over inventory costs (Jonsson and Mattsson, 2006).

- 2) Safety time and safety stock levels vs on-hand stock: As illustrated in the analysis, there were several items in which the inventory levels fell below the safety stock. As previously mentioned, the case company needs all BOM items to deliver final products, and it only works with having three days of safety stock for the finished goods. This would mean that any out-of-stock instant will directly affect service levels. Therefore, measuring the inventory on hand versus safety stock would make a relevant performance measure. Moreover, it is also suggested to utilize the functionalities provided in the ERP system to calculate safety stocks instead of doing this process manually. As mentioned earlier, it is a time-consuming process that can be performed automatically in the system.
- 3) Annual demand calculations: Another relevant measure that affects both service levels and inventory cost is the annual demand calculated in the system. Measuring that against the actual consumption for the component can provide reasonable indications for the company on whether the inventory levels are building up, in case if the actual consumption is significantly less than the calculated demand, or if inventory levels are getting too low when the actual consumption is suggestively more than the calculated demand. It will also indicate how accurately the case company estimates the total annual demand for the different items, which will inform the company on how accurately they forecast future demand.

On the other hand, when measuring the output, the case company can start by measuring the two aspects related to inventory management performance: service levels and inventory costs (Wild, 2002). That is, by, for example, counting the occurrences of out-of-stock incidents and also by establishing a target for stockholding value and measuring the actual tied-up capital against this target. Measuring input performance can help determine a suitable planning method, whereas when the input performance is low, a simpler planning method that is not dependent much on the quality of the parameters might be a better alternative than a planning method that is much dependent on input quality. While measuring the output can indicate the overall performance of the inventory materials management and capture if a specific change contributed to a measurable improvement.

Additional potential areas for improvement will be to *review and update the different parameters regularly* and not limit the frequent update to safety stock levels. Lastly, the company can take a *more structured approach to select the suitable safety mechanism* for the different items. This can be established by categorizing the items into two main categories: (a) items with relatively higher uncertainty in lead time and (b) items with relatively higher uncertainties in supply and demand. Accordingly, category 1 would be more suitable to have a safety time and safety stocks for category 2.

Table 17 Suggested approaches to implement the general recommendations

Suggested improvement		Needed data	Suggested approach
Measuring performance	Lead time deviation	Actual lead time	<ul style="list-style-type: none"> <li>Monitor actual lead time</li> <li>Analyze the trends and capture deviation compared to the lead time set in the system</li> </ul>
	Safety stock/time vs on-hand stock	Safety stock On-hand stock	<ul style="list-style-type: none"> <li>A potential approach is to integrate a formula in Qlik sense and visualize it in a table</li> </ul>
	Annual demand vs consumption	Calculated annual demand Consumption patterns	
	Service levels performance	Count of out-of-stock incidents	
	Inventory cost	Items values On-hand stock Safety stock	<ul style="list-style-type: none"> <li>Calculated a targeted stockholding value: set a targeted inventory level and then multiply it by the item values</li> <li>Measure current stockholding value: multiply current stocks with items value</li> <li>Compare the actual stockholding value with the targeted stockholding value</li> </ul>
Review and update the different parameters regularly		<ul style="list-style-type: none"> <li>Use existing settings in the ERP system that enable automatic calculations without manually updating the system's parameters. This was not explored in this study. However, Infor M3 provides different functionalities to do this.</li> </ul>	
A more structured approach to selecting the suitable safety mechanism		Lead times uncertainties Supply and demand uncertainties	<ul style="list-style-type: none"> <li>Use different safety mechanisms based on: (a) Safety time for items with high uncertainty in lead time and (b) Safety stock for items with high uncertainties in supply and demand.</li> </ul>

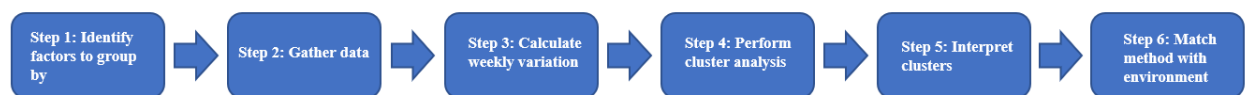
### 5.3.2. Items categorization

The planning method's efficiency and effectiveness vary depending on the planning environment (Jonsson and Mattsson, 2006). This is further supported by a survey within the Swedish industry which indicates that 60% of high-performing companies chose their materials planning method based on extensive analysis and assessment (Jonsson and Mattsson, 2014). The case company uses the ABC classification to classify items based on volume value and frequency, which are considered two of the most common classification criteria used in practice (Teunter et al., 2010). In addition, the empirical findings indicate that other criteria are used to classify items; however, no identified approach systematically links important environmental characteristics to the planning method used by the case company. Therefore, categorizing items based on a systematic approach that considers the different planning environment characteristics is beneficial in matching the planning environment with the most suitable planning method. Depending on the nature of the company and the context it operates, the number and type of criteria and their relative impact may vary (Flores et al., 1992).

An essential outcome of this research was a structured process to categorize the purchased items based on relevant environmental factors. The process consists of six steps, with the first step dealing with identifying factors to cluster with, where the number and type of factors should represent the company's environment. As discussed in section 3.4.3, when conducting the cluster analysis, the following five factors were used as input: item value, lead time, weekly consumption variation, frequency of consumption, and purchase orders. The next step is to gather the relevant data necessary to identify the different factors. Item value and lead time data were available in the system and provided in the dataset. However, the frequency of ordering and consuming parts was calculated by counting the ordering and consumption transactions from the table extracted from the case company's ERP system. In the third step, the weekly standard deviation was calculated to identify the demand patterns for the different purchased items. This was important since a high variation in demand would imply special measures to be taken. Following this step, three different clustering approaches were tested, and the process for all three methods is described in chapter 4.5.

The remaining stages of the process were conducted based on the Excel coding since this method provided more details than the other two approaches. Step 5 included a careful process of interpreting the different clusters based on the various environmental characteristics to ensure that each cluster has a unique representation of the different factors. Ultimately, the goal is to identify clusters with unique characteristics to match the method with the behaviour of the various items. Therefore, this process step needs extra attention to validate the different clusters. Lastly, after identifying items with different characteristics, the process should match the planning method with the given characteristics of the different clusters. The process is illustrated in **Figure 15**.

*Figure 14 Process for matching the planning environment with a suitable planning method*



Although the selected categorization approach for this thesis was the Microsoft Excel coding, it was validated in section 4.5.4 that all the three methods could be used for the classification of items based on the planning environment characteristics. Therefore, the choice of which approach to use by the case company or Meridion AB can be based on which method suits the company or how easy it can be incorporated with the system. For example, IBM SPSS software was considered the simplest and least effort-consuming tool when conducting the analysis; however, the software itself is rather expensive. On the other hand, Excel was the most time-consuming method, and it required higher interference with the data, but it provided accurate outcomes with a high level of detail. Additionally, most companies have already invested in a Microsoft Office suite license. Lastly, the result from the clustering using the python algorithm was less accurate, but it constituted a good visualization tool for the clusters and how the data points/items are distributed.

## 6. Conclusion

*The following chapter will answer the research questions formulated in section 1.3. Additionally, limitations connected to the project will be addressed. Lastly, a continuation of this research project will be suggested, and general future research possibilities within the same area will be provided.*

### 6.1 RQ1: Possible options for inbound inventory planning methods

From a theoretical standpoint, there are multiple planning methods used for materials planning; however, each method performs differently depending on the characteristics of the planning environment. Since all purchased items have a dependent demand, it automatically limits other possible options to MRP, the most suitable method for items with dependent demand. Another limitation of other planning methods is that it is not possible to generate future requirements, unlike MRP, whereas the other methods can solely be used to replenish materials.

Given that the case company works with delivery schedules towards their suppliers, compared to MRP, none of the other methods provides the same support in generating future orders for the supplier. Nevertheless, the outcome of the cluster analysis has identified items with high variation in demand which possibly can hamper the performance of the MRP, where these items might need more attention with regards to how the case company works with the method. Additionally, other items have been identified as potential candidates for the reorder point method, with low variation in demand, low item value, high frequency, and short lead times. Whereas reorder point method can also work for items with dependent demand with particular consideration and planning environment characteristics. Additionally, reorder point has different variants to determine the timing and quantities for ordering, as explained in **section 2.1**. However, the downside of the method is that it cannot generate future delivery schedules. MRP is generally the optimal method to use with dependent demand and when working with delivery schedules. However, the reorder method has the potential to perform in some of the identified environments.

## 6.2 RQ2: How the case company works with the method

The case company currently uses MRP as the only materials planning method for all purchased items, whereas all planning is done automatically by the MRP, with material planners reviewing and confirming orders before sending them to the suppliers. Additionally, when a change in the production plan emerges, MRP automatically updates the orders and suggests either pulling in or pushing out orders based on the updated production plan. The material planners review these suggestions and either accept them when valid or manually adjust the push-outs or pull-ins.

For the case company, the parameters are set and updated manually based on experience or agreements with suppliers. As a result, safety stocks are manually reviewed monthly without utilizing the different functionalities provided by the ERP system. Such functionalities are illustrated in **B. Appendix 2, 3, 4, 5**. This time-consuming process can be performed more efficiently with support from the ERP system without manually updating safety stocks every month. In addition, lead times are often set based on agreements with the suppliers and not by monitoring actual lead time. Determining lead times based on experience has potential drawbacks in terms of the overall planning performance, and it also demands regular manual reviews. Therefore, monitoring and incorporating actual lead time when setting the lead time in the system is considered a critical factor for materials planning as it facilitates better timing for replenishing materials.

Moreover, the case company does not work with lot sizing to optimize order quantities when determining order quantities. Mainly due to constraints regarding reel and packaging size. Nonetheless, the case company uses a dynamic method for deciding order quantities, whereas the order quantity changes according to the demand during the run-out time. However, the period for which the order quantities are determined is fixed and based on experience. Therefore, the run-out time must be maintained manually in the system, similar to safety stocks and lead times.

To answer the second part of the research question, two aspects were examined to indicate the performance of the inbound inventory management. The first one looked into inventory levels compared to safety stocks, and the second was to contrast consumption and demand patterns. Some incidences of when the stock levels fell significantly below the safety stock and when the consumption differed remarkably from the calculated annual demand were spotted. Both cases are problematic since an inventory below safety stock negatively impacts service levels and suggests shortage. Furthermore, higher consumption patterns compared to calculated demand would contribute to lower inventory levels than planned which can also lead to shortages, while lower consumption patterns compared to the demand would result in building excess stock that is not needed and thus increase the inventory costs. These two aspects indicate room for improvement in the inbound inventory planning management.

### **6.3 RQ3: How to improve the inbound materials planning performance**

To improve the performance of the overall inbound inventory materials planning, three improvement suggestions are provided, along with a structured approach for selecting the planning method to establish a better fit between the method and the environment. Matching the method with the environment is crucial to secure desirable planning performance, and researchers are suggesting that the choice of method should be based on extensive analysis (Jonsson and Mattsson, 2014).

Firstly, the outlined improvement suggestions included: (1) Measuring the materials planning performance, mainly due to the criticality of measurement in process improvement processes. Three areas were suggested to measure the performance. These included measuring the deviation of the lead time set in the system from the actual lead time, measuring inventory levels compared to determining safety stocks and measuring the calculated annual demand performance against actual consumption patterns. (2) Regularly reviewing and updating the main planning parameters and not limiting the update only to safety stock levels. And (3) Following a more structured method for selecting safety mechanisms for the different purchased items.

Secondly, this project has illustrated a systematic way of analyzing the planning environment by grouping items based on important environmental factors, using basic data settings and transaction data extracted from the ERP system. The main deliverable is the six-steps process illustrated in **Figure 15**. One of the process outcomes is different groups of items with environmental characteristics, where the behaviour of some items indicates potential candidates for the reorder point method; see **Tables 15** and **16** for detailed information. The key takeaway from this method is to generate meaningful insights to match the materials planning methods with the environments. An added advantage of this approach is the possibility of visualizing the different clusters that support the decision-making process.

Lastly, the thesis utilized Qlik sense as a business intelligence tool to understand the overall trends and get a holistic view of the general materials planning at the company. Both Meridion AB and the case company are familiar with Qlik sense and have previously worked with the tool. Therefore, using such a tool to support the implementation of the suggested improvement is expected to yield significant benefits. This can be done by embedding the suggested performance measurements in the Qlik sense and visualizing the distribution of the different clusters based on environmental factors, as illustrated in **Figures 11** and **13**.

## **6.4 Limitations**

One limitation of the project was that the analysis included only 792 items out of the total 1100 used, which means that further insights can be made if all items were included. The main reason for this is motivated in chapter 3.4.2. Moreover, another limitation of the project was that only a few parameter settings had been investigated, even though there are many parameters available in the ERP system, which potentially can affect the materials planning. There are also more dimensions connected to the materials planning, whereas this project has been limited to only looking at inbound inventory management without doing any deeper investigation of other areas of the supply chain, which can have an impact on materials planning. The reference has been the level above inbound inventory management when investigating the planning environment, which is a manufacturing company's production planning and execution. Furthermore, this thesis was not focused on statistics and the details of the cluster analysis;

instead, cluster analysis was used as a possible approach to how the case company can classify the planning environment. Therefore, the statistical analysis was not elaborated on and was not fine-tuned.

## **6.5 Continuation of the project and future research areas**

This research project has focused on how the planning environment affects the choice of planning method and how different parameter settings can impact the dynamics of the planning methods. Therefore, a possible continuation of this project could be to investigate other possible parameter settings and their impact on materials planning. This can be done by exploring the different functionalities provided by Infor M3 to automatically determine parameters instead of manually reviewing and updating these.

Moreover, a further continuation of this project could be to examine and elaborate on the different approaches provided in **Table 17** for how the case company can implement the suggested recommendations to improve the general materials planning performance. Such as using calculations and functions available in the ERP system or the Qlik sense application to measure the performance. Another area for future research could be to examine in detail the different statistical methods to conduct the cluster analysis and compare them to increase the quality of the clusters, and thus find an optimal method to use to classify the planning environment.



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## **A. Appendix 1 - First interview guide, with Interviewee 1**

1. Please describe your role and responsibilities within the company
2. How does the company initiate and plan for materials orders? Can you describe the process in detail?
3. How many materials planning methods do the case company use, and what are they?
4. How would you describe the planning environment for the different components that the company purchases?
5. From your point of view, how do the different planning environments impact the performance of the materials planning method used?

## **A. Appendix 2 - Second interview guide, with Interviewee 2**

1. Can you please describe your role and responsibilities within the company?
2. What is the general strategy for inbound materials planning?
3. How does the company initiate and plan for direct materials orders? Can you describe the process in detail?
4. The data shows that the active purchased items were mainly planned using MRP, and few were planned manually.
5. How do you decide on what safety time you should use for the different items?
6. From the data, we can see that you calculate safety stocks manually. How is this done, and what variables do you consider in the calculation?
7. Some items have “zero” annual demand (about 20) in 2020; what does this mean?
8. We could also see that you use ABC categorization based on volume and frequency. How do the different categories affect the planning method and the set of the parameters?
9. Are there external-environment factors that influence the materials planning process? What are they?
10. Lead times vary from more than a year to a few hours for the different items; how does this influence the planning method?
11. How do you accommodate the different environments and characteristics of the various items when setting the parameters?
12. How often do you review/update the different parameters, and on which basis?

## **A. Appendix 3 - Third interview guide, with Interviewee 3**

### **Follow up questions:**

1. You mentioned during the previous interview that you have about ten or more groups for purchased items. What are these? Also, In the dataset, we can see 16 item groups.
2. During the last interview, you mentioned that you work with early warnings to handle lead-time variation, but do you measure it somehow?

### **Questions from the data set:**

3. What are the criteria on which the item groups are divided?
4. Some items have zero-order quantities even though they have a high annual demand. What is this the case?
5. How are the different procurement groups divided?
6. Some items have 0 safety stock yet high annual demand; why is that the case?

### **Additional questions:**

7. How do you decide on what service level you should use for the different items?
8. How often do you re-calculate the annual demand?
9. What are the input variables when calculating the annual demand?
10. When setting lead times, are you counting working days or calendar days?
11. How do you measure performance for materials planning?
  - e.g., do you measure the deviation between set lead time and actual lead time, actual stock and the reported stock in the system, annual demand set in the system, and actual annual demand?
12. What do you consider short, medium, and long lead times?
13. What do you consider low, medium, and high demand?
14. From the data, we can see that the stock on hand is below the safety stock level; what are the reasons behind that?

## **A. Appendix 4 - Fourth interview guide, Interviewee 2**

1. How often do you have to update parameters in the ERP system?
2. We know that MRP is doing all the planning automatically, and materials planners are only monitoring the system.
  - What are the most common interventions you have to make when changing something in the system?
  - How often do you have to make manual adjustments?
  - What are the most common adjustments you have to make manually in the system?
3. When you update the items every month, are there specific items you update more often than others?
  - What are the primary triggers for that?
  - What is the typical behavior of those items?
4. In addition to safety stocks, what other parameters do you have to update more regularly than others?
5. What are the most common problems with MRP, according to you?
6. When working with MRP in the ERP system, what problems do you face, if any?
7. What are the common issues when the MRP is not working appropriately?
8. For the item value from the safety stock file, we noticed that most items are below 1 (54%), and there are only around 100 items that cost 20 and above.
  - What do you consider low value in terms of price?
  - Can we consider less than one a low-value item?
  - Or can we consider less than 20 a low-value item?
9. Do you consider item criticality when grouping items?

## B. Appendix 1 – Order policy methods available in the ERP system

Order policy method	Mode of application	Description
<b>00: Manually entered quantity</b>	Fixed quantity/variable period	Quantity is entered manually
<b>01: Fixed quantity calculated from run out time</b>	Fixed quantity/variable period	Number of run-out days is entered per item. The requirement are either yearly requirements, Running yearly usage, Historic usage, or forecasted usage.
<b>02: Economic order quantity, Wilson´s formula</b>	Fixed quantity/variable period	EOQ: Square root of $((2 * \text{Yearly req.} * \text{Ordering cost}) / (\text{Carrying cost} * \text{Stock price}))$
<b>11: Discrete order quantity</b>	Variable quantity/variable period	The order is created for each requirement, which can be several per day.
<b>12: Manually entered run-out-time</b>	Variable quantity/variable period	Quantity is calculated according to the logic used in MRP. When requirements arise, orders are placed that cover the days entered in the system as run-out-time.
<b>13: Economic run-out-time</b>	Variable quantity/variable period	Same logic as the manually entered run-out-time, but the quantity is calculated according to the Wilson formula, and the run-out-time is EOQ/daily requirement.
<b>15: Run-out time using timeTable (so-called point-of-time Table)</b>	Variable quantity/Variable period	Requirements are summarized according to planning points specified in the point-of-time Table. Planning points can be specified to be e.g. 10:00 every day.
<b>21: Least unit cost</b>	Variable quantity/Variable period	Estimates different order quantities by accumulating one daily requirement at a time. Each order receives the quantity that has the least unit cost.
<b>23: Period-based order quantity without balance check</b>	Variable quantity/Variable period	Developed for environments where a requirements-determined order initiation is desirable. Production has to be balance according to min-max order quantities per day. The production rate as to be established for the product.
<b>24: Period-based order quantity with balance check</b>	Variable quantity/Variable period	Same principle as 23. But is considers opening balance for each period and evens out the surplus requirements.
<b>25: Up-to maximum on-hand balance</b>	Variable quantity/Variable period	The method is mainly designed for reorder point method. Order quantities are determined so that the balance after each transaction is equal to the max on-hand balance.

## B. Appendix 2 – Planning methods available in Infor M3



### Planning method



The field indicates the material planning method set for the item/warehouse during acquisition order entry. There are two basic methods (material requirements planning and reorder point planning) used to plan and create acquisition orders.

#### Alternatives

- 0 = Manually planned
- 1 = Material requirements planning (MRP)
- 2 = Reorder point planning (ROP) per item/warehouse
- 3 = Order-driven - Acquisition orders are only triggered, created and released by a requiring order
- 4 = Reorder point planning (ROP) per item and facility
- 5 = Reorder point planning (ROP) per item and global facility.

Material requirements planning (MRP) is a set of techniques that uses bills of material, inventory data, and the master production schedule to calculate requirements for materials.

Reorder point planning (ROP) is a set inventory level that triggers an acquisition order. If the total on-hand balance plus stock on order equals or falls below the reorder point, the triggered acquisition order replenishes the stock.

Order-driven (alternative 3) means that the order is created and released only in direct relation to the controlling order.

#### Note

The planning method is a key parameter and it affects the entire material planning process in M3.

Close

OPLC (MBOPLC)

## B. Appendix 3 – Safety stock methods available in Infor M3

### Safety stock method

The field indicates how the safety stock is calculated and updated.

#### Alternatives

- 0 = Manually
- 1 = Automatically according to the formula: Number of safety stock days \* Daily usage
- 2 = Automatically according to the formula: Safety stock percentage \* Lead time \* Daily usage
- 3 = Automatically according to the formula: Safety factor \* 1.25 \* Mean absolute deviation (MAD) \* Square root of lead time in number of periods
- 4 = Number of safety stock days in accordance with [\(MMS093\)](#)
- 5 = Number of average issues in accordance with the safety stock control table
- 6 = By integration to MerciaLincs
- 7 = Automatically according to Poisson table
- 8 = Automatically, average quantity/issue. Optionally multiplied with safety stock factor.

#### Explanation for alternative 7 and 8

Alternatives 7 and 8 can be selected for items that must be kept in stock, but with few or very few issues and random demand patterns. For these methods, Average quantity per issue = Demand last 12 month / Number of issues last 12 months. This calculation is affected by the 'Include current period' and 'Use number of requests' settings on (FCS300/F). With alternative 8, the components of the calculation are not rounded off. However, the final result is rounded up according to the number of decimals set in [\(MMS001\)](#).

The safety stock according to the Poisson table is calculated as follows:

1. Annual demand in [\(MMS002\)](#) / Average quantity per issue = Number of planned issues.
2. Number of planned issues \* (Lead time + Safety stock days) / Number of working days = Estimated number of issues during lead time.
3. For positioning in the Poisson table, the estimated number of issues during lead time is used as the factor and the safety level from the item and warehouse record in [\(MMS002\)](#) is used as the safety level.
4. The correct number of issues (rounded up) in the Poisson table \* Average quantity per issue = The new safety stock.

If the calculated estimated number of issues during lead time exceeds the highest value in the Poisson table (step 4), the following calculation will be made:

1. Retrieve the security factor for the corresponding service level in [\(FCS320\)](#) based on the service level from a) [\(MMS002\)](#) b) [\(CRS015\)](#).
2. Calculate the new safety stock according to (Issues during lead time estimate + (Security factor \* SQRT(Issues during lead time estimate)) \* Average quantity per issue.

## B. Appendix 4 – Planning parameter settings in Infor M3.

Planning Parameters			
Note			
Planner	JOHBYS72	Facility	A01
Acquisition cd	1-Manufactured	Period frame	2 Months
Planning method	1-MRP	Planning policy	10 MRP
Mastr scheduled	0-Not mstr sch it	Supply c policy	
Admin lead tm		Cont net change	<input type="checkbox"/> 220401
Postal lead tme		Plan horizon	300
Supply lead tm		Safety time	
Transp lead tm		Demand tm fence	
Inspec lead tm		Planng tm fence	
Lead time		Seasonal item	<input type="checkbox"/>
Inventory plnd	30-Stocked	F/C method	
Status	20-Released	F/C logic	
Order type	M10 MO - Direc	Distr table	
Supplying whs		Supplier	
		Multiple supply	2-Multiple

## B. Appendix 5 – Stock parameters available in Infor M3

**Stock Parameters**

Safety stock	<input type="text" value="0"/>	Safety stk mtd	<input type="text" value="0-Manual"/> <input type="checkbox"/>
Safety stk unit	<input type="text"/>	Service level	<input type="text"/>
Reorder point	<input type="text" value="0"/>	RoP method	<input type="text" value="0-Manual"/>
Order quantity	<input type="text" value="0"/>	Order policy	<input type="text" value="12-Man run-out tm"/>
Order qty days	<input type="text"/>	Max stock pct	<input type="text"/> Point of tm tab <input type="text"/>
Maximum stock	<input type="text" value="0"/>	Max stock mtd	<input type="text" value="0-No"/>
Annual demand	<input type="text" value="0"/>	Annual dmd mtd	<input checked="" type="checkbox"/>
Min order qty	<input type="text" value="0"/>	Max order qty	<input type="text" value="0"/>
Order multiple	<input type="text" value="0"/>	Issue multiple	<input type="text" value="0"/>
Min safety stk	<input type="text" value="0"/>	Avg issue qty	<input type="text" value="0"/>

**ABC Class and Method**

ABC cls volume	<input type="text" value="A"/>	ABC mtd volume	<input checked="" type="checkbox"/>
ABC cls freque	<input type="text" value="A"/>	ABC mtd freque	<input type="checkbox"/>
ABC cls contrib	<input type="text" value="A"/>	ABC mtd contrib	<input type="checkbox"/>
ABC cls manual	<input type="text" value="A"/>		
Product line	<input type="text"/>		
Inventory segm	<input type="text"/>		



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