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# MRP nervousness in a complex assemble-to-order environment: investigating decoupling solutions and effects on the human planner

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# MRP nervousness in a complex assemble-to-order environment: investigating decoupling solutions and effects on the human planner

*Master Thesis*

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# Abstract

This research is about MRP nervousness, which has been defined as the instability in planned orders, excessive rescheduling of open orders, or the negative effect of open-order rescheduling (Ho et al., 1992). The purpose of this research was to investigate how this has an effect on the job of the human planner, and how solutions for the problem of nervousness could also improve the job characteristics and job outcomes of the planner. The research was conducted at ASML Veldhoven, where the problem was evident from the high number of projected material shortages and corresponding rescheduling suggestions on purchase orders. By applying job design theory, it was found that nervousness, in terms of how negatively working with shortages under the MRP way of planning was perceived by planners, had a significant positive relation with turnover intention, as well as a significant negative relation with the motivating potential of the job, task identity, and feedback from the job. After two buffering solutions, decoupling safety stock and Supplier Managed Inventory, had been implemented for some parts, the planners responsible for these parts noted that both solutions contributed to their overall perceived task significance and job satisfaction.

# Management Summary


### Problem description

The problem of nervousness has been a known challenge associated with MRP systems since its earliest days (Ptak & Smith, 2016). MRP, which stands for Material Requirements Planning, is still at the core of ERP systems used by thousands of manufacturing firms today to determine production and procurement schedules in a dependent way (Silver, Pyke, & Thomas, 2016). A shortcoming of this way of planning, is that it does not adequately handle all the uncertainties that are present in today's complex supply chains, leading to a high amount of rescheduling suggestions and projected material shortages. This especially affects planners whose responsibility it is to ensure timely material availability by coordinating the incoming flow of purchased materials. On a daily basis, they are involved with all of the rescheduling suggestions and projected material shortages that follow from the planning system. The overall aim of this research was to investigate solutions which would create independencies between demand and supply, i.e. decoupling solutions, in order to reduce the frequently required rescheduling actions whilst simultaneously improving the job satisfaction of the planner.

### Research methodology

The body of this research consisted of three main parts. In the first part, a quantitative survey was sent out to all 55 planners from the Operational Supplier Management Department of ASML to investigate how nervousness was related to the motivational job characteristics and job outcomes of planners. In the second part, ways of coping with nervousness were investigated, mainly focusing on two SAP-based solutions: decoupling safety stock (also known as shared safety stock) and Supplier Managed Inventory (SMI). Additionally, data analyses of demand and shortages were conducted to gain a better understanding in the uncertainty of planned demand and characteristics of shortages. In the third part, qualitative interviews were held with all 6 planners who worked with either of the two solutions after they had been implemented for some of the parts under their responsibility.

### Conclusions and recommendations

The findings of the survey included a significant positive relationship between nervousness (defined as the extent to which a planner experiences working with projected shortages under the MRP way of planning negatively) and turnover intention, as well as a significant negative relationship between nervousness and the motivating potential of the job, task identity, and feedback from the job. This indicated that it was important to improve the meaningfulness of rescheduling actions related to shortages. Furthermore, the analysis of shortages gave the insight that over 75 % of projected material shortages had underlying issues which are not directly plan-related. This mainly entails demand integrity issues (demands in the past, overplanned demand, and non-firm demand on the short horizon) and a high amount of 'stranger' parts (parts with no or hardly any consumption data in the past year) which are carried over every week in the

shortage list. Hence, it is recommended to focus on such issues to enable a more effective use of the planning system. For the remainder of the projected shortages that the planners in scope spend most of their time on, decoupling solutions were implemented that reduce the required rescheduling actions. The main difference noted between the two solutions is that with SMI the responsibility of managing inventory and orders is transferred to the supplier which is not the case with decoupling safety stock. If the supplier is capable enough, this can be more beneficial as it gives the planner an even more monitoring instead of compensational role. In the final part of this research it was found that planners who had worked with these solutions reported that they contributed to the significance and satisfaction in their work, as it allowed them to focus on more meaningful tasks. Therefore, it is recommended to further apply these solutions, in particular for parts which are not complex high value parts, in order to allow planners to focus on more meaningful and challenging tasks and improve their overall job satisfaction. The implication of this research is therefore that MRP nervousness is also relevant to consider from a human perspective, as buffering solutions can positively impact the job of the planner. Overall, this research provided a different view of nervousness, which can be used in future scientific research on job design and MRP nervousness, but also in practice, as it gives a new insight in the benefits of buffering-oriented planning solutions.

# Preface

This research marks the end of my time as a student at the TU Eindhoven. My time at this University has brought me many good memories, in the first years during the bachelor of Industrial Engineering and in the subsequent years during the master of Operations Management and Logistics. I have enjoyed the courses and working together with fellow students, as well as spending a semester abroad in Buenos Aires, which was a great experience where I was lucky to meet many great people as well.

Looking back on the final period of writing this thesis, there are a number of people I want to thank. Firstly, I want to thank Bas Smits for giving me the opportunity to work on such a relevant and interesting project. You have guided me throughout this thesis, also challenging me when needed, which helped me a lot. There have been many other helpful people at ASML, who I want to thank as well. This includes in particular my fellow interns in the organization: we shared some ups and downs, but we certainly had a fun and enjoyable time together. Overall, ASML turned out to be a great environment to work in and learn from, which I am grateful for.

I want to thank Josette Gevers for her guidance as a first supervisor throughout this project. You have always helped me in providing a structure in the broad spectrum of topics that were relevant for this thesis. Even though you experienced some serious setbacks outside of work, you were still continuing to provide me with quick and above all useful feedback, which I truly appreciate. Also, I want to thank Willem van Jaarsveld for his help as a second supervisor, always providing me with clear feedback as well.

Finally, I want to thank my friends and family, who have supported me greatly. My friends may have sometimes not seen me as much as they, and I, would have liked, but I am sure that we will make up for that. I want to give a special thanks to my family, I could always share my stories with you and I think you might have learned a thing or two about planning and nervousness in the process. You have always been there to motivate and support me, many thanks for that.

*Mark Vogels*

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# 1 Introduction

## 1.1 Problem Description

The planning engine in modern enterprise resource planning (ERP) systems is still based on Material Requirements Planning (MRP), with additions of Manufacturing Resources Planning (MRP II), which were mainly developed in the 1970s and 1980s (Wiers & de Kok, 2017). MRP is a basic tool for performing the detailed material planning function in the manufacture of component parts and their assembly into end items (Jacobs et al., 2011). It applies well in situations of multiple items with complex bills of materials, and successful implementations are seen in thousands of manufacturing firms (Silver et al., 2016). In the MRP approach to detailed material planning, end item requirements specified in the master production schedule (MPS) are converted into a time-phased schedule for all intermediate assemblies and component parts (Jacobs et al., 2011). The detailed schedule consists of open orders (scheduled receipts) and planned orders. An open order represents a commitment, meaning a purchase order for a buy part or an open work order for a manufactured part, whereas the planned order is only a plan. Upon updating the schedule by a new MRP run, planned orders are removed and completely rescheduled, starting from end items. On open orders MRP will generate recommendations, by means of rescheduling messages, in case their due date does not match the requirement date anymore (Jacobs et al., 2011). It is the task of the MRP planner to process these recommendations in order to prevent material shortages or overplanned inventory. This might be done by expediting, delaying or canceling an order, or by changing the size of an order (Silver et al., 2016).

A known challenge associated with MRP systems since its earliest days, is the challenge of system nervousness (Ptak & Smith, 2016). MRP system nervousness exists when there is an instability in planned orders and open orders are rescheduled excessively (Ho, 2008). The term nervousness has also been used to describe the negative effects that result from frequent revisions to due dates of open orders and planned orders in Material Requirements Planning (Heisig, 2012; Ho et al., 1992). If the rescheduling messages are not managed adequately, the negative effects will be intensified (Ho et al., 1992). Adverse effects of inadequate handling of rescheduling problems may include considerably high rescheduling costs, fluctuating capacity utilization, and confusion on the shop floor (Campbell, 1971). In a more recent study by Li & Disney (2017), it is pointed out that it is difficult to quantify the cost of nervousness directly and is therefore mostly ignored in dynamic supply chain studies. They do note however, that all costs must be absorbed somewhere in the supply chain. Furthermore, they describe that nervousness is undesirable as an increase in quantity within the lead time cannot be met without expediting production or delivery.

The demand for quick responses and short lead-time delivery in current business environments only intensify the rescheduling problem (Ho, 2005). Furthermore, product variety and complexity have risen, outsourcing is more prevalent, product life and development cycles have been reduced, and supply chains have extended around the world driven by low-cost sourcing, contributing even more to planning complexity (Ptak & Smith, 2016). A shortcoming of MRP based planning systems is that it is unable to adequately take into account the uncertainties that follow from these complexities, resulting in a high amount of rescheduling suggestions. Planners have become reliant on solutions outside the planning system, since it is simply not workable to approve all recommendations given by an MRP system that is constantly changing the picture (Ptak & Smith, 2016). Planners need to assess how important certain rescheduling requests are, investigate root causes of changes to the material plan, and investigate possible rescheduling solutions. Although these tasks are usually part of the planner's formal job description, they can also be seen as compensational tasks, as they are required to make up for shortcomings in the planning system (Jackson, Wilson, & MacCarthy, 2004). This leads to the question of how nervousness is shaping the job of the planner. Are they being overloaded with compensational tasks in case of a highly nervous planning system, and does this influence their motivation and commitment to the job? Although literature does not directly provide answers to these questions, job design research can be applied to further investigate these relations.

Job design, at its most basic level, refers to the actual structure of jobs that employees perform, i.e. on the tasks or activities that employees complete for their organizations on a daily basis (Oldham & Fried, 2016). Study after study has shown that job design (also referred to as work design) is important for a range of individual, group, and organizational outcomes (Morgeson & Humphrey, 2006). Nervousness affects job design because it consistently requires planners to address rescheduling messages that occur because of mismatches in supply and demand in the planning system. These mismatches, in turn, occur because MRP makes use of dependent planning, meaning that all demand and supply planning elements of every component in the product structure are hard-coupled. This way, you make exactly what is needed, when it is needed without any excess (Ptak & Smith, 2016). The downside however, is that any uncertainty such as defects, incorrect counts, changes in customer needs, incorrect bills of materials, engineering design changes, and poor vendor performance all affect finely tuned material planning (Jacobs et al., 2011). To illustrate how this could affect a planner, consider for example a defect that occurs in the factory. When this happens, the planner will urge the supplier to expedite supply, as suddenly a new demand was created. The supplier confirms, but a few days later the defect part appears to function again, upon which the planner needs to communicate to the supplier that the order can be delayed again. Under conditions of nervousness, the requested due dates of outstanding orders are constantly changing. This can be demotivating for planners, as next week they would need to undo or reverse half the things they did this week. It can also be seen that nervousness could therefore affect certain characteristics of the planning job, such as task identity and skill variety. This could potentially lead to reduced personal and organizational outcomes, such as internal motivation, job satisfaction, commitment, and turnover intention. The first aim of this research is to investigate these relations between nervousness, and characteristics and outcomes of the planning job.

The two basic ways of buffering against uncertainty in MRP systems are safety stock and safety lead time. Both approaches produce an increase in inventory levels to provide a buffer against uncertainty, but the techniques operate quite differently (Jacobs et al., 2011). One issue with these buffering techniques is that they do not reduce rescheduling messages in the planning system, and therefore do not effectively reduce nervousness. The effect of safety time in MRP is that the demand is requested for an earlier date than it is actually needed. MRP does not use this slack in time that is created to reduce rescheduling messages, as it still wants all supply to arrive exactly on the request date which includes safety lead time. The effect of safety stock in MRP is that planned orders are determined by subtracting the safety stock from the initial inventory balance when determining the projected available balance (Jacobs et al., 2011). This means that MRP does not use, rather it tries to prevent safety stock from being used, and therefore it also does not reduce rescheduling messages (Guide Jr & Srivastava, 2000).

Decoupling point buffers on the other hand, are quantities of inventory or stock that are designed to decouple demand from supply (Ptak & Smith, 2016). This is different from traditional safety stock and safety lead time buffers in MRP, as decoupling buffers do not maintain the hard-coupling between supply and demand. They are designed with the specific goal of absorbing demand and supply variability (Ptak & Smith, 2016). Decoupling, according to the APICS dictionary, refers to creating independence between supply and demand of a material by placing strategic inventory (APICS, 2010). The second aim of this research is to further investigate decoupling solutions: solutions that would effectively reduce rescheduling messages and nervousness by making strategic use of inventory. Next to that, the implementation of such solutions would change the way orders are generated and/or how materials are replenished. As planners' daily activities such as assessing rescheduling requests and managing supplier deliveries are affected by this, they could also experience differences in their job and job outcomes. Therefore, a third aim of this research is to investigate the effects of decoupling solutions on job characteristics and outcomes of the planning job.

## 1.2 Research Aim and Research Questions

The overall goal of this research is to generate evidence-based solutions that will reduce potential negative effects of nervousness on planners' job outcomes. Campion, Mumford, Morgeson, & Nahrgang (2005) note that one of the challenges remaining today for practitioners attempting to implement job design changes is taking into account multiple disciplines. Given that this research takes into account the planning related problem of nervousness while focusing on the human factor, this research can contribute to this multidisciplinary approach. Findings can be of practical relevance for practitioners aiming to simultaneously maximize efficiency and satisfaction in the workplace. Three main research questions were formulated to guide this research:

(i) **What is the effect of nervousness on human planners?**

(ii) **Which decoupling solutions exist that can reduce nervousness?**

(iii) **How do decoupling solutions affect the job characteristics and outcomes of planners?**

The first research question entails investigating how nervousness manifests itself in the planning job: how do the roles and tasks of planners change due to nervousness and how can nervousness be defined in the context of the planner's job in order to measure its effects. Subsequently, the aim is to generate insights in how the presence of nervousness in the planning job is related to the presence of motivational job characteristics and job outcomes such as satisfaction, commitment, and turnover intention. Following the suggestions provided in job design studies (e.g. Parker, Wall, & Cordery, 2001) to focus more on the context of specific jobs to generate a deeper understanding in job design, a thorough exploration of the planning job in relation to nervousness will contribute to this. From a practical standpoint it is also relevant to investigate these relations, considering that satisfied and committed employees are less likely to be absent or late, are more productive, and show increased citizenship behavior, to name a few (Landy & Conte, 2016; Meyer, Stanley, Herscovitch, & Topolnytsky, 2002). Organizational citizenship behavior occurs when employees are going the extra mile in their job in order to contribute to the work environment, as opposed to limiting themselves to just the required set of formal actions (Landy & Conte, 2016).

The second research question entails an investigation of which solutions exist to reduce nervousness. It further includes a description of two pilot solutions which were implemented during the course of this study. Next to that, the aim is to formulate criteria for when these solutions can best be applied. Finally, a quantitative analysis of nervousness on buy-parts and an analysis of operational shortages will be done in a case study to determine the operational effects of these decoupling solutions. These findings can be of practical and theoretical relevance given that only few empirical studies were presented in literature of nervousness, i.e. 'schedule instability', in manufacturing companies (Pujawan & Smart, 2012).

The third research question entails an investigation of two decoupling solutions, decoupling safety stock and Supplier Managed Inventory (SMI), in relation to the job of the planner. The aim is to investigate how such solutions affect certain characteristics of their job and whether it leads to overall improved feelings of satisfaction and commitment to their job. These findings can also be of both theoretical and practical relevance given that these relations have not been explicitly explored before in literature and practitioners could use findings to improve both efficiency and satisfaction at the workplace.

For research questions 1 and 3, the general approach taken was to follow the empirical research cycle, shown in Appendix A. The empirical research cycle can be used when the aim is to produce descriptive and explanatory knowledge (Van Aken, Berends, & van der Bij, 2012), which in this case entails descriptive and explanatory knowledge of the effect of nervousness and decoupling solutions on planners.

For research question 2, the general approach taken was to follow the field problem solving cycle, shown in Appendix B. The field problem solving cycle can be used when the aim is to redesign a certain aspect within an organization, which in this case entails a redesign of the detailed material planning function in order to generate a more stable plan with less rescheduling messages.

## 1.3 Research Scope

The production environment in scope of this research is the assemble-to-order environment (ATO), where components are assembled into end items after information on customer demand is received, but the decision on what components to procure or produce must be made well before demand materializes (Atan, Ahmadi, Stegehuis, de Kok, & Adan, 2017). In this environment, uncertainty involves the quantity and timing of the customer order, but also the product mix (Jacobs et al., 2011).

Organizations in this environment have different planning departments that work together to cope with these uncertainties. Planners in the production planning department are responsible for scheduling and managing production orders on a daily and hourly level. On the other side of the spectrum, there are planners involved with making strategic demand and supply decisions for more than 5 years ahead. In between there are planners responsible for master planning, whose job it is to plan end items on a weekly level for months ahead. The planners mainly in scope of this research, are the planners that are responsible for managing and coordinating the incoming flow of materials (i.e. 'supplier coordinators') on a daily basis. They are the interface between suppliers and different departments within the organization who are responsible for the supply and demand of components. Demand for buy parts on the short horizon is mainly driven by the production and service departments. On this level, a lot of rescheduling actions are required by the planners in scope in order to ensure an inflow of materials in the right time and quantity.

The scope of the redesign is indicated in figure 1, which shows an overall framework of Manufacturing Planning and Control (MPC) systems. The MPC system is concerned with planning and controlling all aspects of manufacturing, including managing materials, scheduling machines and people, and coordinating suppliers and key customers (Jacobs et al., 2011). The design of the MPC system includes choices on each of the functions shown, which are typically embedded in an ERP system. These choices should fit the marketplace requirements and companies' strategy in order to gain competitive advance (Jacobs et al., 2011). For instance, an assemble-to-order (ATO) master production scheduling approach is designed to be relatively accommodative of changes in product mix, whereas the make-stock-approach better supports products of standard design produced in high volumes for which short customer delivery times are critical.

As indicated in figure 1, the scope concerns the detailed material planning function, including the generation of the material plan and its translation to vendor systems. Detailed material planning options range from a time-phased approach to a rate-based approach. The time-phased approach is based on explosion of requirements and is appropriate for custom products produced in wide variety and low volumes whereas the rate-based approach is appropriate for a relatively narrow range of standard products, with stable product designs produced in high volume (Jacobs et al., 2011). MRP is the most widely used approach to detailed material planning for organizations assembling complex products in low volumes (which is the scope of this research). MRP is a basic tool in the engine portion of the MPC system that uses input from the master production schedule, the bill of materials, and inventory status data to produce a resultant time-phased (period-by-period) requirement record for all components. As illustrated in the problem description, this comes with the challenge of nervousness, affecting planners and suppliers. Hence, a redesign of the functions in scope is required that creates a more stable inflow of component parts (i.e. buy parts).

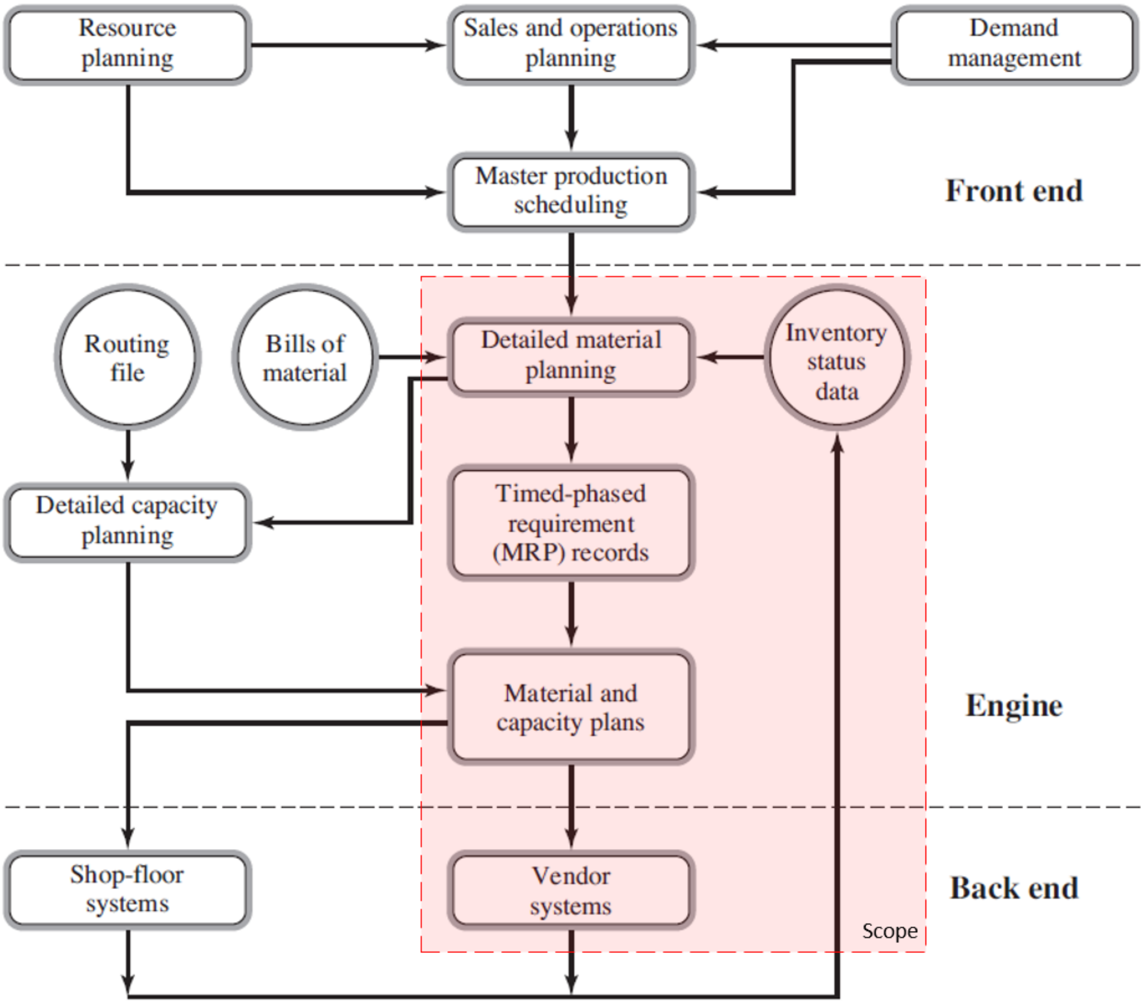



*Figure 1: Manufacturing Planning and Control System framework (Jacobs et al., 2011)*

In practice, the solution possibilities for improving MRP generated material plans by using a buffering method to smoothen processes, depend on the advanced methods that are available in the ERP system in place. In this research, the ERP system referred to is SAP, as it is the system installed and will be used further by the organization in scope. Within this context, two solutions will be further investigated in detail, and in particular their effect on the planners who work with them. The first solution is a SAP-specific variant of safety stock which allows (a percentage of) the stock to be used before MRP generates any new replenishment order requests or rescheduling suggestions on existing replenishment orders. This variant of safety stock will be further referred to as 'decoupling safety stock', given that it is different from traditional safety stock as it actually can be used to cover against changes in demand without creating rescheduling suggestions. This type of safety stock has not been explicitly described in literature, hence new insights can be gained with respect to safety stocks in ERP systems that make use of MRP. The second solution is Supplier Managed Inventory (SMI), which is a SAP-specific variant of

VMI (Vendor Managed Inventory), as noted by Kurbel (2013). With this solution, like the former, the requirements for parts are still determined by customer's MRP system, but the way of replenishment is different. Inventory data and requirements are shared with the supplier, who is responsible for replenishing the customer's warehouse within minimum and maximum stock levels (Knolmayer, Mertens, Zeier, & Dickersbach, 2009). This way of replenishment is based on a schedule agreement on which orders can be booked against, giving higher flexibility to the supplier, and less planning effort for the customer (Knolmayer et al., 2009).

## 1.4 Report structure

In the upcoming chapter, **Chapter 2**, a description of the organization where this research was conducted is given, as well as a description of the research problem of MRP nervousness within this specific context. In **Chapter 3**, a literature review is given, providing more background on MRP, but the main focus is on the MRP planner and job design theory. Subsequently, Chapters 4, 5, and 6 are centered around the three research questions that were formulated. In **Chapter 4**, an investigation is done of how nervousness is affecting the human planner, by building on the concepts from job design theory described in Chapter 3. This investigation was done before any of the proposed solutions for nervousness were implemented. Then, in **Chapter 5**, possible solutions for nervousness are investigated, where two specific solutions that were implemented are described in detail. Next to that, an analysis is given of the uncertainty and fluctuations in (planned) demand, providing a quantitative insight in the nervousness present on buy-materials. Also, additional analyses are provided on the projected shortages and rescheduling messages of the organization in order to create insights in the effectiveness of solution concepts, specifically in relation to the planners using those solutions. In **Chapter 6**, the effects of the two solution concepts on the planning job are investigated through qualitative interviews. These interviews were taken after the solutions were implemented with planners who worked with them for one or more months. In **Chapter 7**, a discussion of results for the three research questions is given, including their theoretical and practical relevance. Finally, in **Chapter 8**, a conclusion is given where the most important results are summarized.

# 2 | Research Context

## 2.1 Company background

The research will be conducted at ASML, world's leading provider of lithography systems for the semiconductor industry. These systems bring together high-tech hardware and advanced software to control the chip manufacturing process down to the nanometer. ASML employs 25,000 people worldwide and has its main manufacturing locations in Veldhoven (Netherlands), Linkou (Taiwan), and Wilton & San Diego (U.S.). All of the world's top chipmakers use ASML's systems which are consistently evolving to produce smaller, faster, and more energy-efficient chips. ASML's guiding principle in this is Moore's law which states that the number of transistors on a chip, and with that the computing power of computers, doubles about every two years. Technological applications like the Internet of Things, 5G connectivity and artificial intelligence drive continued demand for Moore's law. With the industrialization and further development of Extreme Ultraviolet (EUV) systems as a strategic priority, ASML aims to enable these upcoming technologies for the semiconductor end market. For Deep Ultraviolet (DUV) systems, competitiveness is a strategic priority as the lithography equipment industry is highly competitive (ASML, 2020).

ASML can be seen as a high variety, low volume manufacturing organization. System output amounts to around 250 per year which is typical for a low volume plant according to (Jina, Bhattacharya, & Walton, 1997). This output is expected to grow further in 2020. Furthermore, high variety is evident from the many complex parts which are subject to engineering changes that constitute the end system. Next to that, ASML systems have a modular design, which allows for reuse and upgrades. Options and enhancements are sold to improve the performance of installed base systems. Also, older systems are refurbished and resold to customers. In 2019, almost a quarter of net sales accounted to service and field option sales (ASML, 2020). Additionally, system up-time and reliability are important as downtime cost at the customer are high due to the capital-intensive nature of the semiconductor industry.

It is the mission of ASML Supply Chain Management (SCM) to guarantee material availability at the right quality and cost. Within SCM, the Supplier Network Management (SNM) department acts as the interface towards suppliers and manages supplier capabilities, quality, yield, cycle time, and de-risks the n-tier supply chain. This department consists of the operational supplier managers, responsible for managing incoming supply, and quality and logistics supplier managers, responsible for strategic supplier development on the long term. Other departments related to the research problem setting are: Integrated Business Planning (IBP), responsible for the long term market review; Supply Chain Planning (SCP), responsible for the long- and mid-term supply plan; and Production Planning (PP), responsible for the short term production plan. Appendix C shows a concise version of the organization chart with the departments mainly related to the problem scope.

Figure 2 shows the material flow through ASML's manufacturing process. The majority of components in an ASML system are manufactured by suppliers. Work centers in ASML production facilities make the remaining (sub)modules, which are then integrated in the Veldhoven cleanroom. The system is calibrated and tested extensively before it is shipped to the customer. The system integration (final assembly) step, is only started in case of a 'Sales-Go', meaning there is a confirmed customer order including specific configurations for the end system. Hence, the production process can be classified as assemble-to-order (Atan et al., 2017). Some customer specific modules are also only assembled on the Sales-Go moment, whereas other modules are assembled following the plan. For the latter type of modules, an 'assy' buffer stock is in place, controlled by processes of the System- and Module Build Planning, and Supply Chain Planning departments.

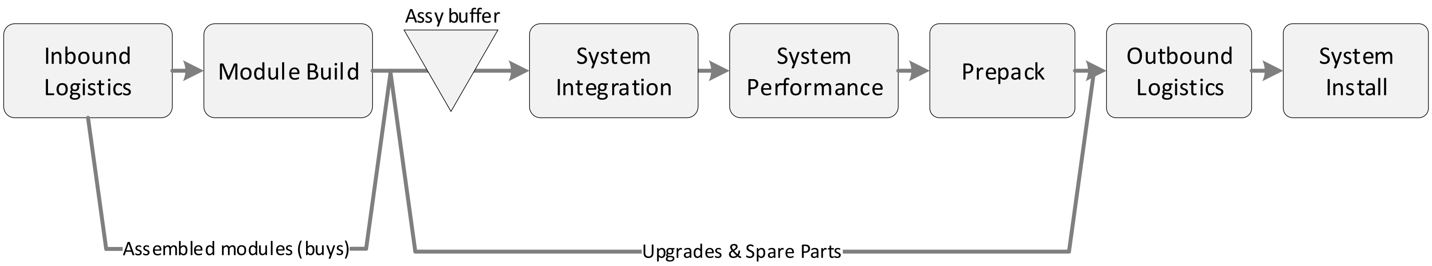



*Figure 2: ASML manufacturing process*

All production and procurement processes, starting at n-tier suppliers up until the final assembly point, are forecast driven. Given the complexities, long lead times, and capital requirements of components, preparing and managing the supply chain to cope with uncertainty can be seen as one of the main challenges of ASML Supply Chain Management. ASML's general way of managing this is planning years ahead, and, as the planning boundary tightens (the shorter the horizon), the planning detail increases. This means that the plan for years ahead only includes bill of material types, whereas the plan for months ahead also includes commercial add-ons, and weeks ahead it includes the specific customer allocation. Next to that, various supply chain buffers are used, which include system buffers in the master plan, as well as buffers in terms of capacity at suppliers. These measures ensure flexibility which is required to cope with the uncertainties in the end market.

## 2.2 MRP nervousness

ASML uses MRP to determine time-phased requirements for all component parts. Upon executing the weekly MRP run, all updated requirements on component and end item level are taken into account to generate new planned orders and update due dates of already outstanding orders. End item requirements specified in the MPS are updated monthly by the SCP department. This process is described in detail in Appendix D. The MPS is also updated weekly to account for changes in the actual execution of the plan, e.g. changes in the sequence by the production planning department.

The outcome of the weekly MRP run includes a high amount of rescheduling messages on purchase orders, reflecting that due dates do not match requirement dates anymore. Next to the updated requirements in the MPS, there are many other factors that lead to a change in the requirements of components. All of the uncertainties that happen during the weekly operation contribute to this, in the end leading to mismatches in supply and demand in the planning system, triggering rescheduling messages. Examples of uncertainty during the weekly operation include:

- Factory defects
- Quality issues
- Urgent service demand
- Changes in the bill of materials
- Engineering changes
- Supplier issues
- Changes to the execution schedule

On average, 70 % of purchase orders in the companies' ERP system have a rescheduling message (measured weekly over the year 2019). This means that every week, when the schedule has been updated after the MRP run, the system suggests to reschedule the due date of 70 % of outstanding purchase orders to match the updated requirement dates. A rescheduling message can be of three types:

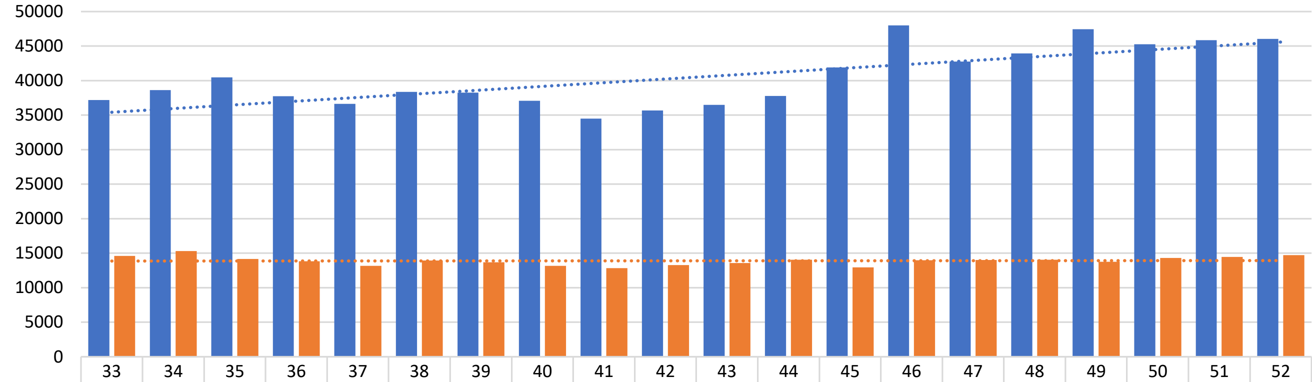
- Reschedule-in: suggestion to bring the process forward, i.e. to pull in/expedite the supply element
- Reschedule-out: suggestion to delay the process, i.e. to push out the supply element
- Cancel: suggestion to cancel the existing order

Only 47 % of these messages are directly communicated to suppliers, meaning that in total 33 % of outstanding purchase orders have a rescheduling message that is also communicated to the supplier via the supplier portal (weekly averages over 2019). The reason that only 47 % of the rescheduling messages are communicated to suppliers, is that the company applies suppression logic. This includes filtering out reschedule-in messages for less than 5 days in case the due date is not within 12 weeks, filtering out all reschedule-out messages on the short (4 week) horizon, and filtering out some reschedule-out messages on the longer horizon, depending on the value of the part and time in days of the reschedule-out message.

Especially for purchase orders that are linked to requirements on the short, 4-6 week, horizon it is important that the reschedule-in messages are assessed and acted upon accordingly by the planner. On this horizon, typically the production planning department has opened production work orders, thereby 'firming' the requirements on a specific day. If the supply elements do not cover these requirements (expediting is suggested), timely execution of the work order at the shop floor could be compromised.

## 2.3 Shortage management

Mismatches where purchase orders (supply) are foreseen to arrive too late to cover the requirements (demand) are projected shortages (note that a shortage is therefore associated with a reschedule-in message on a purchase order). The projected shortages on the 5 week horizon are managed at ASML via an internal communication tool (Fiori) that is used by different departments to avoid costly material unavailability for factory, service, or other requirements. A shortage line consists primarily of a material requirement, a linked supply element, and a slip which represents the difference in the supply and requirement date.




| | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| All shortage lines | 37194 | 38623 | 40480 | 37750 | 36628 | 38365 | 38264 | 37058 | 34507 | 35678 | 36467 | 37758 | 41891 | 48002 | 42745 | 43937 | 47460 | 45283 | 45844 | 46040 |
| Fiori lines | 14591 | 15324 | 14183 | 13843 | 13159 | 13948 | 13673 | 13168 | 12853 | 13267 | 13591 | 14053 | 12956 | 13977 | 14026 | 14061 | 13766 | 14298 | 14476 | 14734 |

*Figure 3: Projected material shortages ASML*

Figure 3 shows the total amount of projected shortages deduced from the planning running on ASML's plants in the Netherlands (plants NL01 and NL10). It shows that the total amount of shortage lines at the beginning of each week has been increasing over working weeks 33 until 52 in 2019. As of week 45, the total amounted to over 41,000 per week. Excluded from this are materials which are planned by reorder point planning instead of regular MRP planning. The amount of shortage lines shown in the internal communication tool Fiori at the beginning of every week has been consistent at approximately 14,000. This is a subset of the total amount of shortages based on the following criteria:

- Requirement (demand) is within a 35 calendar day (5 week) horizon
- The slip, i.e. supply date – requirement date, $\geq$ 6 calendar days
- The shortage cannot be solved by using safety stock

The requirement date is always regarded from a 'safety time on' perspective when checking if the requirement is within the 5 week horizon or when calculating the slip. This means that the demand date looked at includes 7 working days safety time, but the actual factory need date is 7 working days later.

Furthermore, the supply date is regarded from an 'available' perspective when calculating the slip. The actual arrival of supply happens on the 'Goods Receipt Date', but 3 working days safety time for inbound handling are included to get to the 'Available Date' of the supply element. The supply element is always regarded from this 'available' date when calculating the slip.

Therefore, in total there is safety time of 10 working days included as a buffer for supply uncertainty. Shortages are shown in the communication tool if the slip is bigger than or equal to 6 calendar days. This filters out shortages that fall well within the safety time. Technically, shortages with a slip of 7 – 10 working days could have been filtered out as well, as they fall within the safety time buffer, but this leaves little margin for error and hence they are not excluded from the shortage communication tool.

Finally, as conventional MRP logic nets all requirements to the safety stock level, it may calculate a material shortage only because at some point in the time available quantity is projected to fall below the safety stock level. As it is unwanted to expedite on safety stock, the tool filters out these shortages. However, only a small set of relatively low value parts contain safety stock. Next to that, it must be noted that safety stock, similar to the safety time, does not prevent rescheduling messages from being generated and being shown in the supplier portal. Also, these rescheduling messages are still shown in the planning in the ERP system which planners mainly use to check the status of parts under their responsibility.

## 2.4 Role of the Operational Supplier Coordinator

The amount of rescheduling messages and shortages represent the nervousness in ASML's material plan. Operational Supplier Coordinators (OSC), are planners from the Operational Supplier Management (OSM) department who frequently check the material plan in the ERP system to address the status of materials. Next to that, the internal communication tool Fiori facilitates the management of the high amount of projected shortages to prevent material escalations. The way this works is that for every shortage line there is a so called 'demand responsible' and 'supply responsible'. The demand responsible is principally someone from the production or service departments, as they own the requirements (demand) for parts on the short horizon. The supply responsible generally is an OSC from the OSM department (the exception is when the material is still marked as a critical 'new product introduction' (NPI), then the Product Lifecycle Management (PLM) department is supply responsible). The OSM department is the department within SNM responsible for securing sustainable material availability, acting as the interface between the supplier and internal departments. The department consists of approximately 60 people working together at the same floor. The department is divided into strategic product family clusters, each managed by a group lead. For instance, the Optics cluster is responsible for all suppliers of lenses and illumination products. Within the cluster, each planner is responsible for the incoming materials of one or more suppliers. Planners are mostly in contact with Logistic and Quality Supplier Managers, i.e. their counterparts for the same supplier, who are involved with long term logistical management and quality management. Next to that they are frequently in contact with other planners in their cluster and department, as well as internal demand owners and suppliers.

At the beginning of every week, the OSC addresses the shortages for which they are the supply responsible, i.e. the shortages of materials delivered by the supplier(s) to which they are linked.

They prioritize the most important shortages and share this with the supplier, so that the supplier knows which reschedule-in requests on their orders are most important. This guidance is important because it is not possible for the supplier to react to all updated request dates every week on their orders. On the other side, the OSC communicates with the demand owner about the demand element about what would be an acceptable supply date. Next to that, the demand element could be invalid and should already have been removed from the planning system. Frequently this is the case for demand elements in the past that are not actually required. Also, these demands trigger shortages, need to be addressed, and require communication between the OSC and the demand responsible. Furthermore, there can be multiple demand owners of different departments requesting the same material. It can be that both the factory and service department have put in requirements in the planning system. Less commonly, the development and engineering (D&E) department or PLM department may have entered a material requirement in the planning system. There are guidelines which are followed by these departments to not enter requirements violating lead times, in order to prevent planned shortages. However, as a consequence of the uncertainties that are evident in the production environment, these requirements cannot be fully prevented. Next to that, all elements in the planning system are linked to each other, making it difficult to exactly trace which actions have caused the shortages following the latest MRP run. Also on the supplier side issues may occur in (speeding up) the production or delivery process. Therefore, the OSC plays an important role in knowing the stories on both the demand and supply side to manage the incoming purchase orders.

Overall, many tasks of the OSC are related to the MRP output and to the inherent nervousness. The defined tasks of the OSC are:

- Demand analysis:
  - Releasing purchase requisitions.
  - Prioritizing rescheduling messages and shortages.
  - Reviewing and analyzing the MPS to provide feedback to the SCP department, and giving input to suppliers regarding MPS updates.
- Expediting:
  - Following up on demand & supply gaps, including contacting suppliers and demand owners.
- Troubleshooting:
  - Analyzing causes and issues related to reschedule-in messages such as inbound stagnations and rejects.
  - Investigating supplier reschedule-out messages.
  - Preparing and attending critical material escalations.
- Inventory control:
  - Maintenance of master data, including setting lot sizes, safety stock levels, and planned delivery times.
  - Reducing overplanned materials (following up on reschedule-out suggestions) to prevent unnecessary inventory.
- Vendor rating:

  - Assisting the supplier in development and adherence to KPI's.
  - Preparing vendor reports to be discussed in the Supplier Account Team.
- Competences/Projects:
  - Working on one of the various (cross-functional) projects, for example, developments in the Arriba supplier portal, development of the shortage management tool, etc.
  - Competence ownership of one of the various processes such as DHL problem sheets, expeditor change, Material Availability Critical Parts, etc.

Mainly demand analysis, expediting, and troubleshooting are related to rescheduling messages, shortages, and nervousness. It was estimated by an Operational Supplier Coordinator that they spend roughly two-thirds of their time on these tasks, but this differs per person as well.

# 3 Literature Review

The functioning of MRP and the problem of nervousness were already described in the problem definition. In this chapter, some additional background of MRP will be presented, but the main focus will be giving a review of job design theory in order to develop hypotheses of how MRP nervousness might affect the job of the planner.

## 3.1 MRP in modern planning systems

Since MRP's introduction in the 1960s by Joseph Orlicky, it has gone through multiple developments. Closed-Loop MRP is an enhancement in the early 1970s that includes capacity checks which are used iteratively with the MPS and the component production plans (from MRP), to generate feasible schedules (Silver et al., 2016). Closed-Loop MRP can be summarized as a system for generating reasonable feasible solutions to the complex problem of planning, scheduling, and controlling production/procurement in a dynamically changing, assembly situation (Silver et al., 2016). In the 1980s significant incorporation of cost accounting transformed MRP into a system known as Manufacturing Resources Planning, i.e. MRP II (Ptak & Smith, 2016). Finally, by the 1990s, MRP II had evolved into Enterprise Resources Planning (ERP) which included all resources that are relevant to a companies' success, not only those of production related business areas (Kurbel, 2013). Nowadays, an ERP system constitutes the information system backbone of most organizations across all industries (Kurbel, 2013). However, the planning engine of ERP systems still uses the same MRP logic, with additions of MRP II (Wiers & de Kok, 2017). To offset this, large ERP providers such as SAP and Oracle have offered advanced planning capabilities with their ERP systems (Silver et al., 2016). Examples of this are SAP Advanced Planning and Optimization (APO) and its most recent, cloud-based successor: SAP Integrated Business Planning (IBP), see e.g. Eckert (2017). These systems employ finite scheduling tools that ensure capacity limits are not exceeded and use backward and forward scheduling to suggest solutions in real time (Silver et al., 2016).

This has the benefit of allowing the user to see what ripple effects will occur if an order is inserted into the schedule, or if some other disruption occurs (Silver et al., 2016). It also is an improvement to MRP which only identified constraints instead of suggesting solutions. However, MRP logic is still at the core of the production modules in modern ERP systems which includes dependent planning, i.e. precisely time-phasing requirements. This way of planning was a significant improvement to traditional reorder point approaches, but it is still highly subject to nervousness (Ptak & Smith, 2016). Next to that, the capability in modern planning systems of making real-time changes to the schedule can create a whole new level of nervousness in the production- and procurement plan (Silver et al., 2016).

## 3.2 The MRP Planner

The people most directly involved with the MRP system outputs are planners. Their primary actions, adapted from Jacobs et al. (2011), are:

1. Release orders (i.e., launch purchase or shop orders when indicated by the system).
2. Reschedule due dates of existing open orders when desirable.
3. Analyze and update system planning factors for the part numbers under their control (changing lot sizes, lead times, scrap allowances, or safety stocks).
4. Reconcile errors or inconsistencies and try to eliminate root causes of these errors.
5. Find key problem areas requiring action now to prevent future crises.
6. Use the system to solve critical material shortage problems so actions can be captured in the records for the next processing. This means the planner works within formal MRP rules, not by informal methods.
7. Indicate where further system enhancements (outputs, diagnostics, etc.) would make the planner's job easier.

Wiers & de Kok (2017) note that due to the deficiencies of MRP based planning, human planners need to correct infeasible plans. They further state that the planner can truly add value by checking if it is possible to reschedule the orders released, such that planned shortages are resolved. Due to MRP being highly subject to nervousness, the main task of planners has become to determine how important projected shortages really are. For this reason, planners are also referred to as "expediters" (see e.g. Wiers & de Kok, 2017; Ptak & Smith, 2016).

## 3.3 Context of the planning and scheduling job

In classical operations research planning was referred to as "ordering of actions" and scheduling as "allocating tasks to resources in time" (Wiers & de Kok, 2017). Furthermore, (McKay & Wiers, 2003) note that in the past the only criterion that could distinguish between planning, scheduling, and dispatching was that planning was usually on a higher level than scheduling and scheduling was on a higher level than dispatching. It is as of the 1990s that researchers have taken a more holistic view on the jobs of planning and scheduling. The model in figure 4 by (Jackson, Wilson, & MacCarthy, 2004) is a good example of this. It shows that the planning and scheduling job in practice comprises of multiple tasks, roles and monitoring activities. Each of these aspects will be discussed next in more detail.

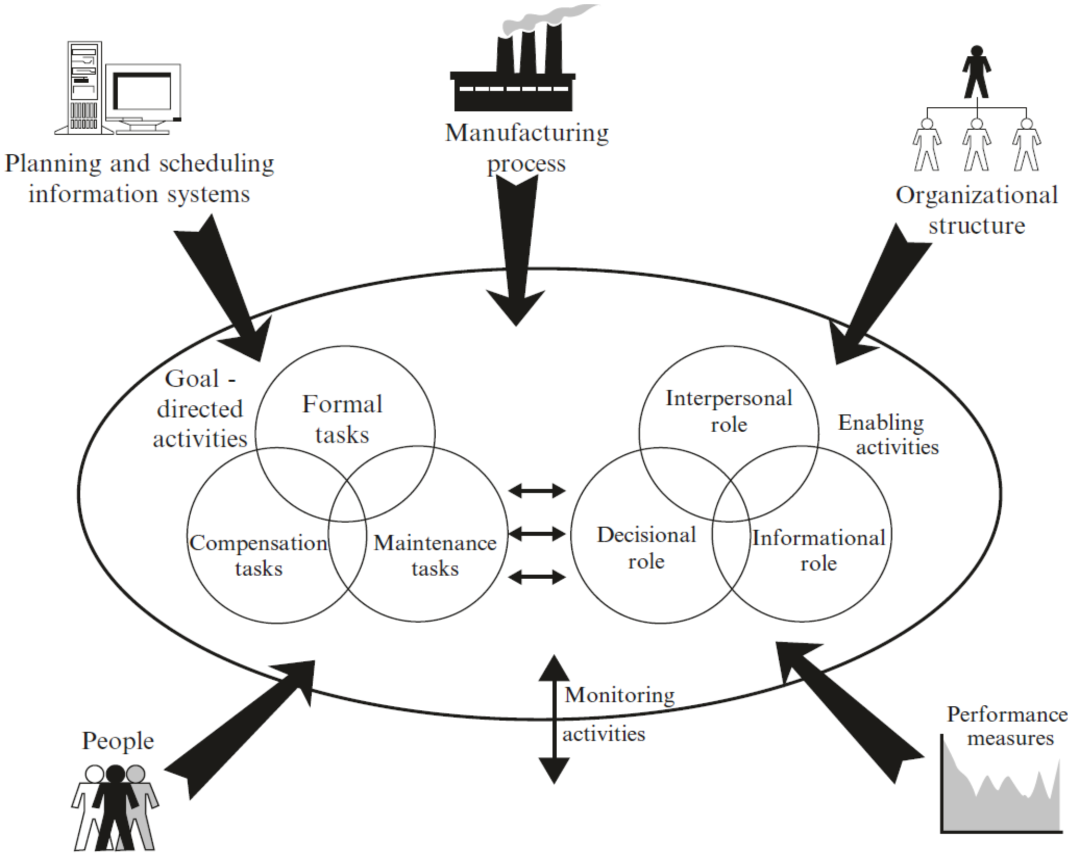



*Figure 4: Context of the planning and scheduling job (Jackson et al., 2004)*

Formal task behavior is what companies have specified that planners and schedulers should carry out as part of their formal job description, maintenance task behavior relates to organizing required information and updating and adjusting the information system, and compensational task behavior make up for the shortcomings in the system (Jackson et al., 2004). It can be seen that there is also overlap between the different categories of tasks. As an example, releasing order requisitions is a formal planner task, while rescheduling entails actions that have elements of both formal and compensational task behavior.

For planners that manage purchase (i.e. supply) orders, rescheduling does not just mean changing the due date of an order. First of all, they cannot change the due date without affirmation of the supplier. Next to that, planners might first have to investigate the reasons as to why the planning's system suggestion to reschedule is valid. This entails contacting other departments within the organization that have entered requirements for the part in question. For instance, the production department requires a part on a specific date, but this date includes some safety time, hence expediting the supply order is not always strictly necessary. Researchers have also found that planners tend to ignore rescheduling messages due to MRP's failure to consider safety stock and safety lead time (see e.g. Ho 2005). Investigating the rescheduling suggestions could also entail sifting through MRP backup files, to see what changes have occurred that have led to the suggestion of expediting the supply of a part. Next to that, planners responsible for managing purchase orders need to be in close contact with suppliers to know to which extent they are capable of expediting the part. Every time MRP is run, the material plan changes and planners need to contact suppliers after they have addressed the many rescheduling suggestions by the MRP system to share their actual priorities. Suppliers in some cases can also directly see the updated request date of an already agreed delivery, but they do not know the background of the suggestion. Planners from the organization procuring these deliveries generally know more about the demand side of the order, and coordinate internally and externally to manage these new requests.

It could be the case that the organization has specified these rescheduling related actions in the formal job description, in which case these actions can be defined as formal task behavior. At the same time however, the rescheduling actions could be seen as compensational tasks behavior because they are required (to a greater extent) as a consequence of MRP nervousness, which is a system shortcoming.

Planners are also responsible for identifying errors in the planning system, such as demand records of a part that are incorrect. By contacting the person responsible for these records and requesting them to resolve the error, they ensure an effective use of the information system. Next to that, planners themselves are responsible for updating parameters stored in the master data settings of each material, such as lead times, safety stock levels and lot sizes. These actions are examples of formal tasks, as they are specified as part of their formal job description, but can also be seen as maintenance tasks, as they entail updating and adjusting the information system.

So far, the formal, compensational, and maintained tasks of planners have been discussed. However, tasks alone provide only a limited view on the human factor, hence roles are also included in the model. Planners and schedulers occupy different role behaviors that enable them to fulfill their tasks. The interpersonal role represents the relationship between the human planner and others. The informational role captures the behavior of acting as an information hub, building on the interpersonal role. Finally, the decisional role captures problem solving behavior and complements the other roles that provide the networks and information needed to make decisions (Jackson et al., 2004). In the described actions of planners (specifically, expediters) the interactions with other departments and suppliers already came to light. Their interpersonal role is extensive because of the interface that planners of incoming purchase orders provide between different stakeholders. Towards suppliers they provide information on up-to-date priorities of the required supply elements, and towards internal departments (usually the production planning department) they provide information on supplier capabilities to speed up the delivery. The decisional role then captures the decisions that need to be made which provide a workable solution for all parties. In nervous MRP systems, making these decisions can be difficult as the information and priorities in the planning system are constantly changing.

Finally, monitoring activities relate to planners being aware of what is going on and what is about to occur in the environment (Jackson et al., 2004). It is an integrating activity that allows planners to carry out their job and make appropriate decisions. For instance, planners need to be aware of developments in the companies' information system, developments in the supplier's delivery and production processes, strategic developments in the organization, and developments on the shop floor.

## 3.4 Job Design Theory

**Job design research**

Job design focuses on the tasks or activities that employees complete for their organizations on a daily basis and it has been one of the most widely researched topics in organizational science (Oldham & Fried, 2016). Years of research and practice with job design have shown clear relationships between characteristics of work and employee reactions that can guide efforts to simultaneously maximize efficiency and satisfaction in the workplace (Campion et al., 2005). This relates to the concept of enrichment, which involves increasing the responsibility and interest level of jobs in order to increase the motivation and job satisfaction of employees performing those jobs (Landy & Conte, 2016). Job characteristics theory by (Hackman & Oldham, 1976), a theory of job design, provided a model for scoring jobs on their potential to motivate the individual, based on the characteristics of the job (Landy & Conte, 2016). This model has been widely applied by managers seeking to enrich jobs by focusing on those job characteristics that were found to be low amongst jobholders.

Early work on job design stems from Taylor's scientific management philosophy that emerged in the early 1900s. Taylor's view was that jobs should be as simple as possible with no discretion for employees such that work could be executed with as little waste as possible (Lawrence, 2010). By the 1950s many organizations had jobs that were designed according to these principles. It was also at this time that researchers showed that employees did not care much for these simplified jobs, and it would even lead to counter-productive behavior, i.e. behavior that undermines the goals and interests of the organization such as tardiness, absenteeism or sabotage (Oldham & Fried, 2016).

This sparked new approaches to job design which in the year 1966 resulted in Herzberg's well-known motivation-hygiene theory, also known as the two-factor theory. It states that a certain set of (motivator) factors cause job satisfaction while a separate set of (hygiene) factors lead to job dissatisfaction (Sanjeev & Surya, 2016), this is also shown in figure 5. Herzberg's theory lead to successful job enrichment projects where managers payed more attention to motivational factors leading to higher job satisfaction of employees (Oldham & Fried, 2016).

Research on job design then focused more on the objective characteristics of jobs that were predicted to relate positively to job satisfaction. In 1965, Turner and Lawrence developed a Requisite Task Attributes (RTA) Index that could be tested for associations with worker responses such as attendance and job satisfaction (Lawrence, 2010). The index was based on six elements: variety, autonomy, required interaction, optional interaction, knowledge skill required, and responsibility (Oldham & Fried, 2016). Expected positive relations between the RTA Index and job satisfaction and attendance were found only for workers from factories in small towns, not for employees in urban work settings (Hackman & Oldham, 1976). A study by Hackman & Lawler (1971) provided further evidence that job characteristics can directly affect employee attitudes and work behavior, but posed that 'growth need strength' was a moderator for the response rather than cultural background. Hackman & Lawler (1971) found that employees with high

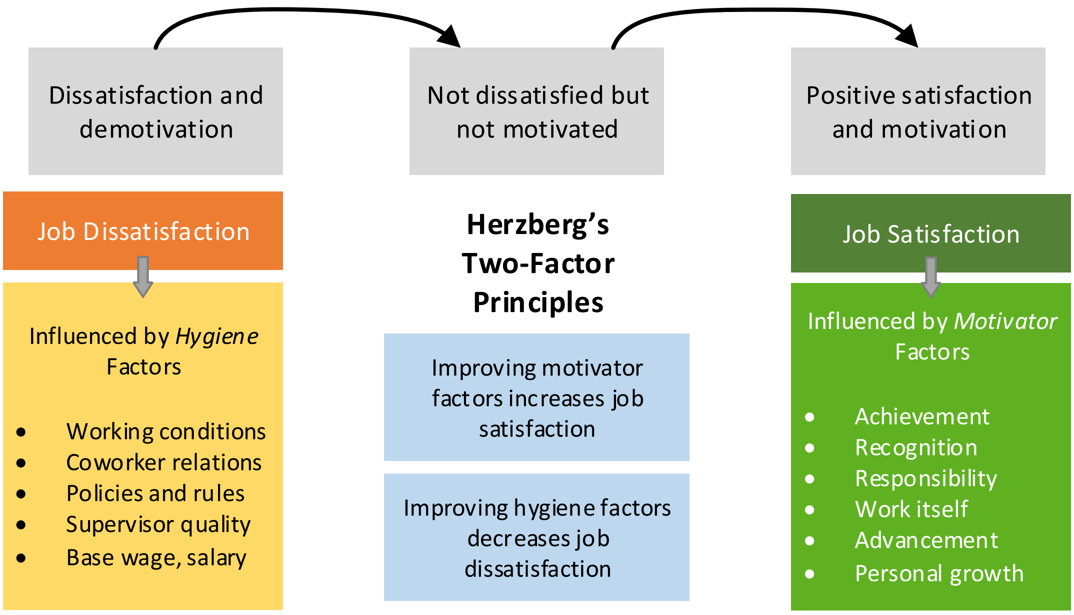



*Figure 5: Herzberg's two factor theory*

measured needs for growth responded more positively to complex jobs than employees with low measured needs for growth. This study provided the basis for job characteristics theory (JCT), which will be discussed in more detail in the next section.

### Job Characteristics Theory

The most widely-researched and debated approach to job design from the late 1970s until the present day is Job Characteristics Theory (Oldham & Fried, 2016). It proposes that five core job characteristics contribute to work outcomes through three psychological states (see the model in figure 6). The psychological states must be present for internally motivated work behavior to develop and can be created by the presence of job characteristics (Hackman & Oldham, 1976). Next to that, there are attributes of individuals that determine how positively a person will respond to a complex and challenging job, these are the moderating conditions at the bottom of the model. The five core characteristics are:

- **Skill variety**: the degree to which the job requires a variety of different activities involving the use of different skills
- **Task identity**: the degree to which the job requires doing a whole and identifiable piece of work
- **Task significance**: the degree to which the job has an impact on the lives of others
- **Autonomy**: the degree to which the job provides substantial freedom to the employee
- **Feedback**: the degree to which carrying out the work provides the employee with performance information

The model could be used as a basis for the diagnosis of jobs and the evaluation of job redesign (i.e. "job enrichment") projects (Hackman & Oldham, 1976). The primary data collection instrument used for this was the Job Diagnostic Survey (JDS), an instrument specifically designed to measure each of the variables in the job characteristics model (Hackman & Oldham, 1976). In practice this

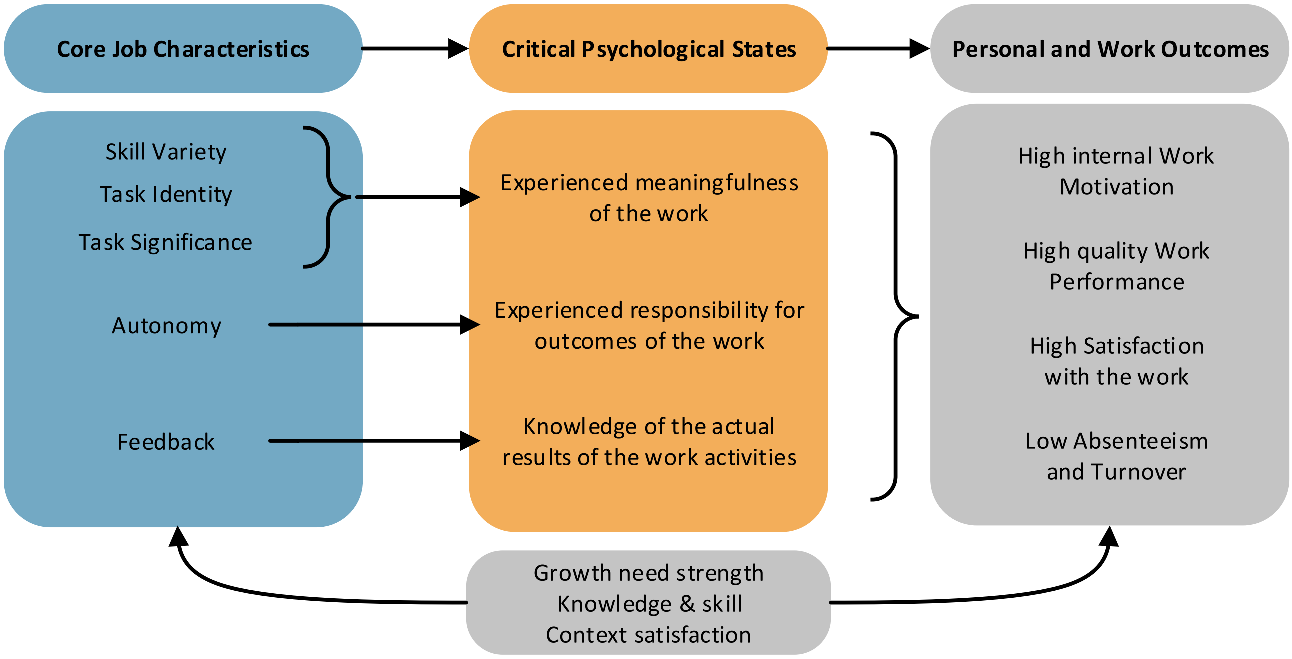



*Figure 6: Hackman & Oldham's Job Characteristics Model of Work Motivation*

meant that the model could be used to determine the motivating potential of a job, to identify those characteristics most in need of improvement, and to assess the readiness of employees to respond positively to enriched work (Hackman & Oldham, 1976). It could also be used to evaluate the effects of a redesign that has been carried out (e.g. which job characteristics changed and what was the impact of the changes).

According to the job characteristics model, the overall motivating potential of a job should be the highest when (a) the job is high on at least one of the three job dimensions that lead to experienced meaningfulness, (b) the job is high on autonomy, and (c) the job is high on feedback (Hackman & Oldham, 1976). This could be measured by the Motivating Potential Score (MPS), which combines the scores of the five job characteristics:

$$MPS = \frac{Skill\ Variety + Task\ Identity + Task\ Significance}{3} * Autonomy * Feedback$$

Hundreds of studies tested the model, providing strong support for the expected positive relations between the core job characteristics and the attitudinal outcomes: satisfaction and motivation (Parker, Wall, & Cordery, 2001; Oldham & Fried, 2016). The relations between job characteristics and behavioral outcomes (work performance, turnover, and absence) were relatively modest in magnitude (Parker et al., 2001; Oldham & Fried, 2016).

Humphrey, Nahrgang, & Morgeson (2007) conducted a meta-analytic study which tested the hypothesis that experienced meaningfulness, experienced responsibility, and knowledge of results would mediate the relationships between the 'motivational' characteristics (i.e. the core job characteristics of the JCM) and the behavioral and attitudinal outcomes. They found that there was strong support for the mediating effect of 'experienced meaningfulness' for skill variety, task identity and task significance. Partial support was found for the mediating effect of 'experienced responsibility' for autonomy, and no support for the mediating effect of 'knowledge of results'. Thus, they concluded that experienced meaningfulness of the work was the most critical psychological state.

Finally, according to JCM, if conditions of job context (e.g. pay, supervisor, job security and co-workers) are acceptable to workers then they can focus more on the work itself and will respond positively to the core job characteristics (Ghosh, Rai, Chauhan, Gupta, & Singh, 2015). This is in line with the role of the hygiene factors in Herzberg's Two Factor model. However, studies have shown only mixed support for the moderators of the job characteristics and outcomes relationships (Morgeson & Humphrey, 2006; Oldham & Fried, 2016). Morgeson & Humphrey (2006) give two major reasons that these moderating, individual characteristics should not pose a major obstacle to job design interventions. First, they argue that when jobs are being designed for multiple employees it is best to focus on the average or typical employee. Second, they argue that these relationships between the job characteristics and outcomes tend to be in the same direction for all employees, even if they differ in strength between employees.

**Extensions to Job Characteristic Theory**

The main critique on JCT was that it focused on only motivational job characteristics, thereby limiting its use in job design. Also, (Parker et al., 2001) noted that the proposed motivational processes in the form of the critical psychological states were a too narrow view in explaining the link between work characteristics and outcomes. Next to that, scales in the Job Diagnostic Survey were found to have low internal consistency and researchers also found problems with its factor structure (Morgeson & Humphrey, 2006). This sparked the development of elaborations on the Job Characteristics Model. The most notable and practical example of this is the Work Diagnostic Questionnaire by (Morgeson & Humphrey, 2006) which will be described here in more detail.

The WDQ includes 21 distinct job characteristics, measured by scales that showed high internal consistency, allowing for a greater range of job design and redesign choices than those in existing measures. The job characteristics were placed in three major categories: motivational, social, and contextual. This is in line with the reasoning in (Parker et al., 2001) that psychological states of empowerment can arise from influences other than just the motivational job characteristics, such as peer helping and supportive customer relationships.

Figure 7 shows all characteristics included in the Work Design Questionnaire. The motivational characteristics are further divided into task and knowledge characteristics. The basic principle of the motivational approach is that jobs will be enriched if high levels of these characteristics are present, similar to the JCM (Morgeson & Humphrey, 2006). Additionally, social characteristics reflect the fact that work is performed within a broader social environment, and contextual characteristics reflect the context within which the job is performed, including physical and environmental contexts (Morgeson & Humphrey, 2006).

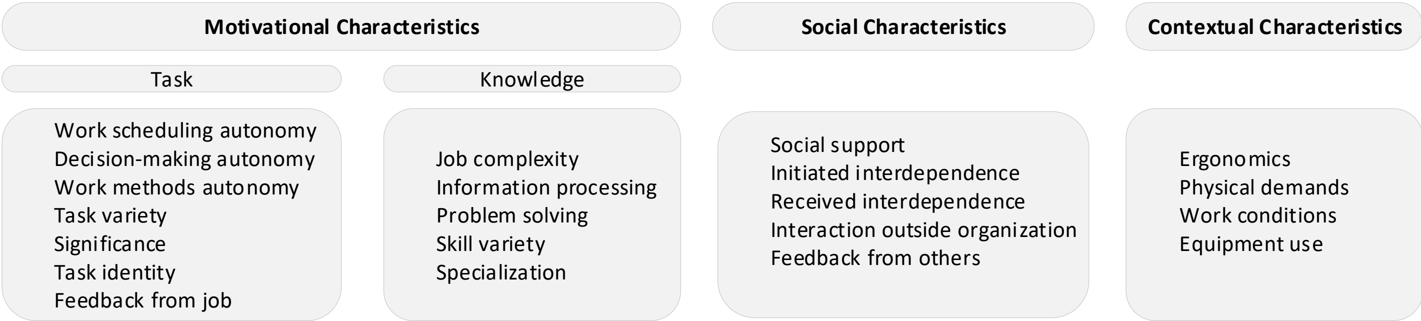



*Figure 7: WDQ Job Characteristics (Morgeson & Humphrey, 2006)*

# 4 | Effect of nervousness on planners

In this chapter, the effect of nervousness on planners will be investigated, using the theory on job design that was presented in the previous chapter. In the following sections, the proposed conceptual model and hypotheses are represented, followed by the method used (a survey), to test the hypotheses. Subsequently, the results and a discussion of results are given, followed by a conclusion for this chapter.

## 4.1 Conceptual Model

Figure 8 presents the conceptual model which will be tested. It explicitly includes nervousness and builds on Job Characteristics Theory, as it contains the widely established relation between job characteristics and outcomes, with the addition of nervousness. It can be seen that nervousness is suggested to be the predictor variable, job outcomes are the outcome variables, and job characteristics are the mediator variables. The intended scope of the model is the job of planners who are responsible for managing incoming supply orders, i.e. 'supply coordinators'. A large part of their job exists of actions that are required because of nervousness in the planning system, such as assessment of rescheduling requests and expediting orders. A smaller part of their job consists of other tasks, which are affected by nervousness but not directly needed because of it. These tasks include releasing purchase requisitions, maintaining master data, managing supplier KPI's, and varying project related tasks. It is therefore interesting to see how nervousness is affecting their overall job characteristics and outcomes. However, the question remains how nervousness can be exactly defined as a variable in the planning job. A proposal for this will be discussed next.

The operational definition of nervousness entails excessive rescheduling of open orders, as well as the negative effects of open order rescheduling (Ho, 2008). Based on this, the variable nervousness in the model of figure 8 includes a component that reflects the amount of rescheduling a planner is involved with in their job, and a component that reflects how negative they perceive the aspects of their job related to nervousness. By taking the product of these variables, the impact of nervousness on a planner's job can be defined. This way, it can be seen that a planner who does a lot of rescheduling actions and perceives them as negative, would score high on nervousness.

The first dimension, experienced amount of nervousness, reflects how much planners are involved with rescheduling related activities, i.e. time spent on assessment of rescheduling suggestions on open orders, prioritizing shortages, following up on orders with suppliers, and contacting demand owners. Most of the planner's attention goes to reschedule-in messages as they trigger expediting at the supplier and potentially indicate problems will occur at the shop floor. Note that the word 'potentially' is used here to reflect that MRP logic also triggers non relevant reschedule-in messages because safety stock and lead time are not taken into account when generating these messages. Reschedule-in messages are closely related to solving shortages, as any projected material shortage on a requirement has a corresponding reschedule-in message on a purchase order. However, addressing and following up on one reschedule-in message or projected shortage is not always the same as the other. The trait of MRP to hard-couple all elements in the planning system will always lead to shifts in requirement dates and new messages every time MRP is run. It is expectedly these 'unnecessary' small shifts back and forth that cause the frustration on the side of the planners and suppliers. The other side is when actual exceptions occur: the plan should be able to cope with variability in the supply chain, but it is never feasible to have accounted for hundred percent of the variability. The rescheduling problems that occur due to unforeseeable, actual exceptional events, could challenge and motivate the planner. The former type of rescheduling can be seen as hindrance demands, which refers to excessive or undesirable constraints in the work, associated with factors such as role ambiguity, role conflict, and hassles (Li, Taris, & Peeters, 2020; LePine, LePine, & Jackson, 2004). The latter type of rescheduling can be seen as challenging demands, which refers to demand that cost effort but also present potential for personal growth and rewards (LePine, Podsakoff, & LePine, 2005).

Therefore, the subjective effect of nervousness related actions should be taken into account, which is the second dimension of nervousness included in the model. It reflects the degree to which planners find solving shortages and rescheduling messages challenging and enjoyable. Next to that, it entails the other feelings planners have related to reviewing and managing shortages and rescheduling messages in the current way of MRP planning. The more adverse the planner is towards these aspects, the more nervousness is subjectively experienced in his or her job.

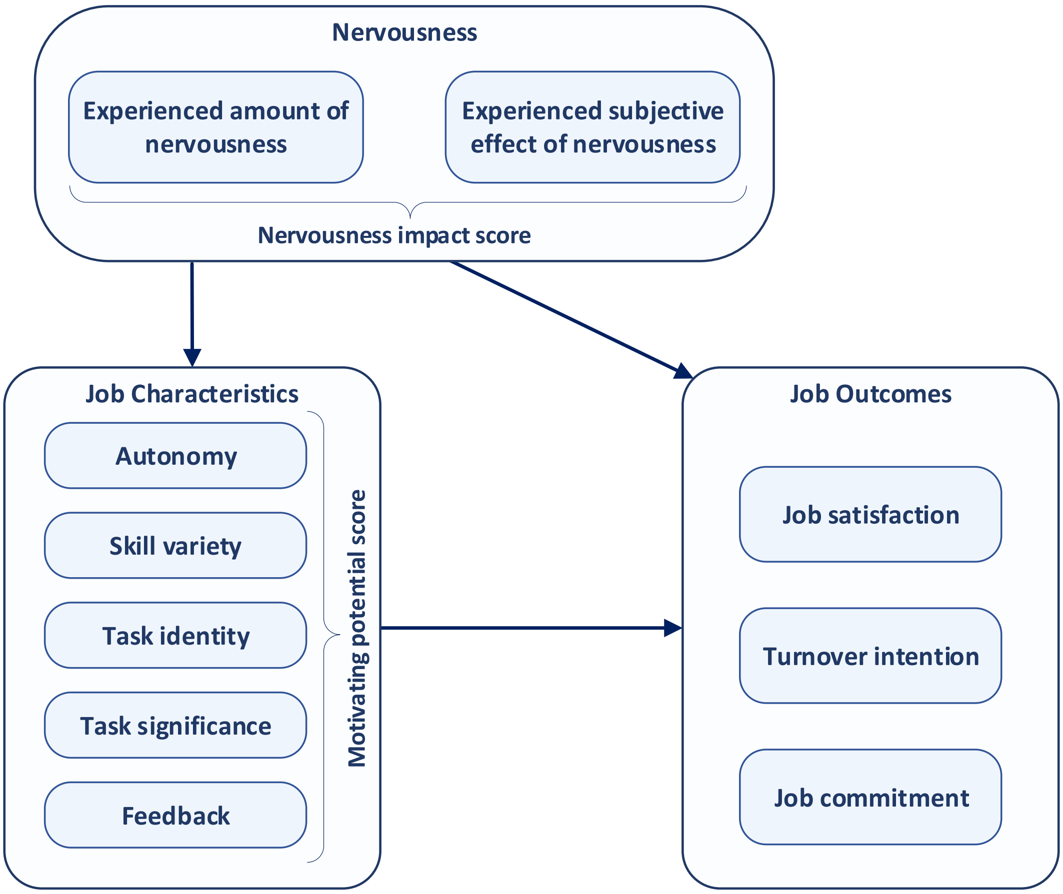



*Figure 8: Conceptual Model Nervousness and Job Characteristics & Outcomes*

## 4.2 Hypotheses

First, the view can be taken where nervousness is a specific contextual characteristic of the planning job, which is expected to be negatively related to job outcomes. One perspective from which this can be seen is that of illegitimate tasks. The core aspect of illegitimate tasks is that employees think they should not have to carry out this task (Semmer et al., 2015). Tasks can be seen as illegitimate if they are unreasonable or unnecessary. Tasks are unreasonable if they fall outside of the range of one's job, and unnecessary tasks stem from organizational inefficiencies due to system shortcomings (Semmer et al., 2015). Earlier, it was described that rescheduling actions can be regarded as compensational tasks, as they make up for shortcomings in the system, which is similar to the definition of unnecessary tasks. Hence, from this perspective it can already be seen how nervousness might relate to the concept of illegitimate tasks. As illegitimate tasks are associated with feeling stressed and job dissatisfaction (Semmer et al., 2015), it can be seen that nervousness could negatively influence job outcomes.

Another perspective that can be taken is that of overqualification. Overqualification refers to the situation wherein employees have more skills, experience, knowledge, and abilities than required for a job (Wu, Luksyte, & Parker, 2015). It negatively impacts job outcomes such as job satisfaction and voluntary turnover (Wu et al., 2015). It can be argued that the extent to which a planner has to compensate for system shortcomings (due to nervousness), reflects the loss in opportunity to focus on those tasks that would better match their competences such as managing and optimizing 'real' problems in the supply chain (e.g. structural improvement of supplier issues), and working on projects and competences in the organization. The problem solving aspect of the planners' job included reviewing shortages and coordinating between departments to reschedule orders to the MRP suggested date. However, this way of problem solving can be demotivating, as in the next week the planning systems' suggested dates are completely different again. Planners might feel this format related to nervousness limits their problem solving abilities. Hence, from this overqualification perspective it can be seen how nervousness could negatively influence job outcomes.

Furthermore, nervousness might affect planners' commitment to the job. The concept of commitment is often associated with both attitudes and emotions (Landy & Conte, 2016). Three forms of organizational commitment were suggested by (Meyer & Allen, 1997): affective commitment, continuance commitment, and normative commitment. Affective commitment occurs when individuals fully embrace the organization, continuance commitment occurs when individuals base their relationship with the organization on what they are receiving in return for their efforts and what would be lost if they were to leave, and normative commitment occurs when individuals remain with an organization based on expected standards of behavior or social norms (Meyer & Allen, 1997). These forms of commitment can also be applied to the planning job itself. Affective job commitment then represents the emotional attachment to the planning job, which is expected to decrease due to nervousness. Also, the relevance of investigating this relation is clear, as it was found that affective commitment had the strongest and most favorable associations with job performance and better predicts turnover than continuance or normative commitment (Meyer et al., 2002).

> *Hypothesis 1*: Nervousness will be negatively related to (a) job satisfaction and (b) job commitment, and positively related to (c) turnover intention.

Second, it is expected that nervousness is negatively related to motivational job characteristics. The job characteristics included in the model are those found in the Job Characteristics Model by Hackman & Oldham (1976). Not all job characteristics (i.e. the social and contextual characteristics of the WDQ) were included to keep the model concise as it will later be tested through survey research. The focus will be on the motivational characteristics, as it is expected that they are more strongly related to nervousness than social and contextual characteristics. From the motivational job characteristics, the original ones from the JCM were chosen as this allows for the use of the Motivating Potential Score (MPS). This summarizing motivating potential score relates more strongly to the outcomes than any of the components of the job dimensions and relates strongly to job satisfaction (Hackman & Oldham, 1976). The measure has also been positively related to organizational commitment (e.g. Bahrami, Aghaei, Barati, Tafti, & Ezzatabadi, 2016) and negatively related to turnover intention (e.g. Hinton & Biderman, 1995).

Next, it will be explained how nervousness could affect each of the job characteristics. **Autonomy** reflects the extent to which a job allows freedom, independence, and discretion to schedule work, make decisions, and choose the methods used to perform work (Morgeson & Humphrey, 2006). As more nervousness will be paired with more frequent rescheduling requests on orders, it is expected that this will leave less room for a planner to freely and independently schedule their work. **Skill variety** reflects the degree to which a job requires a variety of different activities in carrying out the work, which involve the use of a number of different skills (Hackman & Oldham, 1976). It is expected that the presence of nervousness does not contribute to skill variety, as it requires more time to be spend on a list of rescheduling requests on a recurring basis. For the biggest part, this does not require the extensive use of skills and problem solving, as most of the rescheduling requests are found not relevant. This is because incorrect information is used to generate the messages which are therefore ignored by planners (Ho, 2005). **Task identity** reflects the degree to which the job requires completion of a whole and identifiable piece of work; doing a job from beginning to end with a visible outcome (Hackman & Oldham, 1976). It can be seen that rework, first expediting and then delaying a part, does not contribute to task identity. It is expected that nervousness does not contribute to planners' ideas of doing a wholesome job, and therefore would negatively impact the task identity job characteristic. **Task significance** reflects the degree to which the job has a significant impact in- and outside the organization. Given that a higher amount of nervousness leaves less room for planners to deploy other activities that are likely to be more significant in terms of contributing to the organization, it is expected that nervousness will be negatively related to the overall task significance of the planning job. **Feedback from the job** reflects the degree to which the job provides direct and clear information about the effectiveness of task performance (Hackman & Oldham, 1976). The effectiveness of rescheduling related activities is likely to be less clear in case request dates are constantly changing. Hence, it is expected that nervousness is negatively related to feedback.

*Hypothesis 2*: Nervousness will be negatively related to (a) the motivating potential score, (b) autonomy, (c) skill variety, (d) task identity, (e) task significance, and (f) feedback.

Third, it is expected that motivational job characteristics mediate the relationship between nervousness and job outcomes. The proposition is that the presence of nervousness leads to changed perceptions on the motivational job characteristics amongst planners, which explain the reduced job outcomes. The relationship between job characteristics and job outcomes proposed by JCT have been tested in hundreds of studies (Oldham & Fried, 2016). In a meta-analysis by (Fried & Ferris, 1987) it was found that the five core job characteristics of the JCT were strongly related to job satisfaction, growth satisfaction, and internal work motivation, with weaker relationships to job performance and absenteeism. The possible relations between nervousness and job characteristics and outcomes have also been described separately, therefore it makes sense to include job characteristics as a mediating factor. The MPS is a validated measure that summarizes job characteristics and was found to relate more strongly to job outcomes than any of the individual job characteristics (Hackman & Oldham, 1976), for this reason this variable will also be tested as a mediator next to each separate job characteristic.

*Hypothesis 3*: The relationship between nervousness and job outcomes will be mediated by (a) the motivating potential score, (b) autonomy, (c) skill variety, (d) task identity, (e) task significance, and (f) feedback.

## 4.3 Survey Method

A survey was set up in order to formally test hypotheses 1 – 3, which correspond to the first research question of investigating the effect of nervousness on planners. In the next sections the details of the study are presented, including details on the study design, study sample, the variables and items included, and the analysis strategy.

**Study procedure**

An online survey was set up using Microsoft Forms that was sent out to 55 planners, i.e. Operational Supplier Coordinators, from the Operational Supplier Management department of ASML. Prior to sending out the survey, it was reviewed by multiple supply chain employees at ASML Veldhoven, including one planner, to ensure there were no unclarities. Also, all team leads of the department and the planners themselves were informed one week in advance that the survey was going to be sent out to them, kindly asking them for cooperation in this research. In this message as well as in the survey itself, it was noted that confidentiality would be ensured. Planners could optionally specify their name, to prevent them from getting any survey reminders, but all data was anonymized before any processing was done. The survey required approximately 15 minutes to be completed.

**Study sample**

Out of the 55 planners who were responsible for coordinating the incoming materials of one or more suppliers, 37 filled out the survey, resulting in a response rate of 67 %. The response rates within the different product teams ESW, ECI, FM, Optics, Metrology, and MTR ranged from 57 to 75 %. Therefore, the gathered data was deemed representable for the planners within the department. Table 1 shows the general details about the sample of the study.

| **Team** | **Frequency** | |
|---|---|---|
| Electronics & Software | 9 | 24% |
| Environment Control & Infrastructure | 6 | 16% |
| Frames & Mechanics | 7 | 19% |
| Mechatronics | 4 | 11% |
| Metrology | 6 | 16% |
| Optics | 5 | 14% |
| | **37** | |

| **Experience** | **Frequency** | |
|---|---|---|
| 0 – 1 years | 10 | 27% |
| 1 – 2 years | 13 | 35% |
| 2 – 3 years | 4 | 11% |
| 3 – 4 years | 5 | 14% |
| > 5 years | 5 | 14% |
| | **37** | |

| **Number of suppliers responsible for** | **Frequency** | |
|---|---|---|
| 1 | 12 | 32% |
| 2 – 5 | 15 | 41% |
| 6 – 10 | 4 | 11% |
| 18 – 29 | 5 | 14% |
| 90 | 1 | 3% |
| | **37** | |

*Table 1: General information study sample*

**Measures**

Now, the variables and measurement items will be described. A complete overview of survey items can be found in Appendix E.

<u>Nervousness Overall Score</u>

The overall nervousness experienced by planners was computed as a product of two variables, conform the conceptual model presented earlier:

$$Nervousness\ Overall\ Score = Nervousness\ Amount * Nervousness\ Subjective\ Effect$$

This way, overall nervousness in the planning job is represented by the amount of rescheduling activities planners are involved in, taking into account how (adversely) these activities are perceived. Since no scale was available for measuring both components, a scale was developed for this research, as discussed next.

<u>Nervousness Amount</u>

To gather data on the first dimension of nervousness (*nervousness amount*) the set of items shown in table 2 were included in the survey. The questions were open-ended. The choice was made to take the sum of items 2, 3 and 4 to operationalize *experienced amount of nervousness* as this most clearly reflects the time spent on nervousness related tasks. In the scores on items 2, 3, and 4, three observations were excluded because the total sum of each of these observations amounted to 60 hours or more per week, which were regarded as outliers.

The scores on item 1 indicate that on average, planners spend 16.4 % of their time in a week on all tasks related to shortages, which is approximately 0.8 working days. Adding up the average hours spend on reviewing, prioritizing and following up on shortage with suppliers and demand owners (items 2, 3 and 4), this amounts to 12.6 hours, which is approximately 1.5 working days.

| | Item | Mean | Median | Sum |
|---|---|---|---|---|
| 1 | Average weekly time spent on all actions related to the list of shortages (%) | 16.4 | 10.0 | |
| 2 | Average weekly time spent reviewing and prioritizing shortages (hr) | 3.4 | 3 | |
| 3 | Average weekly time spent contacting suppliers regarding shortages (hr) | 8.7 | 5 | |
| 4 | Average weekly time spent contacting demand owners regarding shortages (hr) | 5.2 | 3 | |
| 5 | Average shortage lines responsible for at the beginning of the week | 229 | 120 | 8470 |
| 6 | Average shortage lines considered relevant at the beginning of the week | 45 | 15 | 1675 |
| 7 | Average weekly contact moments with suppliers regarding reschedule-in messages | 32 | 20 | |

*Table 2: Outcomes 'experienced amount of nervousness' items. N ranges from 34 to 37.*

It is remarkable that this does not coincide with item 1, as all of the tasks under items 2, 3, and 4 are related to shortages. Taking into account that items 2, 3, and 4 are less prone to ambiguity compared to item 1, the sum of these former three items were chosen for *operationalization of nervousness amount.*

Nervousness Subjective Effect

To gather data on the second dimension of nervousness (*nervousness subjective effect*), the items shown in table 3 were included in the survey. They were scored on a 5-point Likert scale (1 = "completely disagree", to 5 = "completely agree"). The items add to the various ways in which nervousness could be experienced as negative, which does not necessarily mean they coincide. The items were combined to operationalize *nervousness subjective effect.* The variable therefore classifies as a formative construct, as it is formed, or induced by its measures (Roberts & Thatcher, 2009). Each indicator adds a meaningful part to the formative construct. For example, the reviewing aspect (item 1) is something that planners indicated in preliminary interviews to be a tedious aspect of their job, and the degree to which they experience this tells something about the negative valence of nervousness. On the other hand, it was reasoned that solving shortages and the corresponding rescheduling suggestions can be experienced in a hindering or challenging way (a planner who more frequently reschedules an expensive, vital part because of complex issues might feel more challenged than a planner who more frequently has to postpone and expedite the delivery of some commodity part several times), hence the reversed score of item 2 also tells something about the degree to which nervousness is experienced as negative. This way, each item adds to the formative construct *nervousness subjective effect*, i.e. the negative valence of nervousness.

| | Item | M | SD | Mode |
|---|---|---|---|---|
| 1 | Reviewing shortages is a tedious task | 3.2 | 1.0 | 4 |
| 2 | Solving shortages is one of the most challenging parts of my job (R) | 3.5 | 1.2 | 4 |
| 3 | The current way of material planning (MRP) in the ERP system is discouraging me | 3.4 | 1.1 | 4 |
| 4 | Solving shortages is an enjoyable part of my job (R) | 3.4 | 1.1 | 4 |
| 5 | Working with material shortage involves unnecessary rework: Repeated actions for which you keep wondering if they could have been avoided with better planning processes | 4.2 | 0.8 | 5 |

*Table 3: Outcomes 'experienced subjective effect of nervousness' items. N = 37.*

Job Characteristics

All job characteristics were measured on a 5-point Likert scale. To measure autonomy, 9 items were adapted from the Work Design Questionnaire (Morgeson & Humphrey, 2006). These 9 items originally measured three types of autonomy: Work Scheduling Autonomy, Decision-Making Autonomy, and Work Methods Autonomy. However, all 9 items showed a high internal consistency (Cronbach's Alpha is 0.89), hence they were combined into one scale. One example item was: "The job allows me to decide on the order in which things are done on the job".

The other job characteristics: skill variety, task identity, task significance, and feedback, were each measured with 3 items, also adapted from the WDQ (Morgeson & Humphrey, 2006). All factors had a high internal consistency with a Cronbach's alpha of more than 0.75, also shown in table 4. Example items included "the job requires me to utilize a variety of different skills in order to complete the work" (*skill variety*), "the job is arranged so that I can do an entire piece of work from beginning to end" (*task identity*), "the job itself is very significant and important in the broader scheme of things" (*task significance*), and "the job itself provides feedback on my performance" (*feedback*).

Furthermore, the motivating potential score was computed from the scores of the motivational job characteristics following the original definition by Hackman & Oldham, 1976:

$$MPS = \frac{Skill\ Variety + Task\ Identity + Task\ Significance}{3} * Autonomy * Feedback$$

Job Outcomes

All job outcomes were also measured on a 5-point Likert scale. To measure job satisfaction, 5 items were adopted from the study of Schleicher, Smith, Casper, Watt, & Greguras (2015). An example item was: "Most days I am enthusiastic about my work". The items showed a high internal consistency with a Cronbach's alpha of 0.84.

To measure job commitment, 4 items were adapted from the affective commitment scale of the Three-Component Organizational Commitment Questionnaire by Meyer & Allen (1991). For instance, the item "I would be very happy to spend the rest of my career with this organization" was altered to "I would be very happy to spend the rest of my career in this job", such that the items referred to the job rather than the organization. The job commitment items however, showed a low internal consistency (Cronbach's Alpha of 0.13) and were therefore excluded in further analyses.

*Employee turnover intention* was assessed by two items created by (Mobley, Horner, & Hollingsworth, 1978). An example item was: "I frequently think of quitting my job". The two items had a high internal consistency with a Cronbach's alpha of 0.79.

**Analysis strategy**

The hypotheses stated that:

1. Nervousness will be negatively related to (a) job satisfaction, (b) job commitment, and positively related to (c) turnover intention.
2. Nervousness will be negatively related to (a) the motivating potential score, (b) autonomy, (c) skill variety, (d) task identity, (e) task significance, and (f) feedback.
3. The relationship between nervousness and job outcomes will be mediated by (a) the motivating potential score, (b) autonomy, (c) skill variety, (d) task identity, (e) task significance, and (f) feedback.

An ordinary least squares (OLS) regression was done to test hypotheses 1a, 1c, and hypotheses 2a until 2f. The effect on job commitment (hypothesis 1b) was left out because the construct was not found to be reliable. The predictor variable used was *nervousness overall*, but also the individual components *nervousness amount* and *nervousness subjective effect* were used as predictor variables to test the hypotheses.

To test the third hypothesis, the steps specified by Baron & Kenny (1986) to establish mediation were followed, including:

Step 1: Showing that the causal variable is significantly related to the outcomes. This step was essentially done by testing hypothesis 1.

Step 2: Showing that the causal variable is significantly related to the mediator. This step was essentially done by testing hypothesis 2.

Step 3: Showing that the mediator is significantly related to the outcome. This step was done by investigating the Pearson correlations between the mediators (job characteristics and the MPS) and the job outcomes (job satisfaction and turnover intention).

Step 4: Showing that the effect of the causal variable on the outcome variables is reduced or becomes insignificant once the mediator is added to the model. This was done via a multiple regression analysis where nervousness and the mediating variables were included as predictors, with either job satisfaction or turnover intention as the outcome.

The hypotheses were tested on 34 observations, after removing 3 observations that were classified as outliers, because these observations contained unrealistically high responses on '*nervousness amount*', with a time spent of 60 hours or more per working week.

## 4.4 Survey Results

### General observations

Firstly, the items used to measure nervousness (represented in tables 2 and 3) already give some noteworthy insights. It can be seen that the most chosen answer on the 'rework' item was 5 (strongly agree), showing there is a strong feeling amongst planners that unnecessary rework is involved when working with material shortages. Furthermore, the sum of shortage lines for which the planners are responsible is 8470, which is in line with the expectations, taking into account that this number relates to two-thirds of the planners and that the total shortage lines every week in the communication tool is approximately 14.000. Notably, only 1675 (20 %) of those lines were found to be relevant, meaning: planners find that for only 20 % of shortage lines there is a real need to reschedule the demand or supply element. Reasons given by planners were: demand integrity (i.e. there is an invalid demand element in the past which triggers the shortage), unconfirmed purchase requisitions which trigger the shortage, manual reservations that are not urgent, and finally, the demand elements can still be a forecast (i.e. no actual work orders are opened) which is acknowledged by planners as demand which is most likely overstated and thus not relevant.

| | Variable | Range | M | SD | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Autonomy | 1-5 | 3.8 | 0.6 | (.89) | | | | | | | | | | | |
| 2 | Skill Variety | 1-5 | 3.8 | 0.9 | **.35** | (.89) | | | | | | | | | | |
| 3 | Task Identity | 1-5 | 2.7 | 0.8 | .24 | .33 | (.76) | | | | | | | | | |
| 4 | Task Significance | 1-5 | 3.4 | 1.0 | .10 | .07 | .19 | (.88) | | | | | | | | |
| 5 | Feedback | 1-5 | 3.1 | 1.0 | -.13 | .07 | **.43** | .09 | (.91) | | | | | | | |
| 6 | Job Satisfaction | 1-5 | 3.8 | 0.7 | .14 | .02 | .00 | .05 | .25 | (.84) | | | | | | |
| 7 | Job Commitment | 1-5 | 2.7 | 0.5 | -.10 | .18 | .08 | .14 | .33 | **.57** | (.13) | | | | | |
| 8 | Turnover Intention | 1-5 | 2.2 | 1.2 | -.19 | **-.43** | -.21 | .15 | -.18 | **-.63** | **-.43** | (.79) | | | | |
| 9 | Motivating Potential Score (MPS) | 1-125 | 39.9 | 22.7 | **.40** | **.41** | **.68** | **.38** | **.76** | .21 | .28 | -.20 | - | | | |
| 10 | Nerv. Amount (Time Spent) | 0-40 | 12.6 | 8.1 | -.01 | .25 | .31 | .08 | .18 | -.08 | .03 | -.02 | .31 | - | | |
| 11 | Nerv. Subj. Effect (Negative Valence) | 1-5 | 3.2 | 0.6 | -.16 | -.27 | **-.40** | .01 | **-.36** | -.24 | -.13 | **.50** | **-.36** | -.07 | - | |
| 12 | Nervousness Overall Score | 0-200 | 39.6 | 27.4 | -.08 | .19 | .21 | .11 | .08 | -.17 | -.05 | .11 | .20 | .97 | .15 | - |

*Table 4: Means, standard deviations, zero-order correlations, and internal consistencies. In parentheses: Cronbach's alpha. In bold printing: p-value $< .05$. $N = 34$.*

Secondly, table 4 shows the descriptive statistics (means and standard deviations), zero-order correlations, and internal consistencies of the variables included in the analysis. As mentioned earlier, job commitment will not be taken into further consideration as its measurement items showed low internal consistency (Cronbach's alpha of .19). It can be seen that for *nervousness amount*, the most considerable effect sizes are the correlations with skill variety ($r = .25$), task identity ($r = .31$), and the MPS ($r = .31$). For *nervousness subjective effect*, the most considerable effect sizes are the significant correlations with task identity ($r = -.40$), feedback ($r = -.36$), turnover intention ($r = .50$), and the MPS ($r = -.36$), but also the correlations with skill variety ($r = -.27$) and job satisfaction ($r = -.24$) are notable. In the testing hypotheses section these relations will be investigated in more detail.

Of the job characteristics, task identity had the lowest mean score, with an average of 2.7 (between 'somewhat disagree' and 'nor agree, nor disagree'), indicating that on average, planners are indifferent or somewhat disagreeing in that the job involves tasks with a clear beginning and end. Considering the management of incoming orders, this makes sense, as sometimes actions are required, but it is not necessarily clear that the task is done after having reviewed or rescheduled the order once, because the possibility exists that additional future actions on the order will be required as well.

The combined time spent on reviewing and prioritizing shortages, and contacting suppliers and demand owners regarding shortages (item 11), is 12.6 hours on average (1.6 working days), which is a significant amount in respect to the total amount of 40 available hours in a week of 5 working days. Furthermore, there is a relatively high standard deviation in time spent of 8.1 hours, indicating that the time spent related to shortages is quite variable amongst planners. This could be explained by the experience of planners, by the nature of the supplier(s) and parts the planner is responsible for (e.g. complex, high value parts might require more attention than lower value parts), or simply by differences in the distribution of their set of tasks (e.g. some planners are responsible for less suppliers/materials and do more project related tasks).

Furthermore, the Motivating Potential Score (MPS) is approximately 40 on average, which is a moderate score as it corresponds to an average of approximately 3.5 for each of the job characteristics. The average time spent of 12.6 hours (1.6 working days) on action related to shortages, combined with the negative valence of nervousness lead to the average overall nervousness score of approximately 40. These average outcomes on nervousness are hard to interpret in the absolute sense, given that they have not been researched before. They can better be interpreted in a relative sense, which is done in the next sections where differences in scores on nervousness amongst planners are related to job characteristics and outcomes through regression analyses.

**Testing hypotheses**

Table 5 presents the results of the regression analyses that were conducted to test hypotheses 1a and 1c, that nervousness would have a negative relation with job satisfaction and a positive relation with turnover intention. The results also represent the first step of establishing mediation.

| | Job Satisfaction | | | Turnover Intention | | |
|---|---|---|---|---|---|---|
| Variable | β (95 % CI) | p | $R^2$ | β (95 % CI) | p | $R^2$ |
| Nervousness Overall Score | 0.00 (-.01, .00) | .35 | .03 | 0.00 (-.01, .02) | .55 | .01 |
| Nervousness Amount (Time Spent) | -0.01 (-.04, .02) | .66 | .01 | 0.00 (-.06, .05) | .91 | .00 |
| Nervousness Subj. Effect (Negative Valence) | -.28 (-.70, .13) | .18 | .06 | 1.05 (.39, 1.71) | **.00** | .25 |

*Table 5: OLS regression results for hypothesis 1.*
*$\beta$ = regression coefficient, CI = confidence interval, r = Pearson's correlation.*

The results show that *nervousness subjective effect* has the strongest effect on the job outcomes compared to *nervousness overall* and the *nervousness amount* component. For turnover intention, 25 % of the variance can be explained by *nervousness subjective effect*, which can be classified as a medium effect size, just shy of the threshold of $R^2 = .26$ for a large effect size based on the definition by Cohen (1988). Regarding job satisfaction, 6 % of the variance can be explained by *nervousness subjective effect*, which can be classified as a small effect size (Cohen, 1988). The latter relation was not found to be significant (p = .18), which can be attributed to the lack of statistical power, as both the effect size and sample size are low (Sullivan & Feinn, 2012). Overall, the results indicate that planners who experience nervousness more negatively are more likely to leave their job (and most likely are also less satisfied with their job).

Table 6 presents the results of the regression analyses that were conducted to test hypotheses 2a – 2f, that nervousness will be negatively related to the motivating potential score and each of the motivational job characteristics. The results also represent the second step of establishing mediation. In table 4 already positive relations of a small to moderate effect size were shown between *nervousness amount* and the MPS, skill variety, and task identity. In table 6, these small to moderate effect sizes are also represented by the values of the $R^2$ of .10, .06, and .10, respectively. Although the corresponding p-values of the relations (.07, .10, and .07) were not low enough to establish that they are statistically significant, the effects indicate that time spent on shortages could actually predict a higher motivating potential of the job, mainly due to increased skill variety and task identity. This could be explained by planners who spend a relatively high amount of time on shortages are likely to do so because these shortages entail complex parts that require more varied and meaningful actions. Furthermore, the results show significant negative relations between *nervousness subjective effect* and the MPS, task identity, and feedback. This means that planners who experience nervousness more negatively, tend to score lower on the overall motivating potential of the job (in line with the definition of the MPS by Hackman & Oldham, 1976). It also means that planners who experience nervousness more negatively, have lesser feelings of task identity (i.e. doing a whole and identifiable piece of work), and lesser feelings of getting feedback from the job. Overall, this indicates that nervousness, in terms of how it is experienced subjectively, is indeed negatively related to some of the motivational job characteristics. However, nervousness in terms of the time spent on shortages is not negatively related to any of the job characteristics, and results shows there could even be a positive association between the time spent in itself and the motivating potential of the planning job.

| | MPS | | | Autonomy | | | Skill Variety | | | Task Identity | | | Task Significance | | | Feedback | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | β | p | $R^2$ | β | p | $R^2$ | β | p | $R^2$ | β | p | $R^2$ | β | p | $R^2$ | β | p | $R^2$ |
| Nerv. Overall | 0.17 | .26 | .04 | 0.00 | .67 | .01 | 0.01 | .29 | .04 | 0.01 | .24 | .04 | 0.00 | .55 | .01 | 0.00 | .65 | .01 |
| Nerv. Amount | 0.87 | .07 | .10 | 0.00 | .94 | .00 | 0.03 | .15 | .06 | 0.03 | .07 | .10 | 0.01 | .67 | .01 | 0.02 | .30 | .03 |
| Nerv. Subj. Effect | -14.34 | **.04** | .13 | -0.18 | .37 | .03 | -0.40 | .13 | .07 | -0.56 | **.02** | .16 | 0.02 | .96 | .00 | -0.63 | **.04** | .13 |

*Table 6: OLS regression results for hypothesis 2*

Step 1 and 2 for testing mediation (hypothesis 3) showed a significant relation between *nervousness subjective effect* and turnover intention, and between *nervousness subjective effect* and the MPS, task identity, and feedback. Therefore, the relations between the predictors and the outcomes, and the relations between the predictors and possible mediators have been tested. Hence, the missing relations between the possible mediators and outcomes are presented next in table 7.

The only significant relation that can be seen from the results in table 7, is the relation between skill variety and turnover intention (p = .01). This means that planners who have lower feelings of using varied and complex skills, are more likely to leave their job. It further means that no mediator was found which is significantly related to both a predictor and outcome variable.

| Variable | Job Satisfaction | | Turnover Intention | |
|---|---|---|---|---|
| | r | p | r | p |
| Autonomy | .14 | .45 | -.19 | .29 |
| Skill Variety | .02 | .91 | -.43 | **.01** |
| Task Identity | .00 | .99 | -.21 | .24 |
| Task Significance | .05 | .79 | .15 | .41 |
| Feedback | .25 | .15 | -.18 | .30 |
| Motivating Potential Score (MPS) | .21 | .24 | -.20 | .25 |

*Table 7: Relations between possible mediator and outcome variables*

However, considering the relation between *nervousness subjective effect* and turnover intention, for some of the possible mediators (skill variety, MPS, task identity, and feedback), two of the first three steps of establishing mediation were successful. Therefore, each of those mediators were added to the model with *nervousness subjective effect* as the predictor and turnover intention as the outcome, to see if any (partial) mediation occurred. Additionally, a Sobel test was done to test the indirect effect of each of the proposed mediators, which is a different way to establish if the indirect (mediating) effect is significant (Hayes, 2017).

Table 8 shows the results when each of the proposed mediators is added as a predictor to the standard model with *nervousness subjective effect* as the predictor and turnover intention as the outcome. The results show that the model only improved when skill variety is added as a mediator, evident from the improved $R^2$ (adjusted) of model 2. Next to that, the regression coefficient of *nervousness subjective effect* decreases from 1.05 to 0.87 while the p-value of the coefficient is slightly higher but still significant.

| | Outcome variable: Turnover Intention | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Model 1 Mediator: None | | Model 2 Mediator: Skill Variety | | Model 3 Mediator: Task Identity | | Model 4 Mediator: Feedback | | Model 5 Mediator: MPS | |
| | $R^2$ | F | $R^2_{adj}$ | F | $R^2_{adj}$ | F | $R^2_{adj}$ | F | $R^2_{adj}$ | F |
| | .25 | .00 | .30 | .00 | .20 | .01 | .20 | .01 | .20 | .01 |
| Predictor Variable | β | p | β | p | β | p | β | p | β | p |
| Nerv. Subj. Effect | 1.05 | .00 | 0.87 | .01 | 1.04 | .01 | 1.05 | .01 | 1.03 | .01 |
| Skill Variety | | | -0.45 | .04 | | | | | | |
| Task Identity | | | | | -0.02 | .94 | | | | |
| Feedback | | | | | | | -.01 | .96 | | |
| MPS | | | | | | | | | .00 | .87 |

*Table 8: Results of regression analyses including varying mediators*

However, the results of the additional Sobel test, shown in table 9, showed that this partial mediating effect was not significant (p = .08). It can also be seen that the p-values of the other mediating effects were much higher.

| Mediator | p-value of mediating effect |
|---|---|
| Skill Variety | .08 |
| Task Identity | .94 |
| Feedback | .96 |
| MPS | .86 |

*Table 9: P-values of mediating effect*

## 4.5 Discussion of survey results

The survey was designed to quantitatively investigate the effect of nervousness on human planners, in line with the first research question of this research. Three hypotheses were tested, where the first one focused on the effect of nervousness on the satisfaction and turnover intention of planners, the second one focused on the effect of nervousness on the different motivational job characteristics of the planner and the third one focused on whether the job characteristics mediated the effect of nervousness on job outcomes. The main finding was that nervousness, in terms of how adversely working with shortages is experienced, was significantly related to the turnover intention of planners, as well as a reduced overall motivating potential of the job, and lesser feelings of task identity and feedback from the job.

No significant relationships were found between *nervousness amount* and any of the job outcomes or characteristics. The initial idea was that this variable would represent an objective, quantitative measure of how much planners are involved with tasks related to nervousness, defined by the time spent on activities such as addressing and following up on shortages. One reason why the time spent in itself does not relate to any job characteristics or outcomes, is that it is really about how the planner experiences this time spent. It is not necessarily the case that solving a shortage is always challenging or always feels like rework, it really depends on the nature of the shortage itself. For instance there could be complex underlying production issues of an important part, whereas on the other hand a shortage could concern a relatively cheap, common component with many shifts in requirements. This was also expected, and hence the initial proposal was to multiply the time spent by the average subjective score of working with shortages. However, it turned out that it is better to just use the subjective term for nervousness instead of the product of both. This is because *nervousness amount* had a significantly high standard deviation of 8.1 hours compared to the mean response of 12.6 hours which most likely explains why *nervousness overall*, determined by *nervousness amount* as one of its two multiplicative terms, turned out to be unrelated to any of the job characteristics or outcomes. In future research, if the time spent on rescheduling and shortages was to be used as an operationalization for nervousness in relation to job characteristics and outcomes, then it is recommended to make a distinction between the nature of the shortages on which the time is spent, such that this can be controlled for.

The other way that was used to define how much 'nervousness' is present in the job of a planner, was to take into account how a planner subjectively experiences the effects of nervousness. This turned out to be a more practical definition to differentiate between nervousness experienced by planners (significantly smaller standard deviation compared to the mean response). *Nervousness subjective effect* was formed by different items, describing the averseness towards the planning system, averseness towards working with shortages, and how much rework was involved in the job, amongst others. For this variant of nervousness, in comparison to the other variants, stronger relations were found with job satisfaction, turnover intention, the MPS, and all motivational job characteristics of the Job Characteristics Model, except for task significance. The relations between *nervousness subjective effect* and turnover intention, the MPS, task identity, and feedback were statistically significant, whereas the relations between job satisfaction, autonomy, skill variety, and task significance were not statistically significant. However, for job satisfaction and skill variety this was most likely due to the low sample size, which can be seen as a limitation of this research.

The significant positive relation between *nervousness subjective effect* and turnover intention shows that planners who experience nervousness more negatively have higher intentions to leave the job. Experiencing nervousness more negatively effectively is a combination of: feelings of rework involved, feelings of tediousness of the shortages review process, lower feelings of overall challenge and joy while solving shortages, and adverseness to the MRP planning system. From this relation it can be deduced that most likely experienced nervousness also affects the satisfaction with the job, although this could not be confirmed explicitly by the data. Therefore, a relevant insight from this finding is that if improvements can be made to the planning job which reduce those aspects that make up the negative valence of nervousness, turnover intentions of planners can be reduced, and it is likely that job satisfaction will improve as well.

The significant negative relations between *nervousness subjective effect* and the MPS, task identity, and feedback show that planners who experience nervousness more negatively, in the same way as described in the previous paragraph, find that the job's motivating potential is lower, particularly because task identity and feedback of the job are lower. This is relevant as it means that efforts to reduce the negative valence of nervousness (e.g. efforts to ensure less rework is involved, more planning stability is created, and less 'unchallenging' shortages are generated which require rescheduling) can lead to improved feelings of doing a whole and identifiable piece of work. Task identity was shown to have a lower average score amongst the participants compared to the other job characteristics. This was explained by the nature of tasks related to managing incoming materials and ensuring material availability (where the job mainly comprises of), as they do not necessarily involve a clear beginning and end. The significant negative relation between task identity and *nervousness subjective effect* gives the additional insight that planners who experience the adverse effects of nervousness more strongly are more likely to find that their tasks do not have a clear beginning and end, and that their tasks do not involve a whole and identifiable piece of work. Furthermore, the findings indicate that efforts to reduce the negative effects of nervousness can contribute to a higher motivating potential of the planning job, and improved feedback from the job itself in how effectively tasks are performed.

Finally, the results showed that of all the job characteristics and the MPS, only skill variety had a significant (negative) relationship to a job outcome: turnover intention. This can however, not be directly traced back to nervousness, as the relationship between the *nervousness subjective effect* and skill variety was non-significant. When skill variety was added as a mediator to the relation between *nervousness subjective effect* and turnover intention, it was found that the relation reduced in size, but the mediating effect was found to be non-significant at $p = .08$. However, given this was found in a study with a relatively small sample size ($N=34$), and hence low statistical power (Hair, Anderson, Babin, & Black, 2010), the mediating effect of skill variety is promising and should be investigated in future research. Also, this is advisable because of the sound underlying argument for proposing skill variety as a mediator, namely that higher perceived negative effects of nervousness could lead to reduced feelings of the job comprising of varied and complex tasks, in turn leading to turnover intentions.

## 4.6 Conclusion

The research question that corresponded to this chapter was: *What is the effect of nervousness on human planners?* The main answer to this question is that experienced nervousness is significantly related to turnover intentions and certain motivational characteristics of the job, supported by the findings that planners who scored higher on the experienced subjective effect of nervousness, also scored higher on turnover intention and lower on their feelings of task identity, feedback, and the overall motivating potential of the job. The total time spent on shortages was in itself not significantly related to any job outcomes or job characteristics, which can be explained by the fact that there was a high deviation in the time spent reported by planners, and that there was no control for which type of shortages, i.e. challenging or unchallenging, this time was spent. Overall, this implies that it is highly relevant to reduce the experienced negative effects of nervousness by focusing on the factors which it comprises of, such as enhancements to MRP planning and increasing the challenging nature of shortages overall, because this would improve certain characteristics of the job, and reduce turnover intentions of the planner. Although the negative relationship between experienced nervousness and job satisfaction was non-significant, given the significant relations with turnover intention and some of the motivational job characteristics, which have been validated in many studies to affect job satisfaction (Oldham & Fried, 2016), most likely this means that planners will also be more satisfied with their job in case nervousness is reduced. Hence, the solutions that reduce nervousness do not only create more stability in orders for suppliers, they can also greatly contribute to the planning job. The solutions and the effects of the solutions are investigated in the next two chapters.

# 5 | Investigating decoupling solutions

Now the effects of nervousness on planners has been discussed in the previous chapter, this chapter will focus on possible solutions for the problem of nervousness. The setup of the chapter is as follows: First, the general ways of coping with nervousness are identified, investigating ways of reducing uncertainty and buffering against uncertainty in MRP systems. Then, two specific buffering solutions that have been applied at ASML during the course of this study are described. Next, given that buffering methods are used to protect against uncertainty, the uncertainty of buy-part demand is analyzed. Also, it will be analyzed to what extent buffering solutions can reduce nervousness in terms of the amount of operational shortages. This includes investigating characteristics of shortage lines in the list over time. Then, the different variables and tradeoffs to take into account for further (optimal) implementation of the solutions are presented. Finally, a discussion is given of the limitations of the redesign and directions for future research, followed by a conclusion.

## 5.1 Methods of coping with nervousness

Nervousness, i.e. schedule instability, is the consequence of many factors of uncertainty affecting the MRP system. There are two general streams of literature that can be identified to go about this. Firstly, efforts can be made to reduce or eliminate each factor of uncertainty that affects the material plan (see e.g. Ho et al., 1992; Jacobs et al., 2011;Heisig, 2012). Many of these efforts are already being made by ASML. Examples include:

- Reducing the incidence of unplanned demands, e.g. by incorporating spare parts forecasts into MRP record gross requirements
- Setting appropriate lot-sizing rules, e.g. lot-for-lot policy on upstream stages
- Using firm planned orders
- Controlling engineering changes
- Eliminating transaction/record errors
- Minimizing supply uncertainty
- Controlling the introduction of parameter changes, such as changes in safety stock levels or planned lead times
- Dampening procedures: filtering out rescheduling messages based on a set of criteria (e.g. suppression of reschedule-out messages on the short horizon for certain part types)

Secondly, buffering methods can be implemented to protect against uncertainties and avoid frequent expediting (see e.g. Silver et al., 2016; Jacobs et al., 2011). Buffering methods are ways of providing slack in the production system, mainly in the form of extra time, inventory or capacity. It should be noted that the use of buffers to protect against uncertainty is not mutually exclusive to employing efforts to reduce uncertainty. Instead, reducing uncertainty would lead to a reduction in buffer size (Guide Jr & Srivastava, 2000).

One way of buffering is by overplanning option and end-item demand, leading to excess inventories at all levels of the product structure (Heisig, 2012). More conventional ways of buffering, which also lead to an increase in inventory levels but in different ways, are safety stock and safety time (Heisig, 2012). Though it is not entirely clear which method should be used under specific conditions, safety stock is usually the preferred method in the case of quantity uncertainty, while the use of safety lead time is conventionally favorable in cases of timing uncertainty (Heisig, 2012). Table 10 gives an overview of the different types of uncertainty, showing that timing and quantity uncertainty can exist in both the supply and demand of an item. Uncertainty may exist at all levels of the product structure, demand uncertainty at the end-item level, and yield, capacity, lead time as well as supply and demand uncertainty at the component and sub-assembly level (Guide Jr & Srivastava, 2000). Therefore, there exists a need to evaluate buffering policies at all levels in the product structure in an integrated manner (Guide Jr & Srivastava, 2000).

| | **Uncertainty Source** | |
|---|---|---|
| **Type** | **Demand** | **Supply** |
| **Timing** | Requirements shift from one period to another | Orders not received when due |
| **Quantity** | Requirements for more or less than planned | Orders received for more or less than planned |

*Table 10: Categories of uncertainty (Jacobs et al., 2011)*

It is however, not within the scope of this research to come up with a research model that determines optimal buffer locations, buffer sizes, and buffer methods in an integrated way for the specific environment. Rather, this research focusses on buffering solutions that can be applied to buy-parts in order to reduce nervousness, and on analyzing what exactly is the nervousness in terms of uncertainty on the parts at this level. These topics are described in the next sections.

## 5.2 Decoupling solutions

Decoupling solutions are solutions that make use of a buffer stock to protect against uncertainty in order to minimize the need for expediting. This is in line with the concept of decoupling and decoupling point: to create independence between supply and demand by placing strategic inventory (APICS, 2010). Whereas with traditional safety stock and safety time buffers in MRP the rescheduling messages will remain, as explained in the problem description, this is not the case with decoupling solutions. The two solutions presented next were implemented by ASML with the aim of creating a more stable, less nervous plan.

**Decoupling safety stock**

Decoupling safety stock is a SAP-based variant of safety stock called 'shared safety stock' that can be used as a buffer in MRP. It is different from traditional safety stock in that it effectively removes rescheduling messages on supply orders as long as the projected stock level on hand remains above 0. The working of the solution is presented in figures 9 and 10. The decoupling safety stock level is 3 and the order lead time is 5 weeks. It can be seen that in the first situation (situation week 0), demand and supply are perfectly matched.

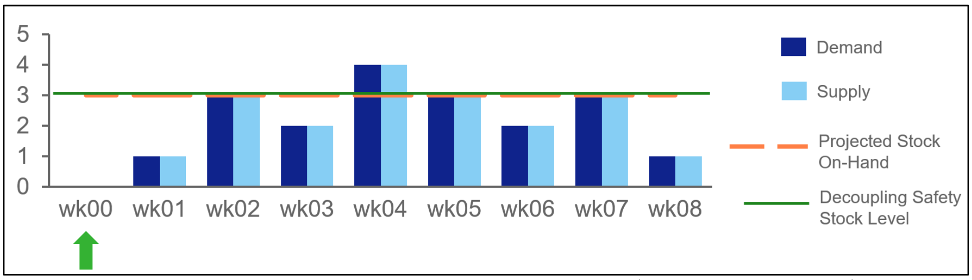



*Figure 9: Decoupling safety stock buffer (Situation week 0)*

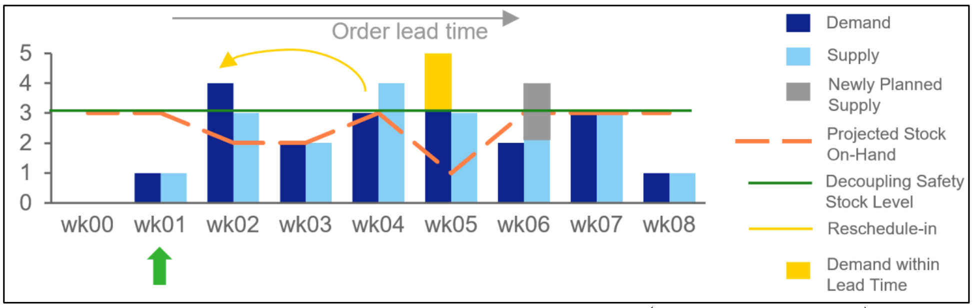



*Figure 10: Decoupling safety stock buffer (Situation week 1)*

In the second situation (situation week 1), one planned demand has been pulled forward from week 4 to week 2 (a 'reschedule-in' of demand). The projected stock on hand for week 2 has therefore dropped to 2. In the conventional MRP system, a reschedule-in would in this case immediately be suggested on all future supply elements in order to maintain a projected on-hand stock level of 3 in week 2 and all future weeks. This explains that the conventional safety stock indeed does not function effectively as a variability absorbing buffer, as it wants to maintain the on-hand stock at all times. The decoupling safety stock concept, shown in figures 9 and 10, functions differently. It actually allows the projected on-hand stock to drop below the level of 3 without triggering rescheduling-in messages on all future supply elements, as the shift of demand can actually be absorbed by the buffer.

It can also be seen that an additional demand has occurred in the second situation (situation week 1), for 2 pieces in week 5. Here also, this demand within the lead time can be absorbed by the buffer. Conventional MRP would in this case, again, have created expediting requests on future supply elements. In case there had been no future supply elements, then it would have created an additional order request within the lead time. The decoupling safety stock concept prevents this, as it allows the projected on-hand stock to drop, and a new order is placed on lead time instead of within the lead time. This can be seen in figure 10, where the projected on-hand stock drops from 3 to 1 in week 5 due to the increased demand, and the new order placed is due for week 6, respecting the lead time of 5 weeks.

Planners working with this solution still need to release and monitor individual purchase orders. However, the solution creates more stability on the request date of orders, as the buffer prevents rescheduling messages on a certain horizon, depending on the height of the decoupling safety stock level. Rescheduling suggestions appear now only in the exceptional case that the projected on hand stock drops below 0.

**Supplier managed inventory**

The second decoupling solution, Supplier Managed Inventory (SMI), is a SAP-specific variant of Vendor Managed Inventory (VMI), with the difference that in the former case it is the customer who manages the system instead of the vendor (Knolmayer et al., 2009). VMI emerged in the retail industry where manufacturers of consumer goods took responsibility of the inventory planning and replenishment for their large retail customers (Govindan, 2013). The key idea in VMI is to mitigate the bullwhip effect by information sharing, as when the vendor has insight in inventory levels, they can typically observe variability in actual demand at their customer, not just in orders received from their customer (Silver et al., 2016). The bullwhip effect is defined as an extreme change in the supply position upstream in a supply chain generated by a small change in demand downstream in the supply chain, caused by the serial nature of communicating orders up the chain (APICS, 2010).

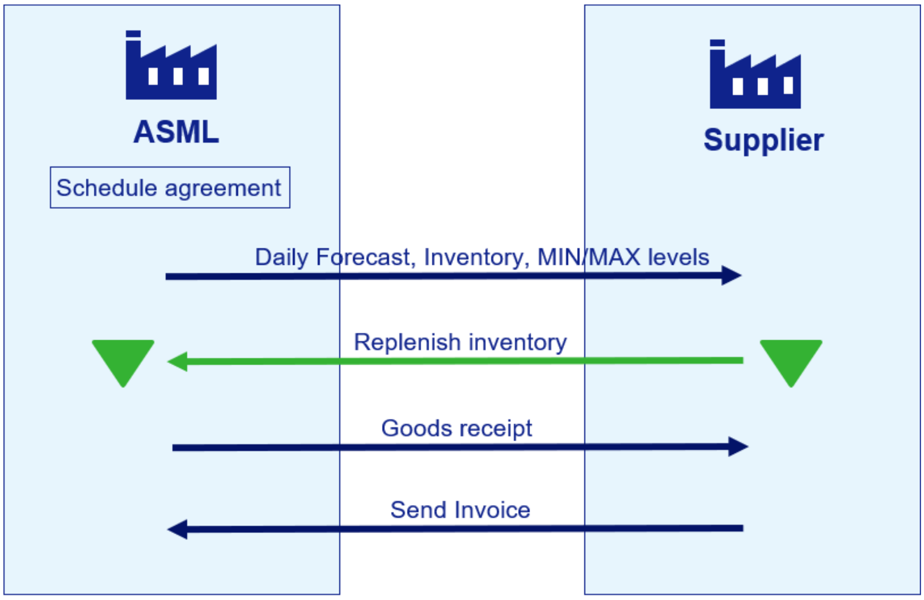



*Figure 11: SMI process*

With SMI, the customer provides the supplier its stock data and its gross requirements to the supplier, and the supplier replenishes the customer's warehouse within minimum and maximum stock levels. The advantage for the supplier is the higher flexibility to synchronize the delivery with its own material availability and capacity utilization, and the advantage for the customer is less planning effort (Knolmayer et al., 2009). It can be seen from figure 11 that the process is managed by a scheduling agreement on which shipments can be booked against. This means there will be no more frequent rescheduling messages on purchase orders. Expediting is only required in the exceptional case that the inventory falls below the minimum specified level.

Also, planners working with this solution have less operational tasks related to releasing and managing purchase orders, because there is one larger scheduling agreement. Instead, they will have a more monitoring role with respect to how the supplier is performing within the Min/Max levels. Also their role will be to ensure that Min/Max levels are updated when needed. The levels are initially determined through a calculation tool based on historic consumption data, XYZ classification (discussed in the next section), value, and size. However, planners also take into account feedback from the supplier regarding the Min/Max levels to make adjustment accordingly.

## 5.3 Demand analysis

There are different types of uncertainty affecting buy-parts. Demand timing uncertainty refers to the shifting of the requirements of these parts in the planning system. Requirements often stem from different types of equipment for factory as well as service needs. However, it is hard to trace all these elements, mainly because they are often removed and recreated. Demand quantity uncertainty, on the other hand, can be determined by using discrete time buckets. In this way, one may abstract from timing uncertainty (De Kok, 2015). Therefore, to determine the nervousness in terms of demand uncertainty on buy-parts, historical (weekly) planning data was aggregated in weekly time buckets. The data was read-in and processed with a script written in MATLAB to determine for each part, in each of the weeks of which data was gathered, the quantities outstanding for each future week in time.

Next to that, buy parts also experience supply uncertainty, where supply timing uncertainty refers to orders not being received when due, and supply quantity uncertainty refers to orders not being received in the right quantity. ASML uses a KPI to measure supplier delivery performance called OTIF, which stands for On Time In Full. The 'On Time' scores of deliveries could be used as a way of defining the supply timing uncertainty, whereas the 'In Full' scores of deliveries could be used as a way of defining the supply quantity uncertainty for a part. In this research however, the main focus will be on demand uncertainty of buy parts, given that the due dates of supply orders are generally determined from demand, where expectedly most volatility resides.

For each of the 22,837 MRP planned buy parts that were consumed at least once in the second half of 2019 a planning matrix was generated. Figure 12 shows this for one example part. It shows the planned (i.e. forecasted) quantities and actual (i.e. consumption) quantities (outlined in blue) at each week in time. For instance, the second row represents the situation at the start of week 28, showing the consumed quantity in week 27, and the planned quantities from week 28 onwards. Both the planned and actual quantities are considered from a 'safety time off' perspective, meaning the actual consumption date and actual needed date were taken into account.

| | 1927 | 1928 | 1929 | 1930 | 1931 | 1932 | 1933 | 1934 | 1935 | 1936 | 1937 | 1938 | 1939 | 1940 | 1941 | 1942 | 1943 | 1944 | 1945 | 1946 | 1947 | 1948 | 1949 | 1950 | 1951 | 1952 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1927 | 1 | 1 | 2 | 3 | 1 | 7 | 3 | 3 | 4 | 3 | 2 | 1 | 1 | 2 | 3 | 1 | 1 | 1 | 3 | 4 | 1 | 2 | 3 | 0 | 0 | 3 |
| 1928 | 1 | 1 | 2 | 2 | 1 | 7 | 3 | 3 | 4 | 3 | 2 | 1 | 1 | 0 | 3 | 1 | 2 | 1 | 4 | 4 | 1 | 1 | 3 | 2 | 2 | 5 |
| 1929 | 1 | 1 | 2 | 3 | 3 | 5 | 3 | 3 | 4 | 3 | 2 | 1 | 1 | 0 | 3 | 1 | 2 | 1 | 4 | 4 | 1 | 1 | 3 | 3 | 2 | 3 |
| 1930 | 1 | 1 | 2 | 2 | 1 | 7 | 3 | 3 | 4 | 3 | 2 | 1 | 1 | 0 | 3 | 1 | 2 | 1 | 4 | 4 | 1 | 1 | 3 | 3 | 2 | 3 |
| 1931 | 1 | 1 | 2 | 0 | 1 | 9 | 3 | 1 | 4 | 2 | 1 | 1 | 1 | 5 | 0 | 3 | 2 | 3 | 3 | 1 | 1 | 1 | 3 | 3 | 1 | 2 |
| 1932 | 1 | 1 | 2 | 0 | 2 | 9 | 4 | 1 | 4 | 2 | 1 | 1 | 1 | 5 | 0 | 2 | 2 | 3 | 3 | 1 | 1 | 1 | 5 | 4 | 1 | 4 |
| 1933 | 1 | 1 | 2 | 0 | 2 | 6 | 2 | 1 | 8 | 2 | 1 | 2 | 2 | 3 | 0 | 1 | 2 | 3 | 3 | 1 | 1 | 4 | 0 | 6 | 1 | 3 |
| 1934 | 1 | 1 | 2 | 0 | 2 | 6 | 2 | 3 | 6 | 0 | 4 | 0 | 3 | 1 | 2 | 0 | 2 | 4 | 1 | 3 | 1 | 4 | 0 | 4 | 0 | 4 |
| 1935 | 1 | 1 | 2 | 0 | 2 | 6 | 2 | 0 | 8 | 1 | 4 | 0 | 3 | 1 | 2 | 0 | 2 | 3 | 3 | 3 | 1 | 4 | 0 | 4 | 0 | 3 |
| 1936 | 1 | 1 | 2 | 0 | 2 | 6 | 2 | 0 | 9 | 0 | 2 | 2 | 3 | 0 | 2 | 0 | 2 | 3 | 2 | 2 | 1 | 4 | 1 | 4 | 0 | 3 |
| 1937 | 1 | 1 | 2 | 0 | 2 | 6 | 2 | 0 | 9 | 1 | 0 | 2 | 3 | 1 | 4 | 0 | 0 | 3 | 2 | 2 | 0 | 4 | 1 | 3 | 0 | 4 |
| 1938 | 1 | 1 | 2 | 0 | 2 | 6 | 2 | 0 | 9 | 1 | 0 | 2 | 3 | 1 | 4 | 0 | 0 | 3 | 2 | 2 | 0 | 4 | 1 | 0 | 0 | 6 |
| 1939 | 1 | 1 | 2 | 0 | 2 | 6 | 2 | 0 | 9 | 1 | 0 | 2 | 3 | 1 | 4 | 2 | 0 | 1 | 2 | 2 | 0 | 4 | 1 | 0 | 0 | 6 |
| 1940 | 1 | 1 | 2 | 0 | 2 | 6 | 2 | 0 | 9 | 1 | 0 | 2 | 3 | 1 | 2 | 2 | 2 | 1 | 2 | 2 | 0 | 3 | 0 | 0 | 0 | 6 |
| 1941 | 1 | 1 | 2 | 0 | 2 | 6 | 2 | 0 | 9 | 1 | 0 | 2 | 3 | 1 | 2 | 2 | 3 | 0 | 2 | 2 | 0 | 0 | 3 | 0 | 2 | 4 |
| 1942 | 1 | 1 | 2 | 0 | 2 | 6 | 2 | 0 | 9 | 1 | 0 | 2 | 3 | 1 | 2 | 2 | 1 | 3 | 1 | 2 | 0 | 0 | 3 | 0 | 2 | 4 |
| 1943 | 1 | 1 | 2 | 0 | 2 | 6 | 2 | 0 | 9 | 1 | 0 | 2 | 3 | 1 | 2 | 2 | 1 | 2 | 2 | 5 | 0 | 0 | 0 | 2 | 2 | 4 |
| 1944 | 1 | 1 | 2 | 0 | 2 | 6 | 2 | 0 | 9 | 1 | 0 | 2 | 3 | 1 | 2 | 2 | 1 | 1 | 2 | 5 | 0 | 0 | 0 | 0 | 2 | 3 |
| 1945 | 1 | 1 | 2 | 0 | 2 | 6 | 2 | 0 | 9 | 1 | 0 | 2 | 3 | 1 | 2 | 2 | 1 | 2 | 2 | 3 | 2 | 0 | 0 | 2 | 2 | 2 |
| 1946 | 1 | 1 | 2 | 0 | 2 | 6 | 2 | 0 | 9 | 1 | 0 | 2 | 3 | 1 | 2 | 2 | 1 | 2 | 2 | 0 | 0 | 3 | 2 | 2 | 2 | 4 |
| 1947 | 1 | 1 | 2 | 0 | 2 | 6 | 2 | 0 | 9 | 1 | 0 | 2 | 3 | 1 | 2 | 2 | 1 | 2 | 2 | 0 | 0 | 3 | 0 | 2 | 4 | 4 |
| 1948 | 1 | 1 | 2 | 0 | 2 | 6 | 2 | 0 | 9 | 1 | 0 | 2 | 3 | 1 | 2 | 2 | 1 | 2 | 2 | 0 | 3 | 0 | 1 | 2 | 2 | 3 |
| 1949 | 1 | 1 | 2 | 0 | 2 | 6 | 2 | 0 | 9 | 1 | 0 | 2 | 3 | 1 | 2 | 2 | 1 | 2 | 2 | 0 | 3 | 0 | 1 | 2 | 2 | 2 |
| 1950 | 1 | 1 | 2 | 0 | 2 | 6 | 2 | 0 | 9 | 1 | 0 | 2 | 3 | 1 | 2 | 2 | 1 | 2 | 2 | 0 | 3 | 0 | 1 | 0 | 0 | 5 |
| 1951 | 1 | 1 | 2 | 0 | 2 | 6 | 2 | 0 | 9 | 1 | 0 | 2 | 3 | 1 | 2 | 2 | 1 | 2 | 2 | 0 | 3 | 0 | 1 | 0 | 0 | 5 |
| 1952 | 1 | 1 | 2 | 0 | 2 | 6 | 2 | 0 | 9 | 1 | 0 | 2 | 3 | 1 | 2 | 2 | 1 | 2 | 2 | 0 | 3 | 0 | 1 | 0 | 3 | 0 |
| 1953 | 1 | 1 | 2 | 0 | 2 | 6 | 2 | 0 | 9 | 1 | 0 | 2 | 3 | 1 | 2 | 2 | 1 | 2 | 2 | 0 | 3 | 0 | 1 | 0 | 3 | 0 |

*Figure 12: Planning matrix for a buy-part*

Before discussing the results gathered from these matrices, two scope levels are defined based on the characteristics of the 22,837 buy parts. Figure 13 shows the distribution of volumes of these parts (in pieces per month), measured over 2019.

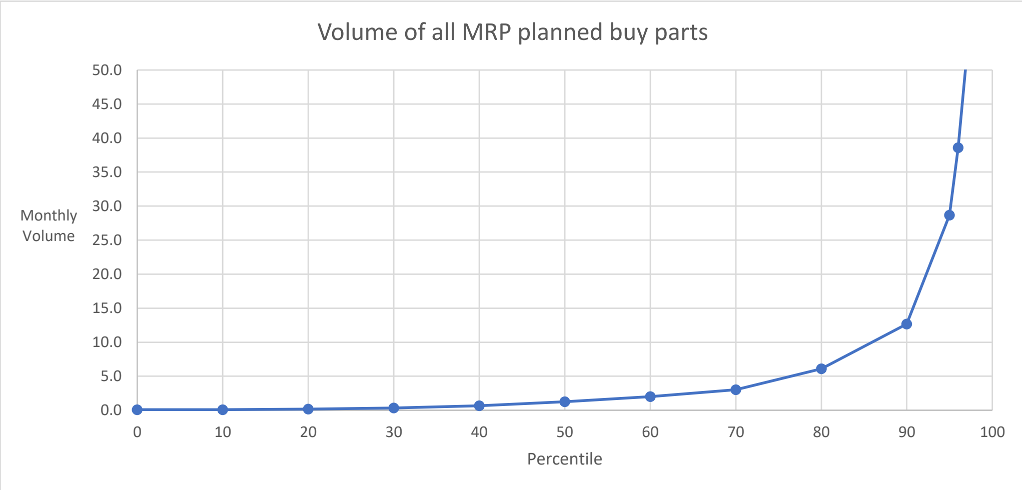



*Figure 13: Volume distribution of buy parts in a low volume end market*

It can be seen that 60 % of parts has a monthly volume of less than or equal to 2.0 per month, 80 % of parts has a volume of less than or equal to 6.1 per month, and there is a steep increase in volume in the highest percentiles. The majority of parts, the first 60 % in the percentile plot, only make up 2 % of total consumption volume (in pieces per year). The parts in the top percentile are mostly commodity parts such as gaskets, washers and screws. Table 11 further describes the characteristics of the parts within the different percentiles.

| Volume (monthly) | Volume (yearly) | Percentile | Value (mean) | Value (median) | CV (mean) | CV (median) |
|---|---|---|---|---|---|---|
| 0.08-2.0 | 1 - 24 | 0 - 60 | 10441.86 | 361.80 | 5.11 | 5.05 |
| 2.01-6.1 | 25 - 73 | 60 - 80 | 7469.48 | 411.12 | 2.18 | 1.47 |
| 6.11-12.7 | 74 - 152 | 80 - 90 | 1703.09 | 84.27 | 1.55 | 0.86 |
| 12.8-29 | 153 - 344 | 90 - 95 | 685.48 | 26.22 | 1.81 | 1.19 |
| 30-148 | 345 - 1782 | 95 - 99 | 140.93 | 8.10 | 1.86 | 1.30 |
| 149-125,573 | 1783 - 1,506,873 | 99 - 100 | 20.90 | 1.57 | 1.97 | 1.50 |

*Table 11: Characteristics of parts within the different volume percentiles*

The coefficient of variation (CV), is defined as the standard deviation of actual demand divided by the mean actual demand. It can be seen that the parts with the lowest volumes have a high coefficient of variation of weekly consumption, which reflects their sporadic nature. Furthermore, the parts within the 90th to 100th percentile have a relatively low median price. Given this, the parts within the 60th – 90th percentile will be analyzed separately, as it is expected that due to the different nature of the parts within the other percentiles (highly sporadic, or very low value), the way of planning and forecast accuracy will be very different. Table 12 shows the two scope levels defined for the further analyses.

| Scope Level | Parts | Description |
|---|---|---|
| 1 | 22837 | All MRP planned buy parts with consumption >0 in second half year of 2019 |
| 2 | 5887 | Subset of scope level 1, including all those parts within the $60^{th}$ – $90^{th}$ volume percentile |

*Table 12: Scope levels for buy part demand uncertainty analysis*

Uncertainty or variability in demand can be measured by standard deviation or variance of forecast errors (APICS, 2010). The standard deviation of actual demand was already included in the calculation of the CV of each part in table 11. The CV represents the standard deviation relative to the mean, which allows for a better comparison between parts.

This section will further discuss results generated from the planning matrices regarding the planning (forecast) accuracy of demand. The focus will be on demand in 5-weekly buckets, including within-period deviations, discussed below. The 5-weekly bucket was chosen to match the horizon on which orders become firm, meaning they do not change anymore unless manually rescheduled. Also, ASML most actively manages projected shortages of demand in the 5-week horizon. In the 26 weeks of data there are 22 five-weekly periods where the planned quantity at the beginning of the period could be compared to the actual consumed quantity for the period.

**Forecast bias**

Forecast bias is defined as the tendency of a forecast to systematically miss the actual demand (APICS Dictionary). To map this tendency for ASML buy part demand, for each part the bias was defined as the difference between the average planned quantity and the average consumed quantity for the 5-weekly period:

$$Bias = Average\ Planned\ Quantity - Average\ consumed\ quantity$$

Subsequently, in table 13 it can be seen that around half of the parts in scope level 1 had a negative bias (underplanned on average) and half of the parts had a positive bias (overplanned on average). Looking at scope level 2 outcomes, approximately 19 % of parts had a negative bias (underplanned on average) and 81 % of parts had a positive bias (overplanned on average). The overplanning on average on materials in the level 2 scope can be explained by the buffers incorporated in the MPS. The Supply Chain Planning department hedges against uncertainty by overstating end-item requirements, or requesting end-items earlier, which evidently translates into a positive forecast bias of requirements on the 5-week horizon for the 'regular' parts that are needed for these end-items, i.e. the scope level 2 parts.

| **Scope Level 1 Outcomes** | **Parts** | |
|---|---|---|
| Negative Bias (underplanned) | 11516 | 50.4% |
| Positive Bias (overplanned) | 10692 | 46.8% |
| No Bias | 629 | 2.8% |

| **Scope Level 2 Outcomes** | **Parts** | |
|---|---|---|
| Negative Bias (underplanned) | **1100** | 18.7% |
| Positive Bias (overplanned) | **4744** | 80.6% |
| No Bias | **43** | 0.7% |

*Table 13: Planning bias for parts in both scope levels*

Also, if we strictly consider all the 5-weekly periods that were measured for all parts, it was found that in more periods demand was overstated than understated, as shown in table 13. It further shows that for scope level 1, 43 % of periods were planned exactly right. This can be explained by the fact that in this scope there are many parts with sporadic demand which have a high number of periods with zero planned and actual demand. For scope level 2, it can be seen that in almost two-thirds of the measured periods demand was overplanned, and in approximately 17 % of the periods demand turned out to be understated.

| Scope Level 1 Outcomes | Periods | |
|---|---|---|
| Underplanned (Planned < Actual) | 112395 | 22.4% |
| Overplanned (Planned > Actual) | 171735 | 34.2% |
| Planned = Actual | 218284 | 43.4% |

| Scope Level 2 Outcomes | Periods | |
|---|---|---|
| Underplanned (Planned < Actual) | 21465 | 16.6% |
| Overplanned (Planned > Actual) | 85374 | 65.9% |
| Planned = Actual | 22675 | 17.5% |

*Table 14: Planning bias based on all observed periods in both scope levels*

### Forecast accuracy

The previous results show that for most parts and periods in scope level 2, demand tends to be overstated. To see the magnitude of this over- or understatement, the mean percentage error (MPE) was calculated for each part in the level 2 scope. The MPE of a buy-part represents the mean relative error of the forecast over the 22 periods:

$$Mean\ Percentage\ Error = \frac{1}{22}\sum_{t=1}^{22}\frac{Actual_t - Planned_t}{Actual_t} * 100\%$$

Note that the error is the actual quantity minus the planned quantity, opposite to the bias. Next to that, only level 2 parts were taken into account for this part of the analysis, because this relative measure compares the error to the actual 5-weekly quantity, which is very frequently 0 for the parts in level 1 scope, in which case the MPE is undefined. In the data of the parts in level 2 scope there were some 5-weekly periods with 0 actual demand, for these periods instead of 0, the average of all 5-weekly periods of the respective part was taken for the respective period t.

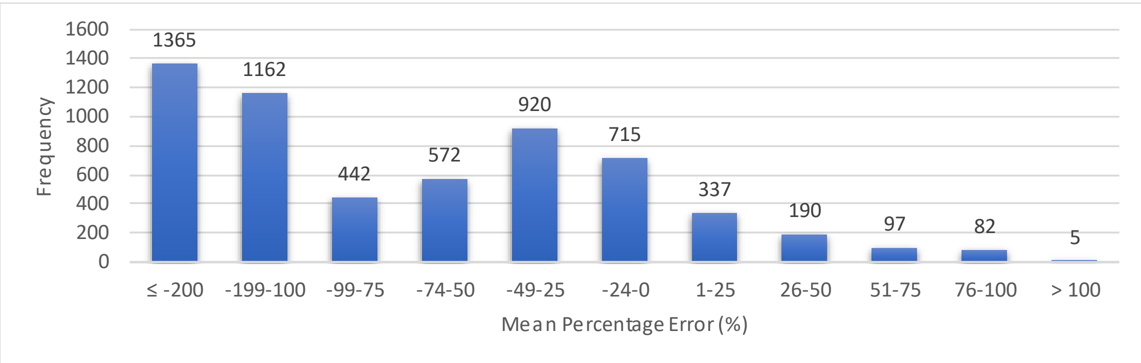



*Figure 14: Histogram MPE all scope level 2 parts*

Figure 14 shows that for 2527 (1365 + 1162) parts (43 %), the 5-weekly demand is significantly overforecasted, as all of these parts have an average period error of ≤ - 100 %, and more than half of those even - 200 %. Furthermore, 711 parts (12 %) have a positive average period error, for which in almost half of the cases (337 parts), the average error is between 1 and 25 %.

The parts in this analysis were also categorized as X, Y, or Z parts, based on their coefficient of variation (CV) of weekly actual consumption. The XYZ classification distinguishes between items according to their fluctuations in consumption, where X parts represent more constant consumption, Y parts represent stronger fluctuations in consumption, and Z parts represent completely irregular consumption (Scholz-Reiter, Heger, Meinecke, & Bergmann, 2012). ASML uses the following thresholds for categorization, which were also used in this analysis:

- X parts: $CV < 0.75$
- Y parts: $0.75 \leq CV < 1.50$
- Z parts: $CV \geq 1.50$

Using this categorization, a separate MPE histogram was made for X, Y, and Z parts in level 2 scope. The tables are shown in Appendix F. From these separate histograms it was found that the parts with a high negative MPE are almost all Y and Z parts. For X parts, the MPE is clearly more centered around the - 49 to - 25 % bin. Also, the parts with a positive MPE are mostly Y and Z parts, meaning that parts which are underplanned on the 5-week horizon on average, are mostly parts with sporadic natural demand.

**Within-period deviations**

From the previous sections is was found that on average for most parts in most periods the demand planned on the 5-weekly horizon was higher than what was actually needed. However, there are also periods where the demand that was actually needed was higher than what was planned, in which case expediting must have occurred to realize this additional demand on the 5-week horizon, in case no safety stock buffer was present. Next to that, the demand specified for the short, 5-week horizon fluctuates on a weekly basis. Although the demand usually ends up being less, during the period the demand specified for the given 5 weeks might have gone up temporarily, which also triggers expediting, as illustrated next.

| | 1927 | 1928 | 1929 | 1930 | 1931 | |
|---|---|---|---|---|---|---|
| 1927 | 1 | 1 | 2 | 3 | 1 | **8** |
| 1928 | 1 | 1 | 2 | 2 | 1 | **7** |
| 1929 | 1 | 1 | 2 | 3 | 3 | **10** |
| 1930 | 1 | 1 | 2 | 2 | 1 | **7** |
| 1931 | 1 | 1 | 2 | 0 | 1 | **5** |
| 1932 | 1 | 1 | 2 | 0 | 2 | **6** |

*Figure 15: Fluctuations in demand on 5-week horizon*

In figure 15, the first few weeks of the example planning matrix of figure 12 are shown. It shows the 5-weekly quantity specified for the first period of the measurement, i.e. weeks 27 – 31 of 2019, after 0, 1, 2, 3, 4 and 5 weeks have passed. Initially, at the start of week 27 when all quantities were still planned quantities, a quantity of 8 was specified. At the start of week 29, the quantity specified for the period went up to 10. Eventually it ended up being 6, as shown by all the actual quantities specified at the start of week 32. The increase to 10 in week 29 shows the problem of nervousness. Assuming that at the start of the period, start week 27, the planner (the OSC) and the supplier ensured the incoming supply (purchase orders) perfectly matched the demand on the 5-week horizon, they would have run into a problem at the start of week 29. At this moment in time there was more demand than supply for the period, and the planner would have needed to expedite. One week later, the short-term demand has changed again, and looking backward, the expediting was not necessary.

From the example it can therefore be seen that such a positive deviation, i.e. increased demand compared to quantity specified at the start of the period, leads to expediting. Even though for most parts the actual quantity required ends up lower than planned at the start of the period, as shown by the MPE graph, often a positive deviation has occurred within that period, which will have caused reschedule-in messages. For 78 % of parts in the level 2 scope, a positive deviation was measured in 5 or more of the 22 periods (see also figures 24 until 27 in Appendix F). The median for all scope level 2 parts was between 7 – 8 periods out of the 22, indicating that for half of the parts, the chance of a positive deviation in any given period was over one-third. It should also be mentioned that the height of the positive deviation determines for how many supply orders a reschedule-in message will be generated.

## 5.4 Analysis of shortages

Now that two decoupling solutions and uncertainty in demand have been discussed, the aim of this section is to investigate how the solutions might reduce the weekly shortage list. As mentioned, ASML most actively manages projected material shortages in the internal communication tool Fiori. The tool contained approximately 14.000 shortage lines at the beginning of every week in weeks 33 – 52 of 2019, for which communication is required between the planner and the internal demand owner, and the planner and the supplier. All these shortages are mismatches in supply and demand on the 5-week horizon, where the slip $\geq$ 6 calendar days, and the shortage cannot be solved by safety stock, as explained in Chapter 2.3. There are, however, some additional important characteristics of shortage lines to address in order to determine the possible impact of decoupling solutions. Next to a matched demand and supply element, material number, slip, and corresponding quantity, shortage lines contain the following relevant characteristics on which they can be distinguished: shortage type, plant, demand in the past, (un)specified corresponding vendor, and the monthly volume of the shortage material.

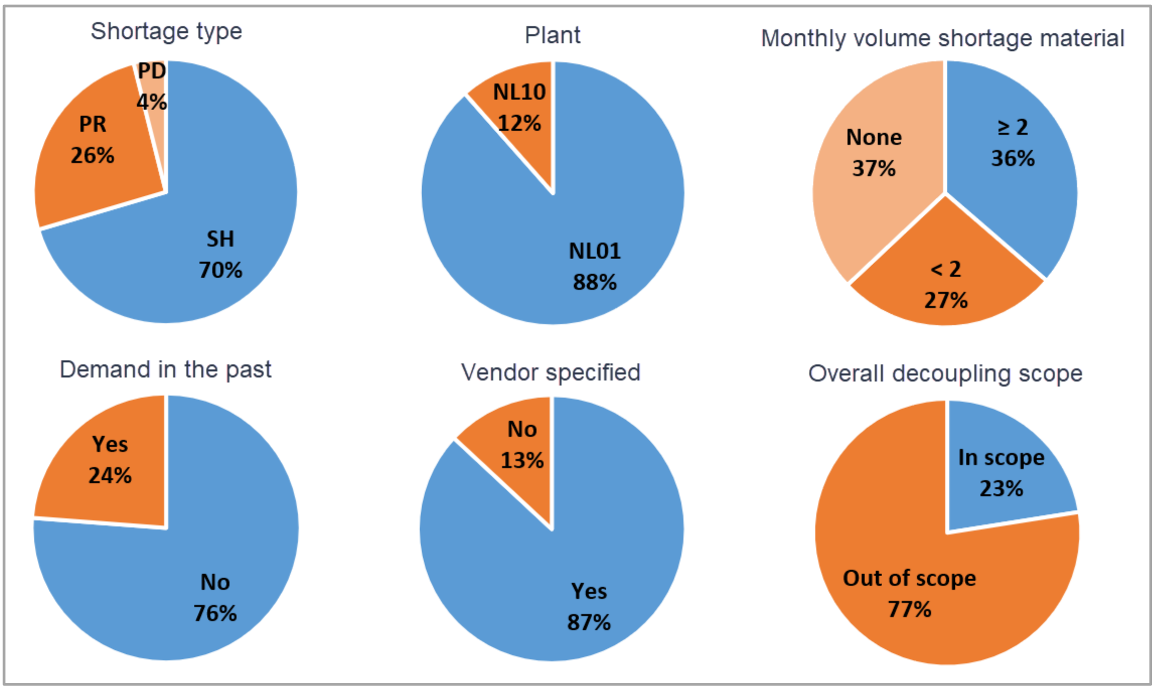



*Figure 16: Different breakdowns of weekly shortage list*

In figure 16, different breakdowns are shown of the shortage list based on each of these characteristics (based on data from the last 5 weeks of 2019). For instance, the pie chart at the top left divides the approximately 14.000 shortage lines based on shortage type, whereas the pie chart beneath it divides the 14.000 lines based on whether the demand date is in the past. When a shortage line satisfies each of the values in blue, they are considered to be part of the scope for decoupling, which is in total 23 %, as shown in the pie chart at the bottom right. This percentage is higher than the product of all the percentages in blue, because the division is not proportional when any of the criteria has already been applied. For instance, shortage lines with demand in the past contain relatively more materials with no consumption data. Hence, after 'filtering out' shortage lines with demand in the past, already relatively more shortage lines with materials with no consumption have been excluded as well. Thus, after applying all the values in blue in figure 16 as a filter of shortage lines simultaneously, 23 % of the total was left. In the next sections, the reasoning behind why shortage lines having the values in blue are considered for decoupling will be explained.

**Shortage type**

Out of the 14.000 shortage lines, approximately 70 % is SH, 26 % is PR, and 4 % is PD, where PR means that the supply element is an unreleased purchase order, PD means the supply element is in the past, and SH is a 'regular' shortage. In case of a PR shortage line type, the supply element may be in time to match demand but it is still regarded as a shortage because the order is not yet firm. In case of a PD shortage line type, the supply should have already been received but this is not yet registered as such, this could happen in case of an inbound stagnation. It can be seen that PR and PD shortage line types are caused by processes that are not directly plan related, as opposed to the SH shortage types, where the supply element is a released order, foreseen to arrive on a future date, but too late to match the demand element. Hence the decoupling solutions mainly target SH lines, and different solutions approaches should be entailed for PR and PD shortage lines.

**Demand date (factory need date) in the past**

For approximately 24 % of the 14.000 lines the demand date without safety time (i.e. the actual, ultimate factory need date), is in the past. This is regarded as a demand integrity issue. For such shortage lines, different solutions than decoupling solutions should be entailed.

**Plant**

Shortage lines in the communication tool can be of the NL01 plant (88 %), ASML's main plant, or they can be of NL10 (12 %), ASML's service plant. In both cases the planner from OSM is generally the supply responsible. However, the supply element of shortages on the NL10 plant is in most cases provided by NL01, ASML's main plant. In the remainder of cases the supply concerns repair purchase orders. Expediting that happens on intra-company orders and repair orders are not the target of decoupling solutions, hence the main focus will be on the shortages of the main, NL01, plant. This is also in line with the demand analysis, which was only conducted for the planning on the main, NL01 plant.

**Vendor (un)specified**

Approximately 13 % of shortage lines do not have an associated vendor of the material. The underlying issue for these lines could be an ongoing engineering change or the material could be 'end-of-life'. Naturally, decoupling solutions will not be effective to reduce these type of shortage lines.

**Monthly volume shortage material**

Approximately 37 % of the 14.000 shortage lines had a material which showed no consumption data in the past half year. Additionally, 27 % of the shortage lines had a material with a volume of less than 2 pieces per month based on the past year. Hence, only 36 % of shortage lines in the list have a material with a consumption of at least 2 pieces per month over the last year. These high fractions of shortage lines with materials with no volume or relatively low volume indicate that a significant portion of parts in the shortage list are 'stranger' parts, which cannot be reduced effectively by placing strategic inventory. These parts are often service parts which had not been required for a long time, or new parts which had not been purchased before. Also, for the lines with materials with no monthly volume (i.e. no consumption data), for over one-third of the lines the demand date is in the past, which is higher than the percentage of demand in the past for the overall shortage lines. This indicates that on these parts with no consumption data, more data integrity issues are present.

**Overall decoupling scope**

Now, taking the cross-section of shortages where the shortage type is SH, the demand date is not in the past, there is a vendor associated to the supply element, and the corresponding plant is NL01, approximately half of the 14.000 shortage lines remain at the start of every week (measured over weeks 33 – 52 of 2019). Therefore, a significant portion of the shortage list could be reduced by improvements other than decoupling solutions. Furthermore, combining the criteria of a volume of at least 2 pieces per month with the former set of criteria (shortage type is SH, demand date is not in the past, vendor associated with supply element, corresponding plant is NL01), then only around **23 % of shortage lines are left** (based on data of the last 5 weeks of 2019).

It was already found through the survey in Chapter 4, that planners find only 20 % of shortage lines for which they are responsible relevant. Reasons given for this by planners were demand integrity (i.e. a lot of shortage lines have a due date in the past which should not be in the system anymore), supply elements which are represented by a non-confirmed purchase requisition, and manual reservations of materials, which they often challenge. The breakdown of the different types of shortage confirmed that a large portion of shortage lines contains demand elements in the past and unconfirmed purchase requisitions. Additionally, a reason given by planners why some shortages are not relevant, is that many demand elements are still a forecast (i.e. no actual production workorders have been opened for these demand elements) and planners judge, based on experience, that in such cases demand is most likely being overstated and therefore irrelevant.

This overstating of demand was confirmed in the demand analysis of section 5.3.

Therefore, planners are mainly focused on a smaller subset of shortages and accompanying rescheduling messages for which rescheduling actions are actually required. For this subset, an analysis was done of the division of A, B, and C class parts, a classification used in inventory management to rank-order parts according to the annual value spent on each (Hopp & Spearman, 2011). The division is made according to a pareto principle as follows (Hopp & Spearman, 2011):

**A parts**: the first 5 – 10 % of parts, accounting for 75 – 80 % of total annual expenditures
**B parts**: the next 10 – 15 % of parts, account for 10 – 15 % of total annual expenditures
**C parts**: the bottom 80 % of parts, accounting for only 10 % of total annual expenditures

ASML also employs an ABC classification based on similar principles. The division of A, B and C parts is shown in the left column of table 15. It can be seen that a distinction is made for A parts, dividing them in A1 and A2 parts, based on the standard cost price. The A1 parts are expensive materials whereas A2 parts are less expensive but high volume, hence their annual expenditures are also high. The analysis of relevant shortages showed that there is a significant difference in the division of A, B and C parts in the shortage list. Although A parts make up only 6 % of the total purchased parts, they are responsible for almost 50 % of the relevant shortage lines. However, most of these A parts are A2 parts with a higher volume and lower value than A1 parts. Only 14 % of total shortage lines contain A1 parts which are typically tens to hundreds of times higher in value than the rest of the parts in the shortage list, and make up for the majority of annual expenditures. These parts are often vital parts of a complex module such as mirror blocks, responsible for holding and positioning the wafer in the waferstage module. It can be seen that planners might be more challenged and find it more meaningful to make efforts for resolving shortages for these parts compared to the other types of parts. If the amount of shortages for A2, B, and C parts can be reduced by placing strategic inventory (which is also relatively cheaper for these part types), then planners can spend more time focusing on the underlying issues for the A1 parts that are generally more significant and challenging. The two solutions described earlier can be used to do so, but there are many important aspects to take into account to optimally apply them, these aspects will be discussed in the next section.

| **All buy-parts** | | **Relevant shortage lines (decoupling scope)** | | |
|---|---|---|---|---|
| ABC Classification | | ABC Classification | | Median value |
| **A1** | 3 % | **A1** | 14 % | 50,724 |
| **A2** | 3 % | **A2** | 36 % | 1,666 |
| **B** | 11 % | **B** | 25 % | 616 |
| **C** | 83 % | **C** | 25 % | 88 |

*Table 15: ABC classification*

## 5.5 Criteria for applying decoupling solutions

First of all, the parts under consideration for decoupling solutions concern all MRP-planned buy parts, given that all those parts are subject to nervousness, i.e. frequent rescheduling. Out of scope are therefore buy-parts which are planned by traditional replenishment systems, i.e. reorder point planning. This is the recommended way of planning for low-value, common-use items such as washers, bolts and nuts, as for those items the cost of precise physical control is likely to be prohibitive in view of the low carrying cost (Silver et al., 2016). ASML uses this way of planning for these parts, however, it should be noted that in the data analysis of MRP planned buy parts also some of these low-value, common-use items with high volumes were seen.

Regarding all the remaining MRP-planned buy-parts, around 22.000 in the second half year of 2019, it was seen that the parts with a 'regular' volume between 2.0 and 13.0 per month, are mostly overplanned on average, considering the quantity for the 5-week horizon. However, it was also seen that within the 5-week horizon, the demand regularly fluctuates in a positive way, i.e. an increase in the planned quantity occurs, currently leading to rescheduling messages. The objective of the decoupling solution is to create stability in the plan by having a buffer in place which allows fluctuations to happen without triggering expediting. Therefore, it is recommended to implement the solution such that most stability can be gained in the most cost-efficient way. However, it is beyond the scope of this research to model and optimize the buffer decision for each part. Instead, the different aspects and criteria to take into account are given, as well as a comparison of both solutions.

**Performance indicators and tradeoffs**

Both solutions are a type of stock buffer with the objective of improving the stability of the planning of the part in a cost efficient way. When considering to implement the solution for a part, there is always a tradeoff in performance indicators affected by the solution. This concerns the reduction of nervousness and rescheduling messages/projected shortages on the one hand (which is the initial reason for considering a solution) against the increased holding cost on the other hand. Next to that, the implementation of either solution will have an effect on the planner's time spent on rescheduling, and their overall job characteristics and job outcomes, discussed extensively in this research. In the next chapter, it will be further investigated how both solutions affect the job characteristics and job outcomes of planners who have worked with them. Furthermore, the supplier benefits from a more stable demand signal / delivery schedule, potentially leading to cost reductions. Next to that, solutions affect the inventory turnover ratio of a part. This ratio is defined as the ratio of throughput to average inventory, and is commonly used measure the efficiency with which inventory is used (Hopp & Spearman, 2011). Finally, the implementation of a solution will affect material availability. If there was previously no form of stock buffer in place for the part, then clearly an improvement in material availability is expected.

**Parameters**

The decision on the parameter(s) of either solution is a complex decision. In literature, it is noted that the issue of buffer size has not been resolved (Guide Jr & Srivastava, 2000), and that the inability to decide on appropriate inventory levels is one of the reasons VMI has failed to become widely implemented (Kurbel, 2013). The best way to cope with this, is to focus on the uncertainty that should be covered by the buffer, which is also the approach in traditional replenishment systems (Silver et al., 2016), and in stocks kept for serial systems (Heisig, 2012).

**Variables of buy part to take into account**

There are many variables of a buy part to take into account when considering a solution to create stability in the plan. These variables are presented next. It was out of scope to determine the optimal buffering decision by creating a model that takes into account all these variables, but this research did provide important insights in one of the most difficult variables, the uncertainty in planned demand. This type of uncertainty represents the plan-related nervousness, as it quantitatively shows how volatile demand is on the short horizon, explaining the high amount of rescheduling messages that are generated in case no decoupling solution is in place.

*Uncertainty in planned demand*

The first variable, or characteristic, of the buy part to take into account is uncertainty. The amount of uncertainty, in terms of volatility of planned demand, determines how high the parameter should be set to reach the objective. For example, if there is high volatility in planned demand, then the level of the decoupling safety stock required to suppress reschedule-in messages on the short horizon will be higher as well. The script written for this research was used by ASML to determine the initial required decoupling safety stock levels to prevent reschedule-in messages based on the uncertainty in planned demand for the part. If considering SMI as a solution, the uncertainty in planned demand is also important to take into account, as the forecast shared with the supplier will be subject to this uncertainty.

*Uncertainty in actual demand (XYZ classification)*

The XYZ classification was already mentioned in the demand analysis section. It is a measure which is used to support the ABC analysis (discussed below), in the classification of inventory (Scholz-Reiter et al., 2012). XYZ classification distinguishes between items according to their fluctuations in consumption, where X items have a constant consumption and fluctuations are rather rare, Y items have stronger fluctuations in consumption, and Z items have a completely irregular consumption (Scholz-Reiter et al., 2012). For both solutions this type of uncertainty should also be considered, as it can be seen that for X items inventory with a steady consumption will be more efficient than for Z items with sporadic consumption. Next to that, the difference in consumption stability (which the XYZ classification indicates), is related to the uncertainty in planned demand, as it was seen that the overstatement of demand for X parts was generally not as high as the overstatement for Y and Z parts.

*Lead time*

In classical replenishment systems where inventory is managed independently, typically the uncertainty within the replenishment lead time is considered for determining stock levels (Silver et al., 2016). With both decoupling solutions, requirements (i.e. planned demands) are still dependent as they are generated with MRP. Therefore, the uncertainty in both planned demand as well as actual demand within the lead time should be taken into account in the parameter setting. The solutions were principally designed to allow for a more stable flow of materials on the short horizon, as on this horizon rescheduling messages and shortages are managed most actively by planners and suppliers. However, if the cost of inventory is relatively low and the efficiency of inventory is relatively high, then it might be viable to set higher parameters of the solution to create stability for a larger portion or the entirety of the lead time.

*Standard cost price*

The price of the material needs to be taken into account. If for two different materials a similar amount of stock was found to be required to significantly reduce the nervousness on the short horizon, then for the more expensive part the increased holding costs will be higher than for the cheaper part. This means that the solutions in most cases will be more appropriate for relatively cheaper materials.

*Volume*

The consumption volume of the part under consideration will impact the performance indicator of inventory efficiency. The average inventory will rise with the implementation of the solution, hence the turnover ratio, which depends on the volume of the part, can be used to determine the efficiency of the inventory. Furthermore, VMI has proven to be efficient for items with a high consumption amount (Ivanov, Tsipoulanidis, Schönberger, et al., 2017). Additionally, for items with high volume in terms of product size, additional restrictions could be set.

*ABC classification*

The ABC classification is a commonly used measure in inventory management to rank-order parts according to the annual value spent on each (Hopp & Spearman, 2011). The ABC classification takes into account the consumption of the past year, multiplied by the standard cost price. Hence, it can be used in conjunction with the other variables to determine the right focus.

*Lot size*

The lot size in which the part is delivered is important to consider as larger lot sizes reduce the number of orders but also increase inventory. ASML has defined lot sizes based on the ABC profile of a part. These should be taken into consideration in the determination of parameters (i.e. buffering levels) of the decoupling solutions.

*Obsolescence risk*

The obsolesce risk of a part needs to be taken into account when considering a buffering solution. If the part is near the end of its lifetime, it is not recommended to apply a buffering solution. Also, the obsolesce risks needs to be taken into account when the solution is already in place for a part. For instance, if an engineering change is foreseen, then the buffer of the current version of the part should be gradually decreased.

*Supplier capabilities*

Lastly, the capabilities of the supplier should be taken into account. This mainly applies for parts considered for SMI, given that the supplier takes over the responsibility of the inventory with this solution. Essentially the supplier becomes responsible for appropriately using the buffer to create stability in their deliveries under conditions of uncertainty in planned and actual demand. This is also the main difference with the decoupling safety stock solution. Furthermore, trust in the partner is the most cited success factor in VMI case studies, due to the high information exchange implied by the solution (Marquès, Thierry, Lamothe, & Gourc, 2010). Therefore, implementation is easier in case of established existing collaborations with the supplier (Marquès et al., 2010).

**Comparison**

Both solutions use a buffer with a certain bandwidth to absorb uncertainty in the material plan. The main difference is in the operation, as for SMI the demand signal shared still contains the volatility, but the supplier has the opportunity to use the entire bandwidth of the buffer (between the Min/Max) to stabilize their production and delivery processes. The main requirement for this is that the supplier has the capability and can take the responsibility of handling the demand and inventory in a good manner. In the case of the Decoupling Safety Stock, the demand signal is already less nervous, with no, or significantly less rescheduling requests on the short horizon. This means that the buffer is effectively used to absorb the demand variability and provide more stability in the orders towards suppliers. However, the supplier is still 'tied' to these orders (supplier delivery performance is judged by timely delivery of orders), hence the decoupling safety stock buffer cannot be used to cover against supply uncertainty. Therefore, the SMI solution allows for more flexibility for suppliers, as they can use the solution for demand as well as supply uncertainty, but this will also require an increased effort and responsibility for controlling the inventory.

## 5.6 Limitations and directions for future research

This research was aimed at investigating buffering solutions that could be used in MRP based material planning to reduce the problem of nervousness in terms of reducing rescheduling suggestions on orders, creating more stability in the plan and delivery of orders, and enhancing the job of the planner. The solutions provided by literature in this scope are very limited, as most academic research focuses on safety stock and safety lead time, which have their known shortcomings (Jacobs et al., 2011). The two SAP-based solutions presented in this chapter were therefore relatively new in this regard. However, there are some additional research directions which are worth investigating. One possible direction includes investigating dynamic safety stock in ERP, see for example: Saad, Perez, & Alvarado (2017). In this paper, a mechanism is described which facilitates the implementation of safety stocks that are recalculated through mathematical algorithms integrated in advanced SAP modules, based on the latest demand profile, forecast accuracy, and required service levels (Saad et al., 2017).

Another noteworthy solution which could fit the scope of a decoupling buffer that functions well with MRP based material planning, is Demand Driven MRP (DDMRP). DDMRP serves as a supply order generation engine that incorporates MRP functionality while explicitly addressing its known problems, including nervousness (Ptak & Smith, 2016). It aims to create independence in MRP based planning by introducing decoupling point buffers at selected positions in the bill of materials (Ptak & Smith, 2016). So far, a handful of studies have interpreted and applied DDMRP (not including case studies from the Demand Driven Institute, the organization associated with the published works on DDMRP). An overview of these studies is given in Appendix G which can be used as a reference for future research.

Finally, a limitation of this research is that no exact methodology was provided to determine optimal buffering levels for each of the buy parts under consideration. Future research is required for this, which can be based on the different aspects provided in this chapter.

## 5.7 Conclusion

The research question that corresponded to this chapter was: *Which decoupling solutions exist that can reduce nervousness?* To answer this question, the different ways of reducing nervousness provided in academic literature were provided, but it was found that research on buffering methods in MRP systems was mainly limited to safety stock and safety time. Subsequently, two SAP-based solutions were described in detail, explaining how they could work in a better way than traditional safety stock to reduce the problem of nervousness. Pilots of these solutions have been implemented by ASML during this research, and the remainder of the chapter focused on how exactly these buffers could work to reduce nervousness. To do so, an extensive analysis was given of nervousness, on the one hand focusing on the uncertainty of demand faced by parts on the short horizon, and on the other hand focusing on the characteristics of shortages.

The demand uncertainty analysis created the insight that most parts with a regular volume, between 2 and 13 pieces per month (60th to 90th percentile based on volume), were overplanned on the short, 5-week horizon. Demand for Y and Z parts was generally more significantly overstated compared to demand for X parts. The finding of overstated demand confirms the earlier reported notion of planners that many shortages are ignored because demand elements of shortage lines are judged as 'overforecasted'. They indicated that for these demands no actual work orders on the short horizon have been opened, hence the shortage in this case usually exists due to an overstatement in demand and is therefore ignored.

Although the consumed quantities usually tend to end up being lower than the planned quantity, it was also shown that the demand stated on the 5-week horizon was highly susceptible to an increase in quantity within this 5-week period, triggering rescheduling messages and projected shortages. The buffering solutions can be used to prevent the rescheduling requests and expediting that follow from these changes in demand, thereby creating more stability in the requested outstanding orders (in case of the decoupling safety stock solution) or allow more stable deliveries (in case of the SMI solution). It is not possible to have no physical buffer in place and ignore the increase in demand while still suppressing the reschedule-in message, because at the moment the demand increases on the short horizon, it cannot be known with certainty that it will decrease again.

The decoupling safety stock buffer creates more stability in the demand signal shared with the supplier, as rescheduling suggestions do not appear on orders as long as the decoupling stock can buffer against the demand fluctuations. With the SMI solution, the demand signal shared is still volatile, as it is based on the MRP plan. However, in this case the supplier can stabilize the deliveries of their orders by using the inventory which they control to buffer against any of the volatility in demand. Other differences with this solution are that it can also be used to buffer against uncertainty in supply, yielding additional flexibility, and that applying the solution depends on the supplier's capabilities of handling the control of inventory under these uncertainties.

The analysis of shortages provided an insight in the nature of the approximately 14.000 shortage lines, and the inherent rescheduling messages in the planning system, to which each shortage line corresponds. It was found that there are many other factors which are not directly related to shifts in the plan that contribute to the high amount of shortages (and thus rescheduling messages). Most remarkably, 26 % of the shortage lines contained a supply element which had not been released (i.e. a purchase requisition). This is most likely due to the overstated demand, as purchase requisitions are automatically generated by the planning system to match demand, but are not released by planners as they do not consider the demand valid. Furthermore, 24 % of shortage lines contained a demand element that was in the past. Next to that, for 37 % of parts in the shortage list, no historical consumption data was present, and an additional 27 % of parts did not have a volume of at least 2 pieces per month, showing that the shortage list contained a high amount of highly sporadic 'stranger' parts. This indicates that there are some planning issues with respect to new parts and sporadic service requirements. Therefore, there is an opportunity to reduce a large amount of the shortages and thus rescheduling messages by implementing solutions other than strategic buffers. For the remainder of shortages, which planners spend most of their time on, it was found that approximately 14 % of shortage lines contained high value A1 parts, and 86 % contained A2, B, and C parts, which are more applicable for both decoupling solutions.

Finally, all of the performance indicators affected by the decoupling safety stock and SMI solution were presented, such as holding cost but also the impact on the job of the planner. Also, the tradeoffs of these performance indicators and the operational differences between the two solutions were presented. Next to that, based on literature of inventory management, the variables of parts to take into account which influence these outcomes were presented. One of the most important variables, the uncertainty in planned demand, was already extensively explored in this research, and the script used to determine this uncertainty for each buy part has also already been applied by the organization to determine the initial levels of the decoupling safety stock. Overall, in combination with the insights in shortages and the directions for future research, this provided a basis for further implementation and optimization of decoupling solutions that had not been described before in literature as solutions for the problem of MRP nervousness.

# 6 Effect of decoupling solutions on the planning job

During the course of this study, pilots of the decoupling safety stock and SMI solution, described in the previous chapter, were implemented for some buy-materials. In this chapter, the effects of those solutions on the motivational job characteristics of the job characteristics model Hackman & Oldham (1976), and job outcomes will be described. The job characteristics and job outcomes are similar to the ones investigated to be affected by nervousness earlier in this research. Now, the aim is to see if the implementation of decoupling solutions which reduce nervousness in terms of significantly reduced rescheduling suggestions on orders, will contribute positively to the job characteristics and outcomes of planners. First, additional background of the implementation of the interventions is provided, then, hypotheses for the effects of the solutions on the planning job are given, subsequently, the interview method is described which was used to qualitatively test the hypotheses, and finally the results are presented and discussed.

## 6.1 Implementation of intervention

The first planner started working with Supplier Managed Inventory around November 2019, just after the quantitative survey on nervousness had been completed by the planners. This planner had around 6 months of experience with the solution at the time of the interview. The solution was implemented for the packaging materials for which they were responsible. Another planner worked with SMI as well for packaging materials, starting around the beginning of 2020, this planner had 4 months of experience with the solution at the time of the interview. A third and fourth planner started working with SMI around February 2020, having approximately 2 months of experience with the solution at the time of the interview. Both planners used the solution for components of B and C classification which had relatively high volume and relatively constant consumption.

For the decoupling stock solution, two planners started working with the solution around the second and third month of 2020, having around 1 to 2 months of experience with the solution at the time of the interview. One planner used the solution as a pilot for certain A parts, also in response to the wishes of the supplier of the part to have a more stable demand signal. The second planner used the solution for mostly high volume, B/C type of parts.

## 6.2 Hypotheses for decoupling solutions

The first solution that will be addressed, decoupling safety stock, is different from traditional safety stock in that it prevents any rescheduling messages in case fluctuations in demand can be absorbed by the buffer, as described in the previous chapter. Rescheduling messages in the lead time horizon will be prevented in the planning system, and therefore also not communicated towards suppliers, as long as the projected inventory on hand remains above 0. Hence, there will be less disturbances on orders for parts to which this solution is applied, giving more clarity to planners and suppliers.

With this solution, it is expected that planners have more autonomy in their work, because it allows them to be more free in how they schedule their work, for instance, because they will not need to constantly update the supplier on the severity of the rescheduling suggestions anymore. It is also expected that by implementing this solution, planners can focus on more important tasks, because for the parts to which the solution is applied, rescheduling suggestions only appear in actual exceptional cases. Skill variety is expected to improve, as the solution allows planners to spend more time on other tasks such as projects which are more likely to require various skills. Task identity, relating to doing a whole and identifiable piece of work, is expected to improve, as less shifting back and forth of orders is required for the materials under this solution. Given that the solution provides more clarity to planners and suppliers in terms of required purchase order due dates, the feedback that the job provides is expected to improve. Finally, given these positive expected effects of the solution, it is also expected that it will relate positively to the overall job satisfaction and commitment of the planner, and negatively to their turnover intention.

> *Hypothesis 4*: The decoupling safety stock solution will be positively related with (a) autonomy, (b) task significance, (c) skill variety, (d) task identity, (e) feedback, (f) job satisfaction, (g) job commitment, and (h) negatively related to turnover intention.

The second solution, SMI, allows planners to shift their focus from operationally managing incoming orders, to monitoring how the supplier performs in terms of managing inventory for parts under the SMI solution.

It is expected that this solution also improves the autonomy of planners in their work, again because they have more freedom in scheduling their work, instead of continuously communicating the importance of the updated requirements to the supplier. Similar to the decoupling stock solution, planners can now focus more on significant tasks, as rescheduling is only required in actual exceptional cases, i.e. when the stock falls below the minimum level. Skill variety and task identity are also expected to be positively affected by this solution, with the similar reasoning that due to less shifting back and forth of orders the task of the planner becomes a more wholesome task, and the planner will have more time to focus on other tasks that most likely require more varied skills. The feedback of their job is expected to improve, as this solution provides a clear insight in the material situation. Finally, due to these expected improvements in various aspects of the job, it is expected that the solution will positively relate to the planners' overall feelings of job satisfaction, commitment, and negatively relate to their turnover intention.

> *Hypothesis 5*: The SMI solution will be positively related with (a) autonomy, (b) task significance, (c) skill variety, (d) task identity, (e) feedback, (f) job satisfaction, (g) job commitment, and (h) negatively related to turnover intention.

## 6.3 Interview Method

The two pilot solutions were implemented for materials delivered by suppliers that are managed by 6 different planners. To gain insights in the effects of the decoupling solutions, interviews were set up with each of these planners. Ideally, if the solutions were fully implemented for all planners in the department where possible, then a repetition of the survey described in Chapter 4 would have given very relevant insights, as then it would have been possible to compare the levels of nervousness and job characteristics and outcomes in the situations before and after the complete intervention. However, given that the sample size is now relatively small, and the additional benefit of interviews is to gain more in-depth, qualitative insights in the experience of planners, the choice was made to conduct interviews to qualitatively investigate the effects of the decoupling solutions on the planning job.

**Interview design**

The interviews were set up as standardized interviews that included mainly open-ended questions, with additional follow-up questions asking respondents to score their answer on a scale. This allowed participants to fully express their viewpoints and experiences (Turner, 2010), which is required to get the most information about the experience of planners regarding decoupling solutions. Next to that, because the questions were structured and included additional scale indicators, they could be easily analyzed and compared.

**Procedure**

Planners were asked one week in advance if they wanted to participate in an interview via a Skype conversation about their experience regarding the intervention they had worked with in the past months, to which they all agreed. The interviews lasted approximately 20 minutes. At the start of the call, the purpose of the interview was explained, after which participants were asked if their answers could be recorded, given that their confidentiality would be ensured. Subsequently, the format of the interview was explained, after which the interview started.

**Participants**

In total there are 4 planners who worked with Supplier Managed Inventory and 2 planners who worked with Decoupling Safety Stock. These planners are again Operational Supplier Coordinators from the Operational Supplier Management department. They have experience with both the conventional way of planning, as well as the new way of planning enabled by the pilot solution for some of their parts. Table 16 provides an overview of the study sample which includes the experience of the planners in their role and with the solution.

| Solution worked with | | Experience in role | | Experience with solution | |
|---|---|---|---|---|---|
| Decoupling Safety Stock | 2 | < 1 year | 1 | 1-2 months | 4 |
| | | 1 - 2 years | 3 | | |
| Supplier Managed Inventory | 4 | 2 - 3 years | 2 | 4-6 months | 2 |

*Table 16: General information study sample*

**Questions**

In the introduction part of the interview participants were asked about how long they had worked with the solution, for which suppliers and materials under their responsibility it was applied, and how their general experience was so far using the solution. Then, specifically for each characteristic and outcome of their job they were asked how they thought the solution had an influence on it. Also, after each of these questions, participants were asked how they would value their answer on a scale from 1 – 5, described in the following section. Finally, participants were asked if they would support further implementation of the solution.

The job characteristics questions were structured as follows:

- "Autonomy reflects the degree in freedom of scheduling, and the way you do your work. How has the solution influenced this for you?"
- "Task significance reflects whether the tasks you do in your job have a meaningful influence within or outside the organization. How has this solution influenced this for you?"
- "Skill variety reflects the use of varied and complex skills. How has (working with) the solution changed this for you?"
- "Task identity reflects whether the job involves a whole and identifiable piece of work, meaning tasks have a clear beginning and end. How has the solution influenced this for you?"
- "Feedback reflects the degree to which the job provides clear insight in how effectively you perform your task. How has the solution influenced this for you?"

Follow-up questions were prepared in case an additional clarification of the question was required. For instance, for feedback this entailed proposing that the solution might change the insight provided in how well material availability is ensured (the main mission of the job).

The job outcome questions were structured as follows:

- "How did the solution change your satisfaction of the work overall?"
- "How did the solution change the commitment to your job overall?"
- "How did the solution influence how likely you are to stay in your job?"

## 6.4 Interview Results

The results will be presented per topic that was discussed in each interview, starting with the general experience of planners of working with the two solutions, followed by their input of how it influences each job characteristic and outcome. Planners also valued their answers on the following scale:

1: The solution has a strong negative influence on the job characteristic/outcome
2: The solution has a somewhat negative influence on the job characteristic/outcome
3: The solution has no influence on the job characteristic/outcome
4: The solution has a somewhat positive influence on the job characteristic/outcome
5: The solution has a strong positive influence on the job characteristic/outcome

The responses on the 1 – 5 scale are shown in table 17.

| Job Characteristics & Outcomes | Decoupling Safety Stock | | | Supplier Managed Inventory | | | | |
|---|---|---|---|---|---|---|---|---|
| | Participant | | Mean | Participant | | | | Mean |
| | A | B | | C | D | E | F | |
| Autonomy | 3 | 4 | 3.5 | 4 | 2 | 5 | 3 | 3.5 |
| Task Significance | 5 | 5 | 5 | 4 | 4 | 5 | 5 | 4.5 |
| Skill Variety | 1 | 4 | 2.5 | 3 | 4 | 5 | 3 | 3.75 |
| Task Identity | 4 | 3 | 3.5 | 2 | 2 | 4 | 4 | 3 |
| Feedback | 4 | 2 | 3 | 4 | 3 | 5 | 4 | 4.25 |
| Job Satisfaction | 5 | 4 | 4.5 | 3 | 5 | 5 | 4 | 4 |
| Commitment | 4 | 4 | 4 | 3 | 5 | 5 | 3 | 4 |
| Turnover Intention | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 3 |

*Table 17: Interview responses on 1 – 5 scale*

**General experience and remarks on the solution**

*Decoupling safety stock*

As indicated, two planners used the decoupling safety stock solution. One planner mentioned the benefit of not needing to make priority reschedule-in lists for parts under this solution. This planner noted that all reschedule-ins that remain for parts under this solution are really necessary, and that the supplier will now only see these important requests in the supplier portal. The planner also noted that their supplier was willing to give a cost reduction in return for significantly reducing the rescheduling suggestions on the short horizon. The other planner noted that the supplier experienced many reschedule-in messages which was a reason for starting with the solution for their parts. However, at the current time the supplier was having some capacity problems, hence the safety stock could not be built up to the required level at the moment.

*SMI*

Four planners used the SMI solution. One planner noted that the solution saves a lot of work, as it leads to less rescheduling messages which in turn leads to less checking at the beginning of the week and less following up on messages towards suppliers. A second planner noted that there were some difficulties in implementation of Min/Max levels due to increased demand of parts at the same time. A third planner, of packaging materials, noted that previously the planning of these materials was problematic, as it contained frequent manual reservations and a high amount of reschedule-in and reschedule-out messages. With SMI, this problem was resolved, and the supplier was content with the disappearing of all the rescheduling requests. The supplier did still have some difficulties in determining what they should deliver in the new way of planning, partly because the forecast that is shared is often unreliable. A fourth planner, also of packaging material, noted that for them it made sense to use this solution for higher volume, lower value parts as it saved efforts to investigate such materials in detail.

**Autonomy**

*Decoupling safety stock*

One planner mentioned the way of planning and doing their job did not change much with the implementation of this solution, this planner scored a 3 (neutral) on the influence of the solution on autonomy. The other planner scored a 4, noting that the solution could contribute to autonomy if it was implemented for more parts, giving more room from planning their work, as without the solution, they spend a lot of time communicating ultimate need dates to suppliers.

*SMI*

Responses of the influence on the autonomy in the work ranged from 2 (somewhat decreased feeling of autonomy) to 5 (strongly increased feeling of autonomy). In the one case where a 2 was given, this was explained by the fact that the supplier has more control over planning and inventory, leaving less autonomy to the planner. In the case where a 5 was given, the planner mentioned that they are not really more free in how they do their work, but rather have more freedom to plan their work as the solution saves them a lot of time. Regarding this freedom in planning and executing their work, a planner who gave a 4 mentioned that a check on each material remains necessary, although the solution will save them some time. Another planner scored a 3, indicating autonomy had not really changed for them. Overall, this indicates that work-scheduling autonomy improves, while work-methods autonomy somewhat decreases.

**Task significance**

*Decoupling safety stock*

Both planners scored a 5, indicating a positive influence of the solution on task significance. One planner noted that if the solution would be implemented for more parts, their work would be more significant overall.

*SMI*

Two planners scored a 4, and two planners scored a 5, indicating the solution positively affects task significance. All planners mentioned that the solution gave them time and headspace to focus on more important tasks or shortages. One planner explained that there is more time to do relevant tasks as the supplier now maintains the inventory, and they only need to get involved in case there is a problem. Also, one planner mentioned that being part of the new process that was implemented felt meaningful.

**Skill variety**

*Decoupling safety stock*

One planner scored a 1 on skill variety, mentioning that with this solution, you do not have to interpret anything, reschedule-in suggestions that are shown in the planning system are always relevant as opposed to before. Working with this solution, this planner mentioned, requires relatively less experience and skills. Another planner scored a 4, indicating that if the decoupling safety stock is successfully implemented, then less operational work needs to be done and more complex work can be done. Hence, the task itself related to the solution becomes less complex, but the time saved could be filled in with other tasks that require more varied and complex skills.

*SMI*

Responses ranged from 3 to 5, but both a planner who scored a 3 as well as a planner who scored a 5 mentioned that the solution will create space for other tasks, and that it would depend on whether these other tasks are complex to know if skill variety would increase. One planner mentioned that during the pilot phase they did more projected related work than operational work. This planner further mentioned that after the pilot phase, their work related to this solution would still be operational, but to a lesser extent than before, hence they scored a 4.

**Task identity**

*Decoupling safety stock*

One planner mentioned there was no real change, in terms of their asks having a clear beginning and end. Another planner mentioned that there was a slight improvement in this respect, because as long as a reschedule-in message exists, you know the material is really needed, hence this would be a somewhat more clear start of the task, compared to before the intervention.

*SMI*

Two planners scored a 2, indicating a lower feeling of task identity. One planner gave as a reason that there was less insight in whether orders are coming on time, as they do not see orders outstanding over time anymore. For example, the supplier now gives a signal that they are not going to deliver on time and will reach a level under the minimum, whereas before a problem could already be seen immediately from the planning. This planner also noted that they still need to give updates to both the supplier and demand owner of the material, because demand owners have less visibility in orders. The other planner who scored a 2 noted that the tasks becomes less clear in the sense that he is more dependent on the supplier to know what is wrong and what needs to be fixed regarding deliveries. However, he added that the lesser feeling of task identity in this way he perceived as positive. Two other planners scored a 4, where one planner indicated that with SMI, tasks that need to be done are quite clear. The other planner indicated that once the parameters are set, the solution works for itself and no more purchase orders need to be rescheduled-in and rescheduled-out as was the case before.

**Feedback**

*Decoupling safety stock*

One planner scored a 2 on feedback, indicating less feedback is provided in terms of ensuring material availability with the solution. This planner noted that a risk could be that you will find out late if there are problems at the supplier, because stock is buffering against this. Another planner scored a 4. This planner noted that before, if you had many reschedule-in messages, you would need to check if there is a safety stock available to know what is going on precisely. Now, it is clear when you have reschedule-in messages that there is something going on, therefore you can more clearly see whether everything is under control or not.

*SMI*

One planner who scored a 3 on feedback, noted that the solution gives a clear overview of the inventory status, however, before in the planning you could precisely see the projected inventories over time. Two planners scored a 4. One of them mentioned that the solution provides a more efficient view of status of materials that are of low value and high consumption, as for those orders it makes sense to just focus on managing the inventory between a min/max level instead of focusing on each incoming individual order line. The other planner mentioned that the solution can create more clearness in feedback of managing material availability with the new view of inventory status. Finally, one planner scored a 5, and mentioned that also the demand owners from the pack  ship department were positive about the clarity generated by the solution in ensuring material availability. They noted there were no more ad-hoc, manual reservations of materials. This is notably opposite to what another planner mentioned when asked about the influence on task identity, who stated that demand owners had less clarity in the status of orders with the new solution, but this could also be because in this case there were still some issues with the implementation due to increased demand at the time.

**Job satisfaction**

*Decoupling safety stock*

One planner scored a 4 and one planner scored a 5 on job satisfaction, where the planner who scored a 4 indicated that if all items are planned conform this solution, it would certainly contribute to job satisfaction.

*SMI*

Three out of four planners scored a 5, indicating a high positive influence of the solution on job satisfaction. Reasons given were that they are doing less boring and tiresome work of following up rescheduling messages. They also noted it was nice to be part of a new project and implementing a new planning mechanism which showed good results. Furthermore, they noted that it gives you time to focus on other things rather than managing high volume parts on a high level of detail. One planner scored a 4, noting it was a slight improvement.

**Commitment**

*Decoupling safety stock*

Both planners scored a 4, indicating that the solution would somewhat contribute positively to their commitment.

*SMI*

For two planners their commitment was unchanged with this solution (both scored a 3). Two planners scored a 5 on commitment, indicating that this was also due to their leading role in the further deployment of the solution at suppliers and remaining involved as a competence owner.

**Turnover intention**

*Decoupling safety stock*

Both planners noted that with the solution, less time is needed to focus on shortages and operational tasks, and more time is available for project or improvement initiatives at suppliers, hence it would make the role more interesting. Hence both planners scored a 2, indicating somewhat reduced turnover intention with implementation of this solution.

*SMI*

All planners indicated that the solution contributes to their enjoyment in their work, but it does not necessarily change how long they would want to remain in their job, hence all planners scored a 3 (neutral).

## 6.5 Discussion of interview results

Firstly, a reflection is given of whether the results confirmed the hypotheses. Then, a comparison and an evaluation of the effects of both solutions are discussed.

**Hypothesis 4**

For the decoupling safety stock solution, hypotheses 4a – 4h were confirmed, with the exception of 4c (skill variety) and 4e (feedback), based on the average scores of the scale items. For skill variety this was because one planner scored a 1, indicating that using the decoupling safety stock solution in itself is simpler compared to before, because there are no more rescheduling messages to investigate. However, it should also be noted that this gives the overall opportunity to focus on more complex tasks, which was indicated by the other planner who used the solution, who found that the solution did contribute to the skill variety of the job overall because of this.

The average response on the contribution of the solution to feedback gained from the job itself was a 3, which in turn was caused by a score of 2 by one planner. This planner indicated that the decoupling safety stock solution gave less direct insight in what is happening, because problems at the supplier do not show up immediately in the planning. The planner noted that, because of the buffering stock, expediting suggestions no longer appear in case demand is delivered late.

For the other hypotheses, it was confirmed that the solution positively contributed to the respective job characteristic or outcome. The positive contribution of the solution was found the strongest for task significance (average response of 5), with the reason that the solution contributes to focusing on more important tasks, followed by job satisfaction (average response of

4.5).

### Hypothesis 5

For the SMI solution, hypotheses 5a – 5h were confirmed, with the exception of 5d (task identity) and 5h (turnover intention), based on the average scores of the scale items. Regarding task identity, two planners indicated that with SMI, they had less insight in when orders are coming in exactly, making their task less clear. Regarding turnover intention, the implementation of the solution did not change for any of the planners how likely they were to stay in the job. Also, it should be noted that regarding autonomy, it was confirmed that the solution gives more freedom in scheduling the work, but it gives less freedom in the way of doing the job, as now the supplier determines how orders are coming in.

### Comparison & evaluation of findings

Firstly, it was confirmed by all planners that both solutions lead to less rework and checking of rescheduling messages. Next to that, for both solutions the contribution to task significance was found to be the highest. Together, these findings imply that the solutions decrease the impact of nervousness on the planning job, as planners noted that they are able to focus on more significant tasks, including more meaningful shortages, projects, and improvement initiatives at suppliers.

Secondly, the biggest difference between the solutions is that with SMI, the main responsibility of managing the inventory is at the supplier's side, whereas with the decoupling safety stock, the planner has the responsibility of managing incoming orders. Also, with SMI, there is even less operational work for the planner because there are no more purchase orders, but one large schedule agreement. Furthermore, one of the two planners who used the decoupling stock solution noted that it lead to a somewhat reduced insight in any problems that might occur at the supplier, because stock is buffering against this, so they would find out later than normal if there was a problem. This makes sense, as per definition of decoupling, independence is created by the strategic inventory buffer, not maintaining the hard-coupling between each shift in demand and supply. This reduced insight in any problems that might be occurring appeared to be stronger for the SMI solution, as 3 of the 4 planners stated in one of their replies that they had less insight or that there was less detail available in the status of orders. From this perspective, SMI appears to be better applicable in cases where the reduced insights in the exact status of each order is relatively less important (for lower value, high volume parts), or where the supplier can take the responsibility of managing the inventory under uncertainties, in which case it can also be applied to some higher value parts. Furthermore, the SMI solution appeared to be a larger change in the way of working for planners compared to the decoupling safety stock solution, requiring more implementation efforts and cooperation with the supplier in the beginning, but in the end leading to higher reductions in operational workload compared to the decoupling stock solution, which still requires individual purchase orders to be managed.

## 6.6 Conclusion

The research question that corresponded to this chapter was: *How do decoupling solutions affect the job characteristics and outcomes of planners?* The results show that both the decoupling safety stock and Supplier Managed Inventory solution positively influence most of the characteristics and outcomes of the job of the planner. Given that the sample size of this interview was small (only 6 planners were interviewed), and that the solutions were implemented for only a few materials under the control of these planners, it cannot be said with certainty what the absolute impact of the interventions are in the job overall. For this, additional research would be required once the solutions are implemented further. The most important finding however, is that all planners confirm the potential of both solutions to successfully redesign some of the aspects of the planning job, and that the solutions contribute mostly to the significance aspect, leading to increased overall satisfaction and commitment in the job, and to a lesser extent also to decreased turnover intentions.

# 7 Discussion

In this chapter, a discussion is given regarding the overall results of this research, combining the findings of earlier chapters and reflecting on the research aim and research questions that were formulated.

## 7.1 Discussion of overall results

In this research, the problem of MRP nervousness was investigated through a case study at the world's leading manufacturer of lithography systems for the semiconductor industry, ASML. In this complex assemble-to-order environment, the problem of nervousness was evident from the high number of rescheduling suggestions on purchase orders and projected shortages of all buy materials. Due to the dependent way of planning by MRP, it is very hard to determine the root-cause of each of these rescheduling messages and corresponding mismatches in supply and demand. Every requirement of a buy material depends on the requirements of all the submodule, module, and end item requirements to which it might be linked. To these requirements (i.e. demands) of buy materials, supply orders (i.e. purchase orders) are exactly matched by MRP in terms of due date. When MRP is re-run at the start of the week, there are approximately 14.000 projected material shortages and 70 % of the purchase orders have a rescheduling message which suggest a new due date of the supply order to match the updated requirements, which in turn are subject to varying types of uncertainty during the weekly operation, amplified by all the dependencies. Around half of these rescheduling suggestions are also communicated automatically to suppliers, most of which are reschedule-in messages. In the end, the planners from the Operational Supplier Management department have to address the importance of each of these rescheduling suggestions, which they mainly do by addressing and following up on the corresponding projected shortages on the short horizon with internal demand owners and suppliers. Therefore, the dependent way of planning by MRP called for creating some independencies by placing strategic inventory such that planners, and ultimately suppliers, do not have to follow up on every small shift back and forth of the requirements. Given that the traditional buffer of safety stock does not effectively achieve this, because MRP just subtracts the safety stock from what is available before matching supply to demand (i.e. it always 'prevents' safety stock from being used), different buffering concepts, referred to as decoupling solutions, were extensively researched as solutions for MRP nervousness, with particular interest for how this might improve the motivational job characteristics and satisfaction of the planner.

The problem was explored from multiple angles, firstly by investigating how nervousness is affecting planners, secondly by analyzing what the nervousness is on each buy part in terms of quantity uncertainty in planned demand on the short horizon, and thirdly by analyzing characteristics of shortages and rescheduling messages. The insights gained from the planners corresponded with the insights of the operational analyses. For instance, through the survey in Chapter 4, it was found that planners only considered 20 % of the shortage lines relevant, because many shortage lines had issues such as invalid demand elements (non-firm, overforecasted demands, demands in the past, and manual reservations that they were unsure of) and supply elements which were represented by non-released purchase orders. In the analysis of shortages, after investigating the characteristics of shortage lines, it was found that approximately 23 % of shortages are relevant for planners to consider for rescheduling, which matches what was found through the survey. Also, the over-forecasting of demand, as indicated by planners, was confirmed in the demand analysis of Chapter 5, as for the majority of parts with a regular monthly volume, the demand on the 5-week horizon tends to be overstated. Therefore, it was recommended in Chapter 5 to focus on reducing the part of the shortage list (and thereby rescheduling messages), with non-planning related issues such as demand and supply integrity issues, which can be done at relatively low cost. This includes preventing the occurrence of demand elements in the past and focusing on preventing the occurrence of all the 'stranger' parts in the shortage list (parts with hardly any historical consumption data) which are carried over in the shortage list every week, see also section 5.4. Preventing unreleased purchase requisitions is more difficult, as these are automatically generated in case there are no more firm purchase orders in the future to match demand. This means that the real cause of these purchase requisitions is not necessarily that they have not been released on time, but that they can also exist because of the invalid demands to which they are automatically matched. Overall, reducing these types of supply and demand integrity issues would already reduce a great part of the shortages and rescheduling messages, thereby enabling an overall more effective use of the planning system, and improving the meaningfulness in working with shortages perceived by planners.

Improving the meaningfulness in working with shortages for planners is important, as it was found through the survey in Chapter 4 that nervousness, in terms of how working with shortages is perceived under the MRP way of planning, was significantly related to turnover intention, the overall motivating potential score of the job, task identity, and feedback from the job. This is an important insight, as for organizations this means that reducing nervousness leads to planners being more motivated and committed to their job, thereby benefiting the organization as a whole. Although some of the nervousness can be reduced by preventing the issues described in the previous paragraph, planners generally quickly identify and set aside these types of shortage lines and corresponding rescheduling requests, and spend most of their time related to shortages and rescheduling suggestions (on average more than 1.5 working days per week) on the remainder part of the shortage list, which requires actual rescheduling.

In section 5.4 it was seen that approximately 14 % of these lines concern parts of type A1. These are parts of high value (their median value was approximately 50.000 euros), and are responsible for the majority of the end-system's cost. These are also critical parts required for complex modules, such as mirror blocks, which are responsible for holding and positioning the wafer in the waferstage module. It was argued that shortages of these parts can be more challenging and meaningful for planners, whereas the other parts of type A2, B, and C could be buffered by one of the two proposed solutions to reduce required rescheduling actions such that planners can focus on the more important parts under their responsibility. There are however, some noteworthy differences and similarities in the operation of both solutions.

With the decoupling safety stock buffer, a SAP-based variant of safety stock, a safety stock is kept which can be used to cover for (temporary) increases in demand, which leads to a reduction of reschedule-in requests or additional orders within the lead time. Both planners that worked with this solution noted that their supplier was satisfied with the reduced reschedule-in messages, and that the planners themselves could focus on more significant parts of their work. However, these planners still work with purchase orders that they have to release on a weekly basis, and in case rescheduling requests occur which cannot be prevented by the decoupling safety stock buffer, they are still primarily responsible for communicating about these exceptions towards the supplier. This is different for planners who work with Supplier Managed Inventory, as with this solution the supplier is responsible for managing the inventory between a given Min/Max level and handling deviations in demand. With SMI, there are no purchase orders which need to be released by the planner, as the supplier has the freedom to deliver orders which are booked against one large schedule agreement. Also, when the inventory falls below the Min level, the suppliers are already aware they are responsible to undertake action and the planner only needs to monitor whether they do. In this case, the planner only needs to assist in case actual problems occur on the suppliers' side. On the other hand, when an exception happens on a part to which decoupling safety stock is applied (e.g. buffer stock cannot cover increased demand or there is a delay in demand), the supplier is not immediately responsible to undertake action, as they had already agreed on a due date for a purchase order. In this case, the planner is responsible to take action, and needs to request the supplier to confirm the new due dates on orders suggested by the planning system, which are likely to change again in the future. Following the definitions of roles a planner can have as discussed in Chapter 3, this means that by implementing decoupling safety stock planners still have a compensational role, whereas with SMI planners have a more monitoring role for their parts. This was also evident from the experiences of planners described in Chapter 6, as all planners using SMI indicated that the autonomy in controlling parts shifted to the supplier, which they found especially beneficial for lower value, higher volume parts. Hence, although planners using both solutions indicated that the solution contributed to their overall feeling of task significance and satisfaction in their job, it can be seen that the SMI solution has more potential as it reduces more operational work and also gives the planner a more monitoring role for parts where this is appropriate.

The way demand is generated, through MRP logic, remains the same under both solutions. However, the difference is that with decoupling safety stock, the stock is used to prevent rescheduling requests on purchase orders, thereby decoupling fluctuations in demand from supply. This means suppliers will have significantly more stability in their order request dates, at least on the short horizon. With SMI on the other hand, the supplier will still directly receive the MRP demand signal, which includes fluctuations in demand, but they can create stability themselves by using the flexibility of the Min/Max buffer. Hence, in both cases a buffer is used to create stability, but the main difference lies in the responsibilities. Also, for SMI it is important that the supplier has the capabilities and can be trusted to manage the inventory in the right manner.

## 7.2 Contributions to theory and practice

### Contributions to theory

System nervousness has been considered an important operational problem associated with MRP systems (Ho, 2005). In this research, nervousness has not only been defined and investigated as an operational problem, but also as a problem that affects the human planner. By operationalizing nervousness in this research as a variable in the job of planners who are heavily involved with rescheduling on a daily basis in their job, additional meaning was given to the concept nervousness, thereby contributing to existing literature. Furthermore, this research gave the insight that nervousness was related to the motivational job characteristics of the Job Characteristics Model by Hackman & Oldham (1976), which has been the most widely-researched and debated approach to job design until present day (Oldham & Fried, 2016). More contemporary works on job design theory (e.g. Parker et al., 2001; Morgeson & Humphrey, 2006) have suggested that, in order to generate a deeper understanding in modern job designs, more attention should be given to the contextual characteristics of the job. In this research this was done by making explicit that MRP nervousness affects the job of planners who are responsible for managing incoming orders. This was achieved by including nervousness both as an underlying, predicting factor for the presence of motivational job characteristics and as an individual, contextual characteristic that directly predicts job outcomes. Results showed that how nervousness, in terms of how adversely working with shortages and rescheduling actions in the MRP way of planning is experienced, had small to moderate effects on most of the motivational job characteristics, and small to large effects on job satisfaction and turnover intention. This contributed to gaining a better understanding of the planning job in relation to the specific context of MRP nervousness by using job design theory.

Another contribution to existing literature of this research is that it demonstrated that buffering concepts, referred to as decoupling solutions, in contrast to the traditional buffering approaches in MRP such as safety stock and safety time, effectively reduce nervousness and contribute to the planner's job. The first solution, a SAP-specific variant of safety stock, does so by removing rescheduling suggestions on orders as long as the decoupling safety stock buffer can absorb the fluctuations in requirements, thereby creating a more stable demand signal towards suppliers and reducing the efforts required by planners to address each rescheduling suggestion. Results from interviews with planners showed that, when applied to the right parts (i.e. less meaningful, less complex parts of lower value), the solution contributes to higher feelings of task significance and satisfaction in their job, which is an important insight for literature. The second solution, Supplier Managed Inventory, a SAP specific variant of VMI (Knolmayer et al., 2009), reduces nervousness by setting Min/Max levels of inventory for the supplier who is responsible for managing the inventory between these levels, thereby providing a buffer, or bandwidth, which can be used to stabilize their deliveries. The requirements are still generated by and shared from the customer's MRP system, so the insight in demand does not change for the supplier. This shows another relevant aspect for literature, as normally the reported benefits of supplier/vendor managed inventory include a mitigation of the bullwhip effect induced by better visibility in the customer's demand (Marquès et al., 2010), but with SMI the visibility in customer demand does not change, and the benefits are mostly gained by the buffer itself which allows the supplier to synchronize its deliveries with its own product availability and capacity utilization under fluctuating, MRP-generated orders by the customer. Results from interviews with planners showed that shifting the responsibility of managing inventory and orders to the supplier contributed greatly to the overall perceived significance and job satisfaction when applied to relatively less challenging and vital parts under the planner's control. Planners reported that addressing the planning and rescheduling suggestions repeatedly for such parts in detail was not particularly meaningful, hence the SMI solution was also an enhancement to their job design as it gave the planner a more monitoring role for these parts, which is an important new insight for literature.

**Contributions to practice**

This research has shown how solutions for nervousness can be of relevance both from the perspective of operations management as well as human performance management. For instance, both of the described decoupling solutions create more stability in (the delivery of) orders, while also contributing to the overall significance of the job of the planner. At ASML, taking this multidisciplinary perspective has already contributed to the significance and meaningfulness that is perceived by planners in executing the tasks in their job. Both decoupling buffering methods allowed planners to focus on actual exceptions for parts to which they were applied, and also there was room for more varying and project-related work in their job. Especially for SMI the less operational role and more monitoring role for planners was experienced by them in a positive way, as for less vital parts the way of working shifted from being responsible for managing every order and corresponding rescheduling request in detail, to monitoring the performance of the supplier. Hence, organizations using MRP can use these findings to reduce rescheduling actions by placing strategic inventory and enhance the job design of planners, thereby simultaneously improving efficiency and satisfaction in the workplace (Campion et al., 2005).

Next to that, in the demand analysis section of this research, a practical method was provided for quantifying nervousness on MRP planned buy-materials which focused on the uncertainty in planned demand and deviations of planned demand on the short horizon. The script (also shown in Appendix H), calculates the forecast error and how frequently demand deviates within the short horizon (where demand should be firm). It was shown that, although demand tends to be overstated on the 5-week horizon, the required quantity also frequently increases *within* this horizon, which leads to expediting in case there are no effective decoupling buffers in place. The script can be used to further optimize the required buffering levels, and the described logic can be applied by any organization using MRP planning on a rolling horizon.

## 7.3 Limitations and directions for future research

Regarding the measurement of nervousness in the planning job, it would have been better to repeat the survey for the same group of 34 planners that had filled it in earlier, after the decoupling solutions which reduce the need for rescheduling had been fully implemented (where reasonably applicable) for the materials of those planners. This could have contributed to the internal validity of the variable used to measure nervousness in the planning job, as it would have given insight in how the variable and its formative constructs would change. Therefore, a limitation of this research is that the survey could not be repeated, as only a few planners started working with the solutions after the survey was conducted. This also would have given additional quantitative insights in how much the different job characteristics, outcomes, and experienced nervousness would have changed after fully implementing the solutions.

Next to that, to operationalize and measure nervousness planners were asked about how much time they spent on shortages and rescheduling actions and how they perceived this, but no distinction was made between challenging and non-challenging shortages and rescheduling actions. As it turned out that the subjective experience of these actions was an important predictor of job characteristics and outcomes, it might have been better to make this distinction more explicit in the measurement of nervousness experienced by planners.

Furthermore, an important limitation of this research is that a small sample size was used of 34 planners. Although some moderate effect sizes were found between nervousness and job characteristics and outcomes, the small sample size made it difficult to establish significance of some relations because of low statistical power (Sullivan & Feinn, 2012).

Additionally, all data was obtained within a single organization, which is a limitation with respect to the external validity of this research. If data was gathered in multiple organizations which also use MRP planning and employ planners with a similar role with respect to managing the MRP planning outcome and incoming purchase orders, then the external validity of the findings would have been stronger.

Also, this research focused specifically on how nervousness affects the planners who are responsible for managing incoming orders, but nervousness is also likely to affect their counterparts at the supplier's side. It is likely that sales and operations employees at suppliers are also affected by the nervous demand signal that leads to frequent expediting of supply orders. It was out of scope to investigate this effect in this research, but it may be relevant to investigate how creating more stability in the delivery of orders may exactly benefit the supplier in terms of motivation and commitment towards the customer.

A further shortcoming of this research is that no optimal buffer sizes have been determined for both decoupling solutions. It should be noted that the issue of buffer size is a complex one, and has not been fully resolved in literature (Guide Jr & Srivastava, 2000). In an article by (Saad et al., 2017), it is noted that in current challenging business environments, the role of inventory has become to smoothen processes, including the processes between different organizations, and its performance is largely evaluated in relation to total cost, cost of holding, replenishment, and handling shortages. They further describe a mechanism which allows efficient configuration of the safety stock parameters in ERP systems, which can be used as a relevant direction for future research for determining the parameters of the decoupling solutions.

Finally, this study focused on solutions that could enhance the current MRP way of planning to reduce nervousness, specifically in SAP-based ERP systems, as both solutions that were presented are supported in this environment. One noteworthy solution which fits this scope and is worth investigating, is Demand Driven MRP. DDMRP serves as a supply order generation engine that incorporates MRP functionality while explicitly addressing its known problems, including nervousness (Ptak & Smith, 2016). It aims to create independence in MRP-based planning by introducing decoupling point buffers at selected positions in the bill of materials (Ptak & Smith, 2016). Other possible solutions which are not readily supported by SAP but are worth investigating include Synchronized Base Stock (SBS) policies, which is an alternative for MRP logic to translate independent demand into orders (Wiers & de Kok, 2017). The concept is based on integrated control policies, developed to synchronize work orders and to determine safety stock across the supply chain to reduce the bullwhip effect and nervousness problems (de Kok et al., 2005; Li & Disney, 2017).

# 8 Conclusion

From this research it has become clear that nervousness is highly relevant to consider from the planner's perspective. Overall, the results indicated that the high amount of rescheduling requests and corresponding projected material shortages that follow from the dependent way of MRP planning are not contributing to the perceived meaningfulness and satisfaction of planners who have to address them. Through a quantitative survey amongst planners, it was shown that nervousness, in terms of how planners subjectively experienced working with shortages under the MRP way of planning, was negatively related to some of the motivational job characteristics and positively related to turnover intention. Also, qualitative interviews with planners who worked with shortages after solutions had been implemented to reduce some of their rescheduling actions, revealed that both solutions contributed to focusing more on the significant tasks of their job and thereby the overall satisfaction in their work. These two SAP-based solutions, decoupling safety stock (i.e. shared safety stock) and Supplier Managed Inventory, both reduce the required rescheduling actions by planners and suppliers, but are different in terms of responsibilities and role of the planner. With the decoupling safety stock, fluctuations in delivery request dates and the corresponding reschedule-in suggestions are significantly dampened, but if an exception happens, the responsibility of handling this still lies with the planner. With SMI, the responsibility of handling fluctuations lies principally with the supplier and no more individual purchase orders need to be managed, which is a bit more ideal for the materials in scope for decoupling. This is because it gives the planner a more monitoring role and they only need to intervene when actually required, whereas with the other buffering solution, they are still a link between the planning system's output and the supplier, having to compensate for possible rescheduling suggestions. Given that planners spend a significant amount of time on shortages and the corresponding rescheduling actions (over 1.6 days per week on average), both strategic buffering solutions can significantly enhance the job of the planner when implemented further. Additionally, the high amount of time spent on shortages is mostly attributed to only a small set of the overall shortages, as planners stated that only 20 % of shortages required actual rescheduling of demand or supply. Therefore, the total portion of shortage lines that can be reduced at most by decoupling buffers is also around this percentage, and it is recommended to also focus on solutions for the underlying issues of the other portion of the shortage list. The most important issues identified were demand integrity (overplanned demand, non-firm demand on the short horizon, and demand in the past) and planning issues of parts with highly sporadic demand (a high percentage of shortages entailed demands of new parts or existing parts with no consumption data in the past year). Although planners might not spend most of their time on these shortages, it is important to reduce them as well as it will also contribute to the meaningfulness of working with shortages and enable a better use of the planning system in general.

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# A | Empirical Research Cycle

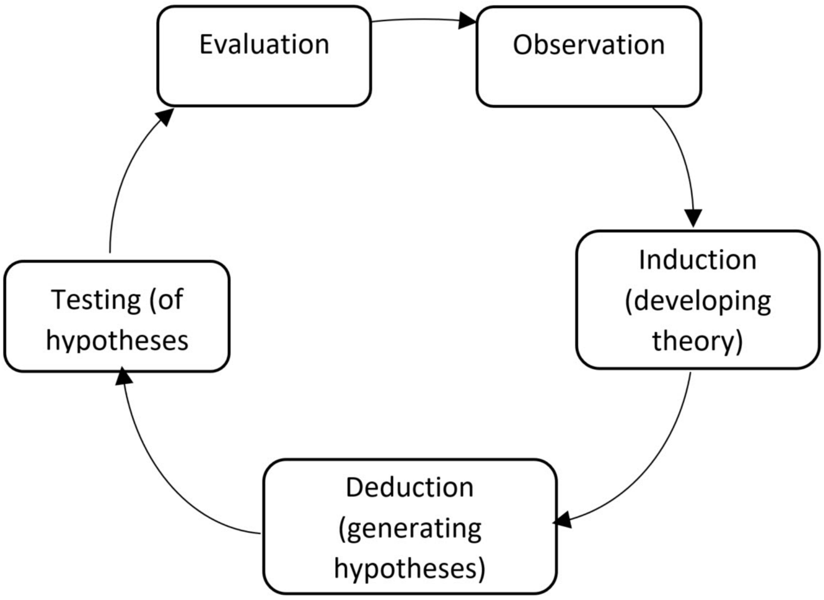


*Figure 17: Empirical cycle (Van Aken et al., 2012)*

# B | Field Problem Solving Cycle

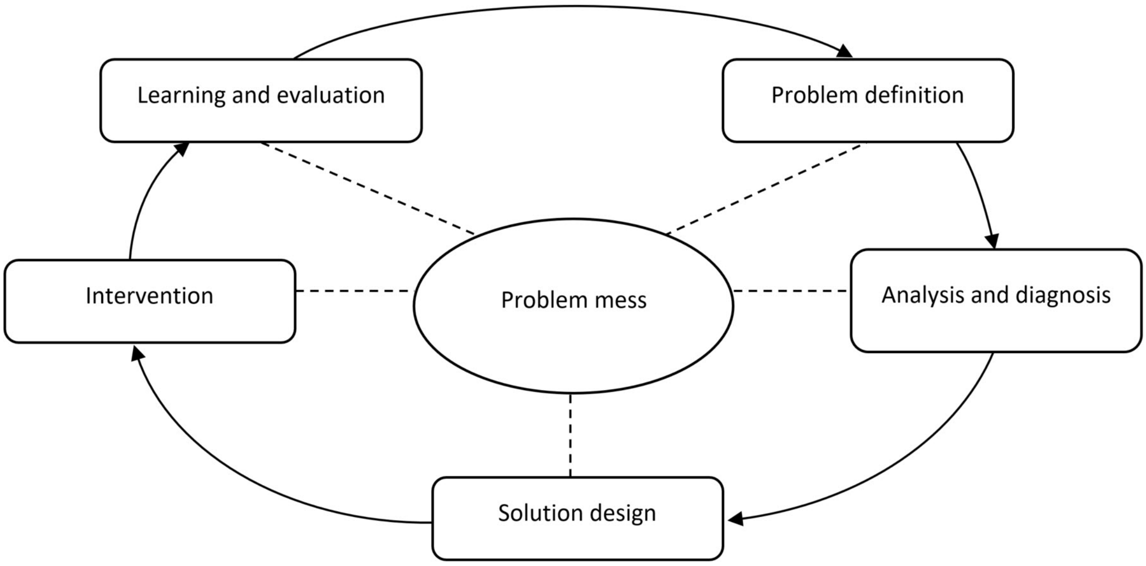


*Figure 18: Problem solving cycle (Van Aken et al., 2012)*

# C | Organization Chart

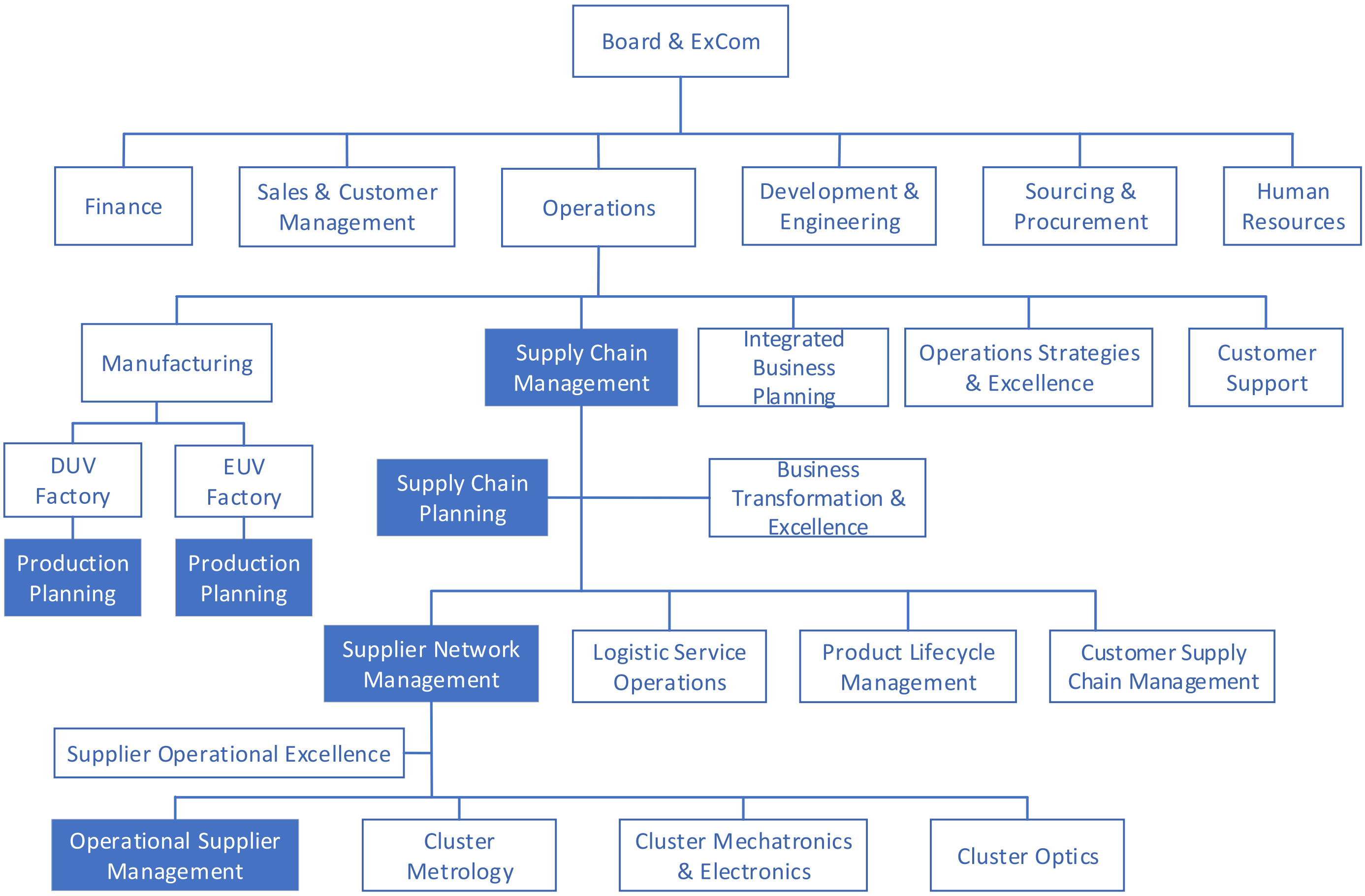


*Figure 19: Concise organization chart with highlighted departments mainly related to problem scope*

# D | Master Planning Process

During the monthly MPS update, the Supply Chain Planning department extracts master data and transactional data from the ERP system to execute a scenario run by using advanced tooling. The aim of this is to take into account material and capacity feasibility before updating the MPS and feeding it back into the MRP system, where the actual MRP run will be executed.

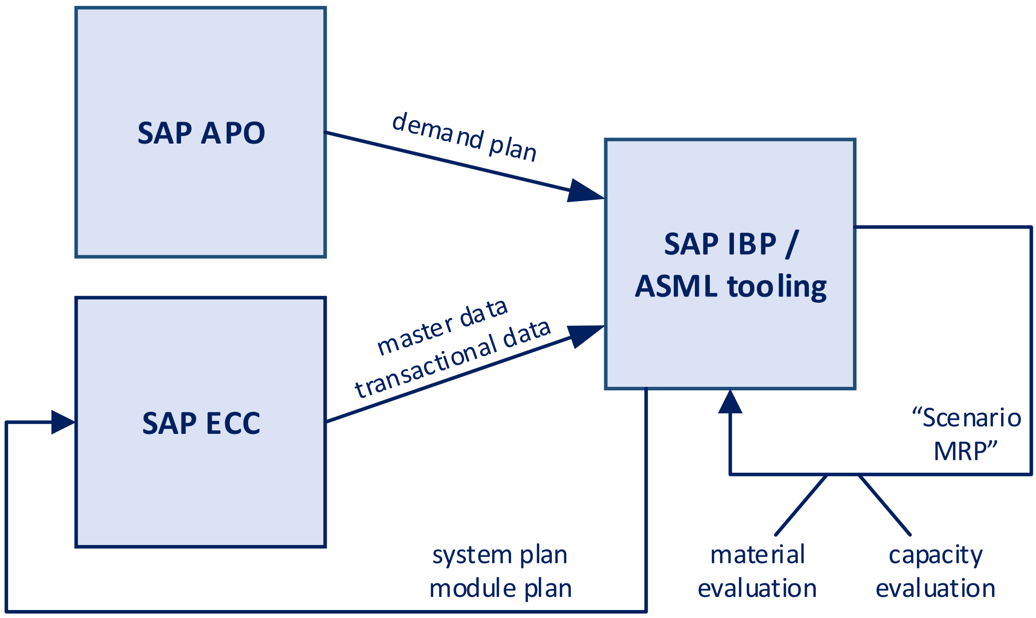


*Figure 20: Master Planning process ASML*

In figure 20 this monthly process is shown. The long term demand, specified by the Sales and Integrated Business Planning departments, is input for the SCP department to match their supply plan against. Next to that, live planning data is extracted from the planning system (SAP ECC). For DUV systems, manual tooling is used to check material feasibility, capacity feasibility (workcenters, cabins, test rigs, FTE's) and the impact on inventory. Material evaluation includes checking whether orders would be generated respecting lead times and suppliers' capabilities. For orders that would be within lead time, there will be a supply investigation, where the planners from the Operational Supplier Management department are contacted to investigate whether the supply could follow up a reschedule-in message. This way, the Supply Chain Planning department takes into account that it should not update the master plan such that it generates rescheduling requests that cannot be met.

Supplier capability evaluation concerns whether the generated orders are within the move rate capabilities of the supplier. For EUV systems, for around 300 critical parts, a standard solution (SAP IBP) is used to evaluate the supply plan. This comes with several options such as 'decoupled planning' which means leveling the output plan of modules, generating a more stable plan on a module (i.e. 'assy') level, and thereby also for components. Another option is lead time constrained planning for modules. This means that the module plan is constrained in the way that MRP takes into account all lead times of components and does not schedule any supply within lead time. On system level this is not yet done, as the infeasibility of just one component would constrain the system start date, which is not what ASML wants, they would then rather challenge this supply element to be delivered earlier.

# E | Survey items

## Nervousness

**Experienced amount of nervousness**

1. On average for a given week, what % of your time do you spend on all actions related to the list of shortages (previously "CPL lines") that exists in Fiori?
2. On average for a given week, how many hours do you spend on reviewing shortages and making a priority re-in list?
3. On average for a given week, how many hours do you spend on solving shortages by following up on supply with suppliers?
4. On average for a given week, how many hours do you spend on solving shortages by following up on demand with internal demand owners?
5. On average, for how many shortage lines are you supply responsible at the beginning of the week (total of all your suppliers)?
6. On average, how many of these shortages do you consider relevant, e.g. there is a real need that the future demand or supply element should be rescheduled?
7. On average, how many times per week do you contact your supplier(s) regarding the rescheduling-in or out of purchase orders (e.g. total mails sent, phone calls made, etc.)?

**Experienced subjective effect of nervousness**

**Scale:** ***strongly disagree (1) – strongly agree (5)***

1. Reviewing shortages is a tedious task.
2. Solving shortages is one of the most challenging parts of my job.
3. The current way of material planning (MRP) in the ERP system is discouraging me.
4. Solving shortages is an enjoyable part of my job.
5. It is difficult to determine the cause of a shortage.
6. Working with material shortages involves unnecessary rework: repeated actions for which you keep wondering if they could have been avoided with better planning processes.

## Job characteristics

**Scale:** ***strongly disagree (1) – strongly agree (5)***

**Work Scheduling Autonomy**

1. The job allows me to make my own decisions about how to schedule my work.
2. The job allows me to decide on the order in which things are done on the job.
3. The job allows me to plan how I do my work.

**Decision-Making Autonomy**

1. The job gives me a chance to use my personal initiative or judgment in carrying out the work.
2. The job allows me to make a lot of decisions on my own.
3. The job provides me with significant autonomy in making decisions.

**Work Methods Autonomy**

1. The job allows me to make decisions about what methods I use to complete my work.
2. The job gives me considerable opportunity for independence and freedom in how I do the work.
3. The job allows me to decide on my own how to go about doing my work.

**Skill Variety**

1. The job requires a variety of skills.
2. The job requires me to utilize a variety of different skills in order to complete the work.
3. The job requires me to use a number of complex or high-level skills.
4. The job requires the use of a number of skills.

**Task Identity**

1. The job involves completing a piece of work that has an obvious beginning and end.
2. The job is arranged so that I can do an entire piece of work from beginning to end.
3. The job provides me the chance to completely finish the pieces of work I begin.
4. The job allows me to complete work I start.

**Task Significance**

1. The results of my work are likely to significantly affect the lives of other people.
2. The job itself is very significant and important in the broader scheme of things.
3. The job has a large impact on people outside the organization.
4. The work performed on the job has a significant impact on people outside the organization.

**Feedback**

1. The work activities themselves provide direct and clear information about the effectiveness (e.g., quality and quantity) of my job performance.
2. The job itself provides feedback on my performance.
3. The job itself provides me with information about my performance.

## Job outcomes

**Scale:** ***strongly disagree (1) – strongly agree (5)***

**Job Satisfaction**

1. I am often bored with my job. (R)
2. Most of the time I have to force myself to go to work. (R)
3. I feel that I am happier in my work than most other people.
4. Most days I am enthusiastic about my work.
5. I find real enjoyment in my work.

**Job Commitment**

1. I would be very happy to spend the rest of my career in this job
2. I enjoy discussing my job with people outside it.
3. I think that I could easily become as attached to another job as I am to this one. (R)
4. This job has a great deal of personal meaning for me.

**Turnover Intention**

1. I frequently think of quitting my job.
2. I am planning to search for a new job in the next 12 months.

# F | Demand analysis additional figures

Figures 21 – 23 show the histograms of the MPE of the 5-weekly planned demand for X, Y, and Z parts.

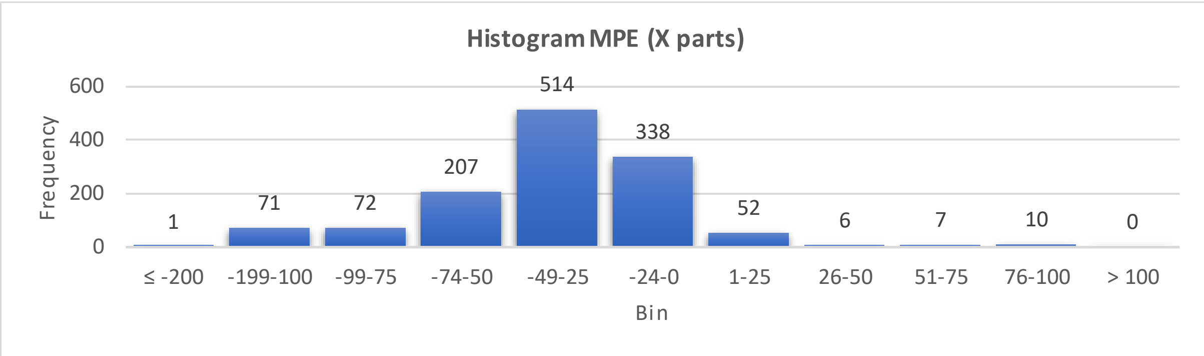


*Figure 21: Histogram MPE X parts*

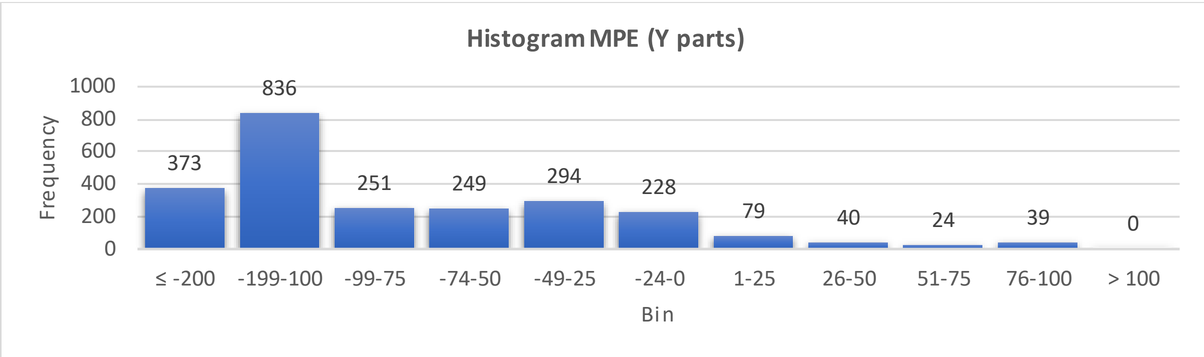


*Figure 22: Histogram MPE Y parts*

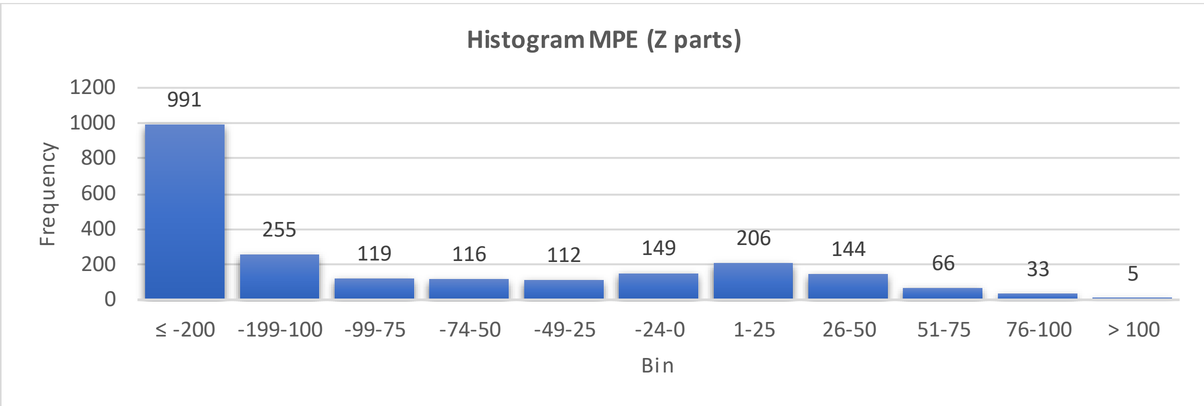


*Figure 23: Histogram MPE Z parts*

For each part, the amount of 5-weekly periods were recorded where the demand for the period had increased after 1, 2, 3, 4 or 5 weeks had passed compared to the baseline. In total there were 22 observed 5-weekly periods. The histograms in figure 24 - 27 show how many parts had 0, 1, 2, etc. periods with a positive deviation out of the possible 22.

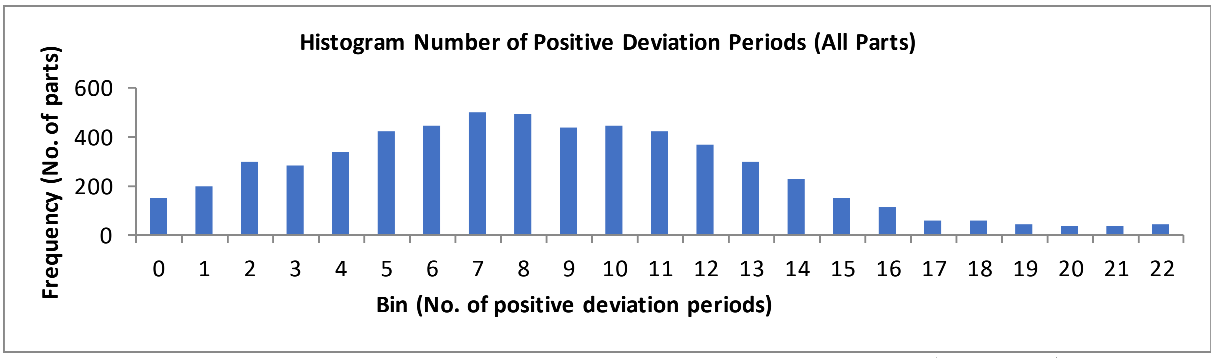


*Figure 24: Histogram No. of Periods with increased demand (All Parts)*

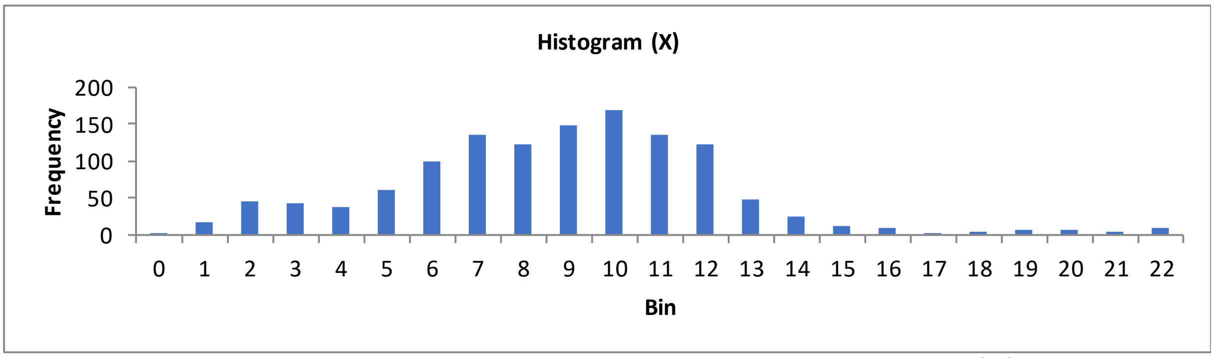


*Figure 25: Histogram No. of Periods with increased demand (X)*

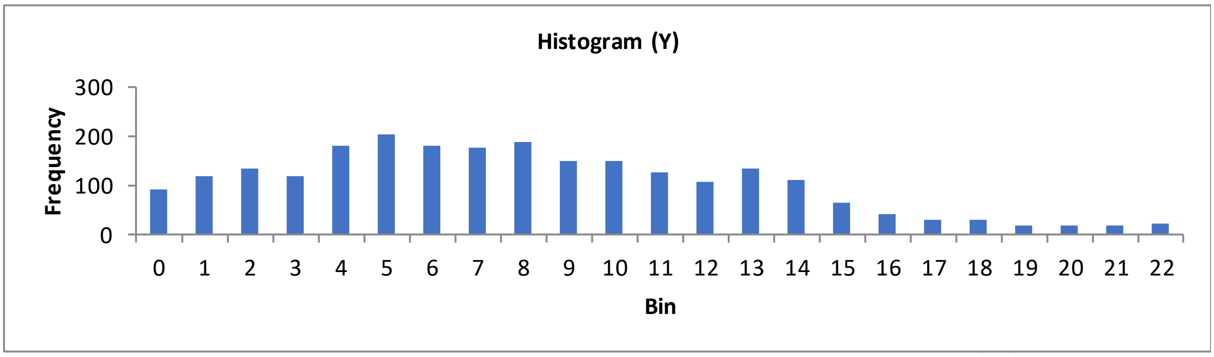


*Figure 26: Histogram No. of Periods with increased demand (Y)*

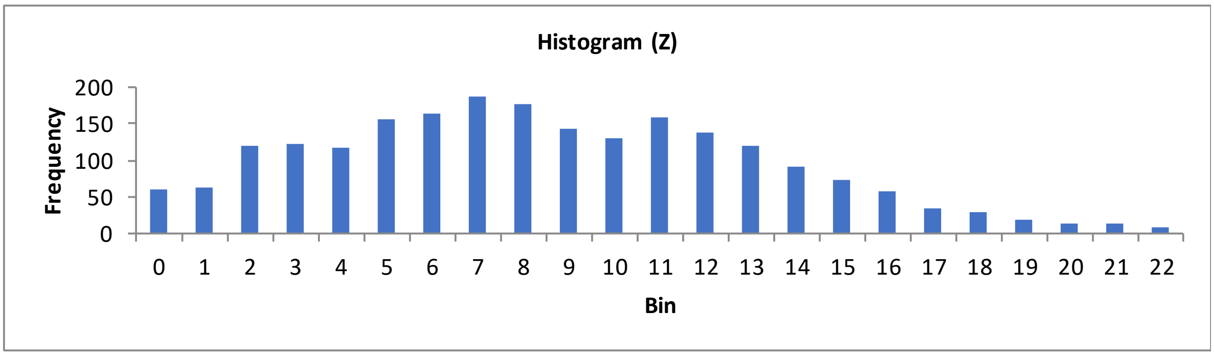


*Figure 27: Histogram No. of Periods with increased demand (Z)*

# G | DDMRP literature

Table 18 presents an overview of the most relevant articles found in literature that extensively reviewed DDMRP. The consensus that follows from this is that DDMRP is a promising concept which can improve material planning in manufacturing companies, but that future research should be carried out to investigate how DDMRP performs in specific environments and how various aspects of its logic exactly impact this.

| Study | Purpose | Important findings |
|---|---|---|
| Miclo et al. (2019) | • Introduce and explore DDMRP.<br>• Evaluate DDMRP effectiveness relative to MRP II and Kanban/Lean production through a series of structured computer simulation experiments. | • DDMRP is an integrative approach that draws on the best features of accepted approaches such as TOC, MRP, Six Sigma and Lean. Consequently, conceptually and from a results perspective, DDMRP is exiting since it appears to work.<br>• Results strongly indicate that DDMRP represents a superior approach. Future research should further explore this new development to assess its limits and better understand how the various aspects of its logic and approach influence performance. |
| Acosta et al. (2019) | • Evaluate applicability of DDMRP in a complex manufacturing environment by simulating a DDMRP model for planning and executing purposes. | • Results demonstrate that DDMRP can perform in a complex manufacturing environment.<br>• Many aspects of DDMRP are subjective and depend on the planner's judgement, such as the strategic positioning of buffers, the choice of LT percentage and variability percentage, buffer profiles, and the frequency of dynamic buffer re-adjustment. Future research will have to analyze how these choices impact performance.<br>• Strategic buffer positioning plays a crucial role in DDMRP's performance. The process of determining buffer positions in a complex manufacturing environment could take a significant amount of time.<br>• Further investigation into the performance of DDMRP in complex manufacturing environments is predicted to yield improved methodologies leading to higher overall performance. |
| Ihme & Stratton (2015) | • Evaluate DDMRP in the context of improving the performance of a printing ink manufacturing company. | • Findings indicate the potential of DDMRP to improve system stability and product availability.<br>• Applicability is seen to be generally given but resulting value depends on the specific and unique situation of the adopting company.<br>• Further research needs to uncover more aspects of DDMRP in terms of its value to manufacturing organizations. |

*Table 18: Overview of DDMRP reviewing literature*

# H Script planning analysis

```
%% 1. Read Raw Planning Data Files

startTime = tic;
fprintf('Started Script \n');

folder = 'C:\Users\markvoge\Documents\MATLAB\RawPlanningData';
filetype = '*.txt';
filePattern = fullfile(folder,filetype);
items=dir(filePattern); % lists items in input folder
RawDataTables = cell(1, numel(items)); % preallocate the set of tables of raw data

%% 2. Read list of Materials in Scope including Consumption Data

startTime2 = tic; % section 2 timer
fprintf('Started section 2 \n');

% Scope is all materials with consumption > 0 in 2019 2nd half

opts2 = detectImportOptions('MaterialsV5.xlsx','Sheet',1); % Create an options object
% disp([opts2.VariableNames' opts2.VariableTypes']); % Examine the current (detected)
data types of the variables.

% Change the data of multiple variables depending on your import needs
opts2.VariableNames(1) = {'Material'};              % change variable name
opts2 = setvartype(opts2,{'Material'},'string');    % change variable type
% disp([opts2.VariableNames' opts2.VariableTypes']); % Examine the updated data types
of the variables

Materials = readtable('MaterialsV5.xlsx',opts2,'Sheet',1); % Column 1 = Material.
Column 2:27 = Actual Consumption Data 2nd half 2019

materials = Materials.Material; % create string array of materials

ConsumptionData = zeros(numel(materials),size(Materials,2)-1); % Store Consumption
Data Seperately

for i = 1:numel(materials)
    ConsumptionData(i,:) = table2array(Materials(i,2:size(Materials,2)));
end

% Replace no consumption data ('NaN') with 0
for i = 1:numel(materials)
    for j = 1:size(ConsumptionData,2)
        if isnan(ConsumptionData(i,j))
            ConsumptionData(i,j) = 0;
        end
    end
end

section2Elapsed = toc(startTime2)/60;
fprintf('Ended section 2 \n');
fprintf('Section 2 duration: %.0f %s \n', section2Elapsed, 'min');

%% 3. Convert Text Planning Data to Tables

startTime3 = tic; % section 3 timer
fprintf('Started section 3 \n');

for k = 1:numel(items)
    baseFileName = items(k).name;
```

```
    fullFileName = fullfile(folder, baseFileName);
    fileID = fopen(fullFileName,'r'); % open file for reading
    fprintf('Opened file %s\n', fullFileName);

    tline = fgetl(fileID);

    UpperDate = datetime('January 1, 2020');
    LowerDate = datetime('December 30, 2018');

    MaterialArray = strings(700000,1);
    DemandWkArray = zeros(700000,1);
    QuantityArray = zeros(700000,1);

    count = 1;
    while ischar (tline)
        if contains(tline,'Material.. ')==1
            Material = convertCharsToStrings(tline(12:25)); % material
        end
        if length(tline) > 90 && tline(87) == '-' && tline(88) == ' '
            DemandQty = str2double(tline(80:86)); % demand
            date = datetime(tline(1:10),'InputFormat','dd.MM.yyyy'); % date
            if date < UpperDate && date > LowerDate % store date if in 2019
                DemandDateSTOff = week(date-1);

                MaterialArray(count) = Material;
                DemandWkArray(count) = DemandDateSTOff;
                QuantityArray(count) = DemandQty;

                count = count + 1;
            end
        end
        tline = fgetl(fileID);

    end
    % Store table for week k
    RawDataTables{1,k} =
table(DemandWkArray,MaterialArray,QuantityArray,'VariableNames',{'DemandWkSTOff','Mate
rial','Quantity'});
    fclose(fileID); % close file
    fprintf('Closed file %s\n', fullFileName)
end

section3Elapsed = toc(startTime3)/60;
fprintf('Ended section 3 \n');
fprintf('Section 3 duration: %.0f %s \n', section3Elapsed, 'min');

%% 4. Compute Planning Matrix for materials in scope

startTime4A = tic; % section 4A timer
fprintf('Started section 4A \n');

Matrix = zeros((numel(items)+1),numel(items),numel(materials)); % preallocate Matrix
with planning data per material

% we work with a 3D matrix M(a,b,c)
% a: the row: is the planning week (from this week we look at the planning for the
coming weeks)
% b: the column: also planning week
% c: the page: e.g. the material under consideration, we create a 2D planning matrix
for each material
```

```
% Outer loop:   considers planning data as stated in week k (e.g. will fill the rows
of "Matrix")
% Middle loop:  considers next material in scope (e.g. will fill the page of "Matrix")
% Inner loop:   considers the planned demand per week for the current material
%               and current week of planning data from which we look at (e.g. will
fill the column of "Matrix")

for k = 1:numel(items)
% iterate over weeks of planning data
    for i = 1:numel(materials)
        string = materials(i);
        data = RawDataTables{1,k}(contains(RawDataTables{1,k}.(2),string),:);  % Skim
Raw Data to current Material
        for t = (k+26):52 % only fill rows on the diagonal and to the right
        woopdata = data(data.DemandWkSTOff==t,:);% Skim Further to data week t
        Matrix(k,t-26,i)=sum(table2array(woopdata(:,3))); % For week 1927 (row), for
time t(1927,column), and material i (page)
                                                                % fill in the total
planned qty
        end
    end
    fprintf('finished matrix week (e.g. row) for all materials %.f \n',k);
end

section4AElapsed = toc(startTime4A)/60;
fprintf('Ended section 4A \n');
fprintf('Section 4A duration: %.0f %s \n', section4AElapsed, 'min');

startTime4B = tic; % section 4B timer
fprintf('Started section 4B \n');

% Fill below the diagonal with actuals:
for i = 1:numel(materials)
    for k = 1:numel(items)
        Matrix((k+1):(numel(items)+1),k,i) = ConsumptionData(i,k);
    end
end

section4BElapsed = toc(startTime4B)/60;
fprintf('Ended section 4B \n');
fprintf('Section 4B duration: %.0f %s \n', section4Elapsed, 'min');
%% 5 Compute Results Matrix

startTime5 = tic; % section 5 timer
fprintf('Start section 5 \n');

Results = zeros(7,(numel(items)-4),numel(materials)); % preallocate a matrix with
results per material
  % columns: specify the weeks
  % row 1: planning for 5 wk period (start of period specified in column)
  % row 2: actual for 5 wk period (start of period specified in column)
  % row 3: Delta for 5 wk period (start of period specified in column)
  % row 4: Relative Delta for 5 wk period (start of period specified in column)
  % row 5: Relative Delta (abs) for 5 wk period (start of period specified in column)
  % row 6: Max Deviation during period (deviation relative to baseline)
  % row 7: Relative Max Deviation
for i = 1:numel(materials)
    %for row = 1:numel(items) % row 1 = wk1932 % row 21 = wk1952
    %row = 1;
    for column = 1:(numel(items)-4)  % column 1 = wk1932 % column 21 = wk1952
```

```
                                            %(Items is manually set to 20 in stead of 21 to
exclude wk1952 for now-see earlier in script)
            Results(1,column,i) = sum(Matrix(column,column:(column+4),i));      % 5 wk
plan
            Results(2,column,i) = sum(ConsumptionData(i,column:(column+4)));    % 5 wk
actual
            Results(3,column,i) = Results(2,column,i) - Results(1,column,i);    %
Delta
            if Results(2,column,i) == Results(1,column,i)
                Results(4,column,i) = 0;                                         % if
plan = actual then relative Delta = 0
            elseif Results(2,column,i) == 0 && Results(1,column,i) ~= 0 % divide by
average if plan not 0 and actual 0
                Results(4,column,i) =
Results(3,column,i)/mean(ConsumptionData(3,(1:numel(items)-1)));
            else
                Results(4,column,i) = Results(3,column,i) / Results(2,column,i);    %
Relative Delta
            end
            Results(5,column,i) = abs(Results(4,column,i));                     %
Relative Delta (abs)
            Results(6,column,i) = max([sum(Matrix(column+1,column:(column+4),i)),
                                   sum(Matrix(column+2,column:(column+4),i)),
                                   sum(Matrix(column+3,column:(column+4),i)),
                                   sum(Matrix(column+4,column:(column+4),i)),
                                   Results(2,column,i)])- Results(1,column,i);   % Max
Deviation during period
                                   % Compares the demand for a fixed 5wk period (start
op period specified in column)
                                   % after 1, 2, 3, 4, and 5 weeks of the periods have
passed
                                   % so e.g. after 3 weeks the demand concerns 3 weeks
actuals and 2 weeks planned demand...
                                   % ...for the period under consideration
                                   % each time comparing it to the planning at the
start of the period (baseline).
            if Results(2,column,i) == 0
                % divide by average consumption if actual == 0
                Results(7,column,i) = Results(6,column,i) /
mean(ConsumptionData(3,(1:numel(items)-1)));
            else
                Results(7,column,i) = Results(6,column,i) / Results(2,column,i);
            end
    end
end

section5Elapsed = toc(startTime5)/60;
fprintf('Section 5 duration: %.0f %s \n', section5Elapsed, 'min');
fprintf('End section 5 \n');

%% 5 Compute End Results Matrix

startTime6 = tic; % section 6 timer
fprintf('Started section 6 \n');

EndResult = zeros(numel(materials),10);  % Specifies Results per mat.->Rows:
Materials, columns: outcomes per Material

for i = 1:numel(materials)
    EndResult(i,1) = mean(Results(1,:,i));      % Average planned demand (5wk)
    EndResult(i,2) = mean(Results(2,:,i));      % Average actual demand (5wk)
    EndResult(i,3) = mean(Results(3,:,i));      % Average Delta (5wk)
```

```
    EndResult(i,4) = mean(Results(4,:,i));       % Average Relative Delta
    EndResult(i,5) = mean(Results(5,:,i));       % Average Relative Delta (Abs)
    EndResult(i,6) = sum(Results(6,:,i) > 0);    % Periods with Positive Deviation
during period
    EndResult(i,7) = mean(Results(7,:,i));       % Average Relative Max Deviation
during period
    EndResult(i,8) = sum(Results(3,:,i) > 0);    % Periods with Positive Delta
    EndResult(i,9) = sum(Results(3,:,i) < 0);    % Periods with Negative Delta
    EndResult(i,10) = sum(Results(3,:,i) == 0);  % Periods where Delta = 0
end


section6Elapsed = toc(startTime6)/60;
fprintf('Section 6 duration: %.0f %s \n', section6Elapsed, 'min');

%% 6 Print Results

startTime7 = tic; % section 7 timer
fprintf('Started section 7 \n');

Table = array2table(EndResult);
Table.Properties.VariableNames{1} = 'AveragePlanned5Wk';
Table.Properties.VariableNames{2} = 'AverageActual5Wk';
Table.Properties.VariableNames{3} = 'AverageDelta';
Table.Properties.VariableNames{4} = 'AverageRelativeDelta';
Table.Properties.VariableNames{5} = 'AverageRelDeltaAbs';
Table.Properties.VariableNames{6} = 'PeriodsWithPositiveDeviationDuringPeriod';
Table.Properties.VariableNames{7} = 'AverageRelativeMaxDeviation';
Table.Properties.VariableNames{8} = 'PeriodsWithDeltaPositive';
Table.Properties.VariableNames{9} = 'PeriodsWithDeltaNegative';
Table.Properties.VariableNames{10} = 'PeriodsWithDelta0';

EndTable = [Materials(:,1) Table];

writetable(EndTable,'EndResultDateHere.xlsx');

section7Elapsed = toc(startTime7)/60;
fprintf('Section 7 duration: %.0f %s \n', section7Elapsed, 'min');

%% 7. Check if Material is in every week of Planning Data

startTime7 = tic; % section 7 timer
fprintf('Started section 7 \n');

CheckList = zeros(length(materials),numel(items));
for i = 1:length(materials)
    for j = 1:numel(items)
        CheckList(i,j) = sum(contains(RawDataTables{1,j}.(2),materials(i)));
    end
end

section7Elapsed = toc(startTime7)/60;
fprintf('Ended section 7 \n');
fprintf('Section 7 duration: %.0f %s \n', section7Elapsed, 'min');

%% Extra: Write plannings matrix / plannings results of single material to Excel

MatrixExample = array2table(Matrix(:,:,15115));  % PlanningsMatrix for material(16942)
writetable(MatrixExample,'12NCExampleMatrix2.xlsx');
```

```
ResultsExample = array2table(Results(:,:,15115)); % ResultsMatrix for material(16942)
writetable(ResultsExample,'12NCExampleResults2.xlsx');

%% 7B. Check if Material in MRP Backup

startTime7B = tic; % section 7B timer
fprintf('Started section 7B \n');

MaterialsInRD = strings(30000,numel(items));

for k = 1:numel(items)
    baseFileName = items(k).name;
    fullFileName = fullfile(folder, baseFileName);
    fileID = fopen(fullFileName,'r'); % open file for reading
    fprintf('Opened file %s\n', fullFileName);

    tline = fgetl(fileID);

    count = 1;
    while ischar (tline)
        if contains(tline,'Material.. ')==1
            Material = convertCharsToStrings(tline(12:25)); % material
            MaterialsInRD(count,k) = Material;
            count = count + 1;
        end

        tline = fgetl(fileID);

    end
    fclose(fileID); % close file
    fprintf('Closed file %s\n', fullFileName)
end

section7BElapsed = toc(startTime7B)/60;
fprintf('Ended section 3 \n');
fprintf('Section 7B duration: %.0f %s \n', section7BElapsed, 'min');


%% Extra: Count 5 weekly periods with 0 demand
ActualCons5wks = Results(2,:,:);
% count how many (out of the 22 measured 5-weekly periods) contain 0 demand
% if a material has a 5 weekly period with 0 demand, then out of scope (i.e. MAPE
breaks down, and too sporadic)
ZeroPeriods = zeros(length(materials),1);
for i = 1:length(materials)
    ZeroPeriods(i) = sum(Results(2,:,i) == 0);
end
ZeroPeriodsPerMat = [array2table(materials), array2table(ZeroPeriods)];
writetable(ZeroPeriodsPerMat,'ZeroPeriodsPerMat.xlsx');

%% 8. End
Elapsed = toc(startTime)/60;
fprintf('Ended Script \n');
fprintf('Duration: %.0f %s \n', Elapsed, 'min');
```