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Defining the scope of materials for demand-driven material requirements planning

A case study in operative purchasing of an MNC

School of Technology and Innovations
Master’s thesis in Economics and
Business Administration
Industrial Management

Vaasa 2023

UNIVERSITY OF VAASA
School of Technology and Innovations
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Title of the Thesis: Defining the scope of materials for demand-driven material requirements planning : A case study in operative purchasing of an MNC
Degree: Master of Science in Economics and Business Administration
Programme: Industrial Management
Supervisor: Ahm Shamsuzzoha
Year: 2023 **Pages:** 98

ABSTRACT:
In today's fast-paced business environment, effective material planning is crucial for companies with manufacturing activities to improve their operations, or even remain competitive. Demand-driven MRP (DDMRP) is an approach to material planning that emphasizes responsiveness to customer demand, allegedly resulting in the improvement of material flow. The aim of this research is to determine which proportion of purchased materials could be beneficial to purchase with planning done in a demand-driven way in a complex manufacturing environment, and what the financial impact of implementing DDMRP would be. The structure of the theoretical framework is formed on the themes of DDMRP, suitability identification tools, and profitability. The topic areas are reviewed from the perspective of the operative purchasing department located in a manufacturing plant of a multinational company.

The research problems are approached with three different questions about suitability, features of the identification tool, and financial impact. The objective of this study is to address existing study gaps by defining what materials are DDMRP-suitable and building a tool that helps to identify such materials. Furthermore, the research problem of financial impact originating from DDMRP implementation is addressed to form a comprehensive image of the implementation process of DDMRP. The study focuses solely on purchased materials.

The research methodology consists of a mixed method case study approach, where semi-structured interviews were conducted with supply chain professionals from the case company, and quantitative data related to the case company's operations was analyzed. The quantitative analysis was done with the help of an Excel calculation sheet, that simulated DDMRP buffers for the sample materials. The data consisted of the relevant data of over 10,000 purchased materials. The findings of this study suggest that there are no certain characteristics that materials suitable for DDMRP have, but the potential must be defined individually in the case of every purchased material. The tool initially developed in this study helps to identify materials that meet the requirement of providing potential positive financial impact if brought into DDMRP scope by analyzing historical demand data, lead times, and inventory carrying costs.

The results of this study provide insights for supply chain professionals on how to identify materials that could have a positive effect from demand-driven planning. The tool developed in this study can be used by companies to analyze their material procurement process and identify areas for improvement. This study contributes to the field of supply chain management by providing a practical tool for companies to understand DDMRP phenomena and improve their material planning. Limiting factors of the research include data accuracy and the employment of the tool as an aid for decision-making only.

KEYWORDS: material requirements planning, supply chain management, supply chains, inventory management, order management

VAASAN YLIOPISTO
Tekniikan ja innovaatiojohtamisen akateeminen yksikkö
Tekijä: Tuomas Jaakkola
Tutkielman nimi: Defining the scope of materials for demand-driven material requirements planning : A case study in operative purchasing of an MNC
Tutkinto: Kauppatieteiden maisteri
Oppiaine: Tuotantotalous
Työn ohjaaja: Ahm Shamsuzzoha
Valmistumisvuosi: 2023 **Sivumäärä:** 98

TIIVISTELMÄ:
Nykypävän nopeatempoisessa liiketoimintaympäristössä tehokas materiaalisuunnittelu on ratkaisevan tärkeää valmistavan teollisuuden yrityksille toimintansa parantamiseksi ja pelkästään kilpailukykynsä säilyttämiseksi. Kysyntävetoinen materiaalitarpeiden suunnittelu (DDMRP) on kohtalaisen uusi, kysyntävetoisuutta painottava lähestymistapa materiaalisuunnitteluun, jonka väitetään vähentävän ylivarastoinnin ja varaston loppumisen riskiä. Tämän tutkimuksen tavoitteena on selvittää, mikä osuus ostetuista materiaaleista voisi olla hyödyllistä ostaa kysyntälähtöisesti monimutkaisessa teollisessa ympäristössä, ja mikä olisi DDMRP:n käyttöönoton taloudellinen vaikutus. Teoreettisen viitekehyksen rakenne muodostuu DDMRP:n, soveltuvuuden tunnistamisen työkalujen ja kannattavuuden teemoista. Aihealueita tarkastellaan monikansallisen yrityksen tuotantolaitoksessa sijaitsevan operatiivisen oston näkökulmasta.

Tutkimusongelmia lähestytään kolmella eri kysymyksellä, jotka liittyvät soveltuvuuteen, tunnistamistyökalun ominaisuuksiin ja taloudellisiin vaikutuksiin. Tämän tutkimuksen tavoitteena on käsitellä aukkoja aiheeseen liittyvässä tutkimuksessa, määrittelemällä DDMRP:hen sopivien materiaalien laajuus ja rakentamalla työkalu, joka auttaa tällaisten materiaalien tunnistamisessa. Lisäksi DDMRP:n käyttöönottoon liittyviin taloudellisiin vaikutuksiin liittyvän tutkimusongelman tarkoituksena on muodostaa kattava kuva DDMRP:n toteutusprosessista. Tutkimus keskittyy pelkästään ostettaviin materiaaleihin.

Tutkimusmetodologia koostuu sekamenetelmäisestä tapaustutkimuksesta, johon sisältyi puolistrukturoituja haastatteluja case-yrityksen ammattilaisten kanssa ja case-yrityksen toimintaan liittyvän määrällistä datan analysointia. Kvantitatiivinen analyysi tehtiin Excel-laskentataulukon avulla, joka simuloi DDMRP-puskureita otoksen materiaaleille. Data koostui yli 10 000 ostettavan materiaalin datasta. Tämän tutkimuksen tulokset viittaavat siihen, että ei ole olemassa tiettyjä ominaisuuksia, joita DDMRP:hen sopivilla materiaaleilla on, vaan potentiaali on määriteltävä erikseen jokaisen materiaalin kohdalla. Tässä tutkimuksessa alustavasti kehitetty työkalu auttaa tunnistamaan materiaaleja, jotka täyttävät vaatimuksen mahdollisten positiivisten taloudellisten vaikutusten tarjoamisesta DDMRP:n piiriin tuotaessa. Työkalu tunnistaa sopivat materiaalit analysoimalla historiallisia kysyntätietoja, tilausaikoja ja varastointikustannuksia.

Tämän tutkimuksen tulokset tarjoavat oivalluksia toimitusketjujen ammattilaisille siitä, miten tunnistaa materiaalit, joilla voisi olla positiivinen vaikutus kysyntälähtöiseen suunnitteluun. Tässä tutkimuksessa kehitetyn työkalun avulla yritykset voivat analysoida materiaalihankintaprosessiaan ja tunnistaa parannuskohteita. Tämä tutkimus edistää toimitusketjun hallintaa tarjoamalla käytännön työkalun ymmärtää DDMRP:tä ja parantaa materiaalisuunnitteluaan.

AVAINSANAT: materiaalitarpeiden suunnittelu, toimitusketjujen hallinta, toimitusketjut, varaston hallinta, tilauten käsittely

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Abbreviations

ADU	Average daily usage
BOM	Bill-of-material
CoV	Coefficient of variation
CPF	Case production facility
DDMRP	Demand-driven material requirements planning
LTF	Lead time factor

MM	Material master
MRP	Material requirements planning
MOQ	Minimum order quantity
OP	Operative purchasing
PLT	Purchasing lead time
PO	Purchase order
PI	Purchased item
ROI	Return on investment
RQ	Research question
SKU	Stock keeping unit
TOG	Top of green buffer zone
TOR	Top of red buffer zone
TOY	Top of yellow buffer zone
VF	Variability factor

1 Introduction

In this section, a comprehensive introduction to the central themes of the research is presented. This serves not only as an orientation for the readers but also as a foundational base, outlining the broader context of the research. While establishing the importance of the research topic, the existing gaps in current knowledge are highlighted, emphasizing the need for further exploration. Within this introductory segment of this thesis, the primary objectives aimed to achieve are delineated, pivotal research questions are raised that guide the inquiry, and the specific delimitations that bound the scope of the study are set forth. To provide readers with a clear tentative understanding of the investigative approach, the chosen research methodology is briefly outlined. This includes strategies for collecting relevant data, the instruments employed, and a concise description of the case company that forms the core of this research.

1.1 Background

1.1.1 Material requirements planning and its impact on industrial operations

Effective planning of operations and materials is crucial for companies to remain competitive in today's fast-paced business environment. MRP is a widely used planning and control system for managing production and inventory (Butturi et al., 2021, p. 463), which involves forecasting demand (Lee & Adam, 1986, p. 1), planning production (Thevevin et al., 2020, chapter 1), and managing inventory levels (Thürer et al., 2022, p. 5). However, despite its popularity, traditional MRP systems have limitations. The limitations can be demeaning for profitability in the business environment of today’s world, which has been depicted as volatile, uncertain, complex, and ambiguous (VUCA-world).

To address the shortcomings of conventional MRP, professionals and academic literature have invented many new approaches to material planning across decades. One of them, demand-driven MRP (DDMRP), is a relatively new approach that aims to improve material planning by emphasizing responsiveness to customer demand and reducing the risk of overstocking or stockouts (Orue, 2020, p. 67). The core intention of the planning method is to “position, protect and pull” (Ptak & Smith, 2019, p. 52), which has been identified as a crucial element in different segments of business.

1.1.2 Case company introduction

This research is conducted in cooperation with a case company that has piloted a procurement system that implements DDMRP as the planning methodology. The case company is a multinational company with production activity in an important business sector. This study concentrates on the portion of the case company’s operations that are conducted in one of its production facilities in Finland. Furthermore, the scope of this study is the case company’s operative purchasing department, the objective of which is to ensure with the help of logistics, that all material needed by production is available at the needed time and in the needed quantity. Due to confidentiality, the studied company is addressed as the case company in this thesis, and the production facility as the case production facility (CPF). Moreover, some numerical values are excluded from the public version.

Now, as a part of continuous improvement in the case company, development of material planning has led to initiating the project of developing some practices, including procurement. Some changes have originated from the volatility and uncertainty of the business sector, and major amendments in the production facilities and information systems utilized. According to the case company, the uncertainty has led to increasing excess inventory levels in some portions of the purchased material portfolio, and to material shortages in other sectors. Both scenarios are highly unprofitable since e.g., material shortages lead to increasing costs from various areas. Also, excessive stock levels tie too much capital to the inventory, increase storage unit costs, and raise the risk of obsolete materials.

While the piloting of the DDMRP method has provided the case company with some results, there is a gap in knowledge about what the restrictive characteristics of purchased materials are that would exclude them from the DDMRP scope. Furthermore, the financial impact of implementing DDMRP is unknown. Consequently, if the case company had all the needed information about the implementation of DDMRP, the presumed benefits of DDMRP could be exploited in a way the whole process of procurement would face improvements.

1.2 Research Problem and Objectives

While there have been some promising results from the implementation of DDMRP in the industrial sector, it might be that not all materials are suitable for DDMRP. Consequently, companies need to identify the materials that can be purchased using DDMRP as a planning method. According to Azzamouri et al (2021, p. 14), Organizations are keen to eradicate their current systems when introducing a new one and thus, it is important to assess how DDMRP could be integrated seamlessly into the case company's operations. Furthermore, the case company desires to identify what scope of purchased materials could be reasonable to include in the procurement system dictated by the demand-driven planning method.

This study aims to define the scope of materials suitable for purchasing with the DDMRP method and build a tool for the case company that helps to identify such materials. Furthermore, an estimate of the financial impacts of implementing DDMRP is provided. The study provides insights for supply chain professionals on how to identify materials suitable for DDMRP and contribute to the field of supply chain management by providing a practical tool for the case company to implement DDMRP and improve their material requirements planning. Consequently, the research problem is the lack of knowledge about what purchased materials could be procured with the DDMRP method.

1.3 Research Questions

As mentioned, the research problem consists of the lack of knowledge on general characteristics of materials suitable for DDMRP and a lack of tools available to help companies identify such materials. Nevertheless, the financial impact of DDMRP as a planning method must not be neglected. This study addresses the objectives by answering the following research questions:

RQ1: What conditions must be met for a purchased item to be purchased with the DDMRP method?

RQ2: What features should a tool designed to identify DDMRP-suitable materials include?

RQ3: What are the consequences of deploying the DDMRP method with respect to a financial perspective?

Research questions 1 and 2 are exploratory by nature, and RQ3 can be defined as an explanatory question. The research questions are addressed in a separate way in this thesis. The first research question is addressed to find the appropriate breakdown of the purchased materials from the point of view of DDMRP-suitability with the help of DDMRP buffer levels and protected inventories. The second question, on the other hand, is centered around the identification of features that are required from an identification tool that aids in dividing SKUs of the CPF into DDMRP-suitable and unsuitable items. Thus, the second question is subject to contributing to the development of the objective of developing the tool to identify DDMRP-suitable materials. The third research question is addressed by calculating an estimate of the possible monetary effects of implementing DDMRP on a larger scale in the use of the CPF.

1.4 Scope and Limitations

The scope of this study is limited to the identification of materials that would be beneficial to be included in DDMRP scope, from all purchased items that are currently active in the CPF. The study does not cover the implementation or evaluation of DDMRP in general, but rather only in the operating environment of the case company. Consequently, the identified material scope and financial impact are highly limited to only the application of the case company. However, the basic logic of the identification tool of suitable materials for DDMRP can be adapted to the use of at least organizations operating in similar business fields and supply chain environments.

Furthermore, planning schemas apart from the most common ways of planning material requirements are excluded from the scope of this study, as well as reflecting the DDMRP-suitable material identification process to BOM structure. This is justified by the fact that this research focuses exclusively on the purchasing department of the CPF. Consequently, the sample scope of the materials that are analyzed in this research, consists of purchased materials of the CPF. One limitation factor is also the currency of the MM data used for the calculations, which might have an unpredictable impact if not up to date. Moreover, the suitability of each material as found in this research can be merely taken as an aid for decision-making, and the suitability in real-world circumstances might differ from the one stated in this thesis.

1.5 Research Methodology and data collection

The research methodology of the research consists of a mixed methods case study approach, where different research methods are used to address different research problems. This is done to appropriately find answers to the research questions based on the objectives and characteristics of each. The study incorporates qualitative, quantitative, and mixed methods research methodology.

To address the qualitative problems of the research, preliminary interviews, and semi-structured interviews were conducted with supply chain professionals from the case company. The gathered data was used to develop the tool for the identification of DDMRP-suitable materials. Furthermore, the findings from the interviews are compared with results from quantitative analysis of the case company's ERP data to thoroughly explain phenomena regarding the matter. The quantitative data is also analyzed statistically and individually. The tool developed in this study was built, tested, and validated using historical data from the case company.

1.6 Structure of the Thesis

The structure of the thesis is as follows: Chapter 2 provides a literature review of existing literature on the topics of conventional MRP, DDMRP, the general characteristics of materials suitable for this approach, and tools for identifying DDMRP-suitable materials. Chapter 3 describes the research methodology, including the research design, sampling and data collection, data analysis, and quality of the research. Chapter 4 presents the case study results, including the identification of characteristics of materials for DDMRP, the development of the tool for identifying such materials, and the financial impacts of different implementation scenarios. Finally, Chapter 5 provides a summary of the study, its contributions, practical implications, and recommendations for future research.

2 Literature review

In this section, the relevant literature on the topic is reviewed and analyzed to form a theoretical foundation for the case study. The literature used in this section consists of books and mostly peer-reviewed academic articles from multiple databases written about the topics of DDMRP, implementation of DDMRP, and conventional MRP. The databases that were used to conduct the explorative literature review include Emerald, Google Scholar, and Tritonia Finna. The review was done over literature from between the years 2014 and 2023 to address DDMRP as a topic. The review period for DDMRP literature was since the method was first introduced in the literature in 2008. Furthermore, the review of MRP was done over a wider scope, including source texts from up to the year 1970. The range was justified by the fact that the wider introduction of the MRP method was done in the 1970s by Joseph Orlicky (1975).

The literature review is divided into four main subject areas. First, the text goes through a historical overview and assessment of conventional MRP, after which the theory behind DDMRP is reviewed throughout. After that, the literature about general characteristics of DDMRP suitable materials is examined, as well as the implementation of DDMRP, and literature about tools to identify the suitable materials. The literature about financial impacts is excluded from the literature review since the results are presumably not applicable or commensurable with the case company. At the end of the section, the findings are summed up and applicable research gaps are identified.

2.1 MRP

In this sub-section, the history of planning systems and production control is examined from the point of view of MRP. With the help of the examination, the need for an alternative planning system is analyzed. In addition, the positive and negative aspects of conventional planning systems are mapped to assess the demand for an alternative purchasing planning system in the operative environment of the CPF. This part of the text is divided further into three sub-headings. First, the focus is directed on a historical overview of MRP, after which the method is analyzed with a SWOT analysis. In the SWOT analysis, the strengths and opportunities of the method are analyzed, and finally, the text covers the subject area of threats and weaknesses of MRP.

2.1.1 MRP and its evolution over time

The intention of materials planning is to determine the requirements of materials beforehand based on the overall requirements of a production facility (Chunawalla, 2008, p. 30). The act of determining the requirements contributes to efficiently managing a production facility, by aligning the scheduling of purchasing raw materials and component handling to customer requirements. For example, if the customer requires a final product manufactured by the CPF, it is not optimal to store an excessive amount of raw material or too much in advance in the warehouse. Addressing the need for a way to determine the requirement schedule ahead of time has generated a demand for a planning tool.

MRP was first conceived in the late 1950s and was widely introduced in 1975 when it transformed material planning (Miclo et. al, 2019, p. 1) and the overall manufacturing world (Smith & Smith, 2014, p. 2) profoundly. From the 1980s forward, MRP has faced improvements that have altered the capability of the system from simple MRP toward the BOM explosion and furthermore via MRP II to integration with ERP (Mabert, 2007, p. 355; Ptak & Smith, 2019, p. 3). These models have been incorporated with ideologies such as Lean and Kanban to improve the operations of companies (Miclo et al., 2019).

ERP is a comprehensive tool that is designed to improve overall business flow (Rondeau & Litteral, 2001, p. 5). According to existing literature, MRP is often integrated into an ERP system when it comes to the practical world (Butturi et al., 2021, p. 463; Thevenin et al., 2020, p. 2), because of the numerous limitations of a plain MRP system (Miclo et. al, 2019, p. 167), such as lack of integration with other functions of a company. A couple of years ago nearly 80 percent of companies with manufacturing activity implemented MRP in their new ERP systems (Ptak & Smith, 2019, p. 4)

The MRP’s ability to calculate dependent demand with the help of BOM was a massive improvement. The model establishes the base for the ability that improves the planning and scheduling of demand items that are dependent on one another. This means, that the schedules of different level components in the BOM that indicates the component hierarchy (Thevevin et al., 2020, p. 2) are linked together to determine an efficient supply schedule. Additionally, behind the main idea of MRP, there are also time-phased requirements, as well as the usage of statically formed safety stocks (Miclo et al., 2019, p. 1).

MRP as a planning method has been referred to as one of the industry's most extensively utilized systems for production control and planning by e.g., Butturi et al. (2021, p. 463) and Ptak and Smith (2019, p. 4). This might be due to simple mathematics in the core of the model, as well as easy integration. A conventional planning schema is illustrated in Figure 1. The model shows the basic structure of the planning schema. Furthermore, MRP’s major features have stayed the same from the beginning of the model, throughout the developmental phases (Miclo et al., 2019, p. 166; Ptak & Smith, 2019, p. 3)

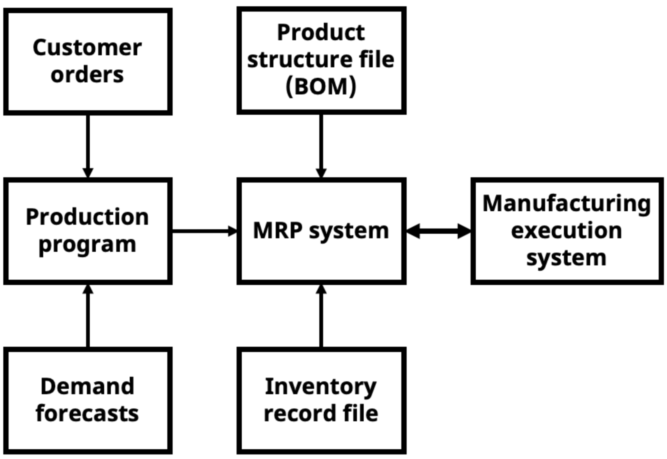

Figure 1. The conventional planning schema (adapted from Ptak & Smith, 2019, p. 22).

As implied, MRP enabled a big leap to happen in the world of production and procurement planning. MRP uses simple mathematical formulas in the calculation of purchase requisitions based on the BOM (Thevenin et al., 2020, p. 2). For example, if Item 1 is demanded on the date of June 4th, the purchase requisition is released for the purchaser to be purchased based on factors related to time, quantity, and price.

The date on which the purchase requisition is released is equal to the date of demand minus the effective LT (Louly et al., 2008, p. 5442). The demand for a specific day is calculated in MRP from the requirements of components that are on a higher level of the BOM, and eventually from the demand for future finished goods (Cooper & Zmud, 1989, p. 473). Because the levels of the BOM are interlinked, the MRP material requirements are referred to as dependent.

2.1.2 MRP strengths & opportunities

The strengths and opportunities inherent in Material Requirements Planning (MRP) can provide a competitive edge for organizations seeking to optimize their production and inventory management. These insights are drawn from a comprehensive review of existing literature on the subject, providing a well-rounded perspective. MRP proves to be particularly effective in scenarios where different parts come together seamlessly to create the final product, a point emphasized by Thürer et al (2022, p. 6).

The strengths and opportunities presented by MRP are systematically outlined in Table 1. This tabulated presentation serves as a convenient reference, capturing the various advantages and future possibilities associated with MRP. The presence of an 'x' at the intersection of a specific academic reference with a given row and column indicates a mention of the related strength or opportunity. This analysis shows the agreement in academic literature about the values and potential of MRP. It not only enhances understanding of the method but also underscores the scholarly basis supporting the arguments presented in this study.

Table 1. Relevant MRP strengths and opportunities in existing literature.

No	Authors	Type	Year	Strengths			Opportunities		
				Vast implementation	Simple inventory management	Production scheduling	Integrability with advanced technology	Simulation and modeling	Optimization
1	Jiang & Rim	Article	2017		x			x	
2	Azzamouri et al.	Article	2021				x		
3	Thürer et al.	Article	2022	x	x	x			
4	Favaretto & Marin	Article	2018	x	x	x			
5	Li & Disney	Article	2017		x				x
6	Ptak & Smith	Book	2019	x	x		x		
% of total				50	83	33	33	16	16

Some of the strengths of MRP that are implied in the existing literature include supply chain collaboration, inventory management, and efficient production scheduling. For example, supply chain collaboration is considered a strength of MRP by Azzamouri et al (2021), Thürer et al (2022), and Orue et al (2020). Inventory management can however be interpreted as a strength of MRP from texts implied in Table 1 above. In general, all strengths and opportunities are not stated directly in the literature listed in Table 1, but some can be interpreted from the overall text.

In this context, supply chain collaboration means efficient collaboration with all stakeholders in supply chains. This collaboration can be seen as a factor that has the potential to improve the responsiveness and effectiveness of MRP. Furthermore, inventory management can be defined as the optimization of inventory levels by minimizing carrying costs. This is achieved by reducing excess inventory. Efficient production scheduling, on the other hand, helps planning production activities, which leads to efficient allocation of resources.

Opportunities of MRP that arise from the existing literature consist of e.g., integrability with advanced technology, simulation and modeling, and parametrization and optimization. According to the text by Azzamouri et al (2021), and Duhem et al (2023), MRP can benefit from incorporating advanced technology, including AI, IoT, and data analytics. Furthermore, using simulation and mathematical models, MRP can be evaluated to assess the effectiveness of the planning method and to identify improvement areas. Finally, existing literature explores the parametrization and optimization of MRP, to enhance its performance and adaptability.

2.1.3 MRP weaknesses and threats

While MRP is a valuable tool for production and inventory management, it is essential to recognize the potential threats and weaknesses associated with it to mitigate any adverse effects on operations. One aspect that is highlighted by Ptak and Smith (2019, p. 7) is the excessive usage of external information systems on top of an MRP system. This concentrates mainly on the reliance on spreadsheets. As stated by Ptak and Smith (2019, p. 7), if purchasers made every system-proposed recommended adjustment to the open POs, massive issues would emerge. Consequently, an increasing amount of work is done around the system with the procedures of each employee (Ptak & Smith, 2019, p. 7), limiting the efficiency and performance of the MRP system.

To broaden the view, MRP as a planning method exposes the supply chain to nervousness, which leads to inventorial issues and, according to Li and Disney (2017, p. 1992), declining productivity and operative confusion. The nervousness originates from changes in schedules (Li & Disney, 2017, p. 1994) – considering both customers demands and supply from the supply chain. The nervousness is further developed by the compounding inaccuracy of information and material when moving toward the ends of supply chains.

The previously introduced inaccuracy can be described as the bullwhip effect, which results in unpractically varying production and procurement plans, causing a loss of capacity and increasing inventories (Li & Disney, 2017, p. 1993). In plain terms, the variability leads to a rising need for active operative purchasing and purchase order rescheduling, which might not be sustainable in the long run. The bullwhip effect has been argued to transfer and multiply the unpredictability, in the supply chain (Butturi et al., 2021, p. 463). The compounding influence of the bullwhip effect in a simple supply chain is illustrated in Figure 2, where the distortions of relevant information and relevant materials are described with meandering arrows. The distortion of relevant information increases when the information moves towards the beginning of the chain, whereas the distortion of material flows increases as the raw material is processed, manufactured, assembled, and brought to be a part of the final product through the supply chain.

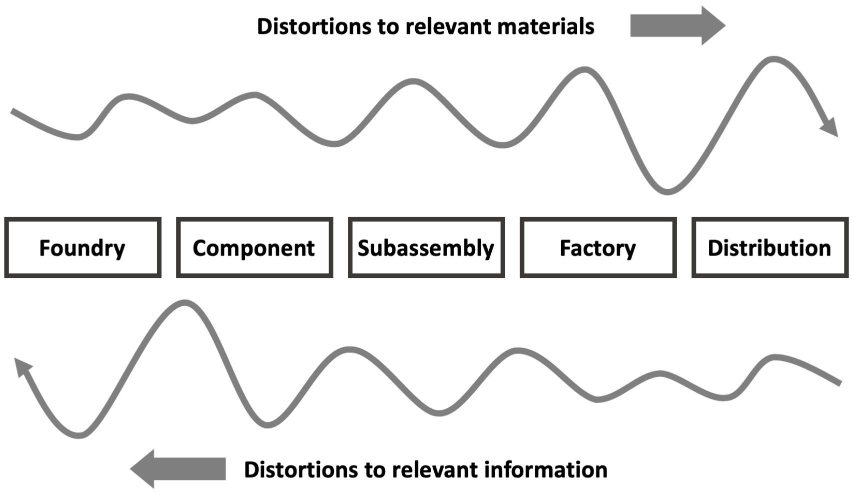

Figure 2. The bullwhip effect (adapted from Ptak & Smith, 2019, p.19).

The bullwhip effect is attributed to untrustworthy forecasting and uncertainty of material supply. To mitigate the uncertainty, the accuracy of demand forecasting is often attempted to be improved (Thevevin et al., 2020, p. 2). Nevertheless, the accuracy of forecasting is always more untrustworthy the further the demand is forecasted to the future, as the forecasts are always dependent on uncertain customer needs. Furthermore, according to Lee and Adam (1986, p. 3), effective forecasting in an MRP system would mean that the forecast is not conducted more to the future than the length of the total lead time of a product. Total lead time in this context means the time between the first order of raw material to the completion of a final product.

Even though the accuracy of forecasts is not great since the master production schedule (MPS) is variable by nature (Lee & Adam, 1986), MRP can redetermine relatively promptly the production plan based on updated demand data (Thevenin et al., 2020, p. 2). However, the reactive design is not optimal, since the new plan lacks proactivity in dealing with uncertain future demand. Also, when the MPS is shifted, the MRP often notifies with pressure to adjust all open POs to match the new requirements of each item in the BOM of each final product.

In MRP, there are some embedded buffers that can be used to assess the issues generated by the planning method itself. Static safety stocks and safety times are determined to overcome nervousness (Li & Disney, 2017, p. 1994) by hedging against the uncertainty of demand (Thevevin et al., 2020, p. 3). However, Thevevin et al. (2020, p. 7) claim that there is no analytical method that would determine MRP safety stocks in a direct way. The determination of different parameters is often done by each purchaser based on their own viewpoints and professional knowledge. However, Van Kampen et al. (2010, chapter 6), argue that time buffers improve delivery performance in a multi-product setting in a scenario where supply is under higher variability and safety stocks are considered as an enhancement in delivery performance when the demand information is unreliable.

Based on my observations, the effectiveness of the buffers is highly dependent on the accuracy of the parametrization. For example, if the safety stock is determined manually to either a level that is too low or high, the net benefits of the embedded safety are insignificant. This weakness of dependency on accurate data is also identified elsewhere throughout the planning system (Gupta & Snyder, 2009; Cooper & Zmud, 1989).

Even though conventional MRP has issues that evolve from various limitations (Cooper & Zmud, 1989, p. 472), it is still highly utilized, as most medium and large-sized enterprises with manufacturing activity today incorporate the planning method in their operations (Smith & Smith, 2014, p. 2). The vast implementation can be due to the development of information technology, which is argued by Rondeau and Litteral (2001, p. 5) to be the most important factor in changing the foundation of production economics by improving accuracy and reliability for instance. However, as stated previously, the MRP is often an integrated part of a wider planning system in an enterprise. Since this study focuses on material planning and procurement, the case company's system are referred to as MRP rather than ERP.

As stated in Table 2, the most relevant weaknesses of MRP were found to be the dependence on data accuracy, inaccuracy of forecasting, and inflexibility. These weaknesses were interpreted from the texts by Jiang and Rim (2017), Azzamouri et al (2021), Miclo et al (2019), Velasco Acosta et al (2020), and Mabert (2007) in the fashion implied in Table 2, where 'x' is marked under each reference suggesting the weakness listed in the first column to be true. It was found that if the data that is relevant for MRP is inaccurate, major issues can occur. In addition, forecast inaccuracy can lead to issues such as worse supply chain collaboration based on my observations. Furthermore, the inflexibility of MRP potentially reduces the opportunities of a production facility to quickly adapt to shifts in the market environment they are operating in.

Table 2. Relevant MRP weaknesses and threats mentioned in existing literature.

				Weaknesses			**Threats**		
No	**Authors**	**Type**	**Year**	Dependence on accurate data	Forecast inaccuracy	Inflexibility	Bullwhip effect	Nervousness	LT variability
1	Jiang & Rim	Article	2017	x	x				
2	Azzamouri et al.	Article	2021	x		x	x	x	
3	Thürer et al.	Article	2022				x	x	x

No	Authors	Type	Year	Weaknesses: Dependence on accurate data	Weaknesses: Forecast inaccuracy	Weaknesses: Inflexibility	Threats: Bullwhip effect	Threats: Nervousness	Threats: LT variability
4	Miclo et al.	Article	2019		x			x	
5	Li & Disney	Article	2019	x	x		x	x	
6	Velasco Acosta et al.	Article	2020	x			x	x	
8	Benton & Shin	Article	1998	x		x		x	x
9	Ptak & Smith	Book	2019	x	x	x	x	x	x
% of total				67	55	33	44	88	33

The threats that were identified, on the other hand, include the bullwhip effect, nervousness, and potential variability of lead times. From the aspects listed, the bullwhip effect is already defined at the beginning of the chapter. Nervousness on the other hand can be described as the frequent rescheduling and adjustments that can disrupt production schedules. These adjustments are often originated from minor fluctuations. Furthermore, as the idea behind MRP is that purchased materials arrive at the production facility's premises just before the production requires it, the variability of lead times can cause additional work or even production stops.

2.2 Demand-driven material requirements planning and its impact on material planning

As stated in the preceding part of this text, the business environment in which factories and entire corporations operate nowadays has also been referred to as the VUCA world (volatile, unstructured, complex, and ambiguous) (e.g., Johansen & Euchner, 2013, p. 10; Bayard et al., 2021, p. 1005) has changed greatly throughout the years since MRP was first introduced. The change has been inevitable, considering the change that the whole society has gone through in the past 50 years, and the problem of using similar planning methods as back then is also emphasized by Ptak and Smith (2019, chapter 1).

Consequently, the changing environment of manufacturing, originating from increasing competition for instance (Olhager, 2013, p. 6836), requires a more efficient way of planning, since companies’ performance often depends on one or another automated production planning strategy (Werth et al., 2023, p. 1117). The differences between a modern supply chain environment and a more traditional planning environment are implied in Table 3.

Table 3. Supply chain environment then vs. now (Ptak & Smith, 2019, p. 13; Olhager, 2013, chapter 2).

Circumstance	**1965**	**Present**
Supply chain complexity	Low	High
Product life cycles	Long	Short
Customer tolerance times	Long	Short
Product complexity	Low	High
Product variety	Low	High
Long lead time parts	Few	Many
Forecast accuracy	High	Low
Pressure for leaner inventories	Low	High
Transactional friction	High	Low

Even though the differences implied in the literature have been observed during the past ten years, the environment in which companies operate has not faced any critical changes. Due to the clear difference in today's operating environment compared to the one from the beginning days of MRP, companies have implemented various approaches to overcome the challenges generated by the prevailing operating environment e.g., according to Azzamouri et al (2021, p. 440), reducing costs and becoming increasingly reactive and flexible. Ptak & Smith (2019) argue that MRP as a part of a conventional planning method cannot work effectively, even if all the requirements and assumptions are perfectly known. In addition, existing research (e.g., Miclo et al., 2019; Thürer et al., 2022), has identified that MRP is clearly outperformed by other planning methods.

Since MRP, joined by other more advanced material planning techniques, such as MRP II, Lean, Theory of Constraints, etc. (Ptak & Smith, 2019, chapter 5), have limitations and room for improvement, different forms of hybrid push-pull systems (Miclo et. al, 2019, p. 168) have been developed throughout the years. On the contrary, the combination of push and pull systems has been argued to be difficult since it can lead to conflicts (Miclo et. al, 2019, p. 168). For instance, Ghrayeb et al (2009) found that push systems enable low delivery lead times for customers while holding more capital in inventories. On the other hand, pull systems do the exact opposite. Definitions of the different planning techniques according to the ASCM Supply Chain Dictionary (2023) have been listed at the end of the text in Appendix 1.

2.2.1 DDMRP: Definitions and its importance in material planning

A widely accepted fact in the academic community and business world is that the essence of successful, continuous, and profitable manufacturing and supply chains lies in the flow of materials, information, and cash (e.g., Ptak & Smith, 2019, p. 15; Thiede et al., 2019, p. 647). When the flow of the aforementioned factors moves in a favorable direction, ROI (return on investment) improves, making the shareholders satisfied. As the middle of all profit-seeking businesses is to drive equity to shareholders (Ptak & Smith, 2019, p. 15; Eloranta, 2018, p. 17), optimizing the flow of materials, information, and cash is in a crucial role in manufacturing entities.

While today's business environment offers companies easier ways of acquiring customer demand due to globalization, as customers are more likely to come from all around the world, many have argued that the increasing complexity, product variety, competitiveness, and dynamism of SCM (Azzamouri et al., 2021, p. 440; Butturi et al., 2021, p. 462; Duhem et al., 2023, chapter 1; Pekarcıková et al., 2019, p. 50) lead to growing needs for optimization of supply networks. According to Miclo et al. (2019, p. 166), the environment of today has created a need for developing different options for SCM systems to control better the challenging surrounding business field. Also, Azzamouri et al (2021, p.

440) have stated that traditional planning of manufacturing or control systems is not developed to deliver acceptable results in the volatile context of today.

As the modern supply chain can be defined perhaps more accurately in many cases more as a supply network due to the increasing number of suppliers, the problems are also formed with a multi-spindle nature, rather than a straight-forward, chain formatted one. As mentioned, the flow of materials, cash, and information forms the basis of success in SCM. It is crucial that the flows are optimized in order to improve business, ROI, and profitability for example. Consequently, the challenges posed by the modern business environment are being examined by organizations to gain competitiveness and overcome the issues. Apart from the traditional MRP, DDMRP has been identified as a possible solution to address the issues generated by the VUCA world.

DDMRP is a relatively new method, introduced by Ptak and Smith in the third edition of the book Orlicky's Material Requirements Planning (2011) that has been proposed as a hybrid push-pull solution (Butturi et al., 2021, p. 463) to overcome MRP nervousness and uncertainties caused by the bullwhip effect. The main idea behind the planning method is to "position, protect, and pull" (Ptak & Smith, 2019, p. 53), which is established to get rid of the problem of bi-modal distribution (see Figure 3).

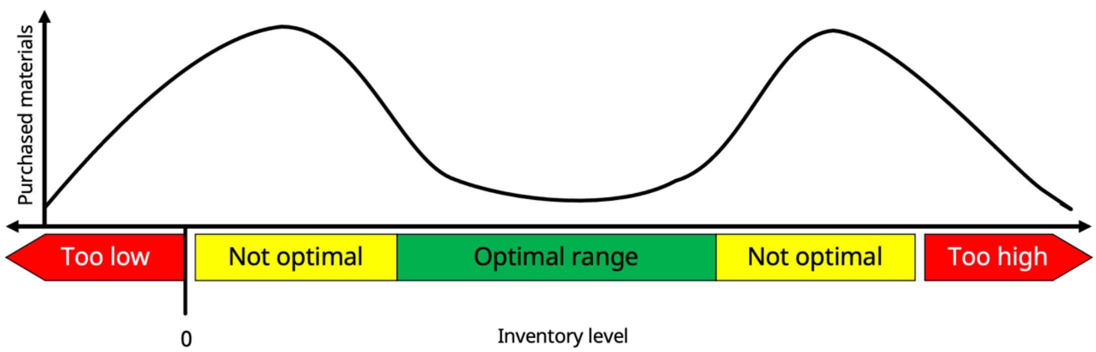

Figure 3. Bi-modal inventory distribution (adapted from Ptak & Smith, 2019, p.11).

In Figure 3, bi-modal inventory distribution is described with a graph that suggests that inventory is usually distributed disadvantageously to the lower and upper parts of the stock levels. The unideal distribution leads to the scenario in which the optimal range is somewhat underrepresented in the entity of stock levels, most of the materials are in stock in a state either approaching a level that is too low or too high. This contributes to possible stop or delay of production, or on the other hand, excess stock levels that negatively affect a company's cash flow. According to Pekarcıkova et al. (2019, p. 51), DDMRP aims to remove the negative influence generated by the bi-modal distribution, as well as to alter the supply chain towards a pull system, that reacts better to real demand.

DDMRP has been argued to solve the problems caused by volatile markets, fluctuating demand, and the great variety of products (Azzamouri et al., 2021, p. 440). Ptak and Smith (2019, p. 51) enlighten the origins of the term by stating that the original definition was formed around the idea of being able to detect variable customer demand to change planning and production accordingly, while at the same time acquiring materials from suppliers with the pulling strategy all in real-time. At the core of DDMRP is the intent to control material flow effectively (Ptak & Smith, 2019, p. 52), and the main difference from MRP is the focus of DDMRP toward the pull method, which shifts the control on qualified demand signals (Pekarcıkova et al., 2019, p. 58).

According to Miclo et al (2019, p. 166), basic MRP logic forms the foundation of DDMRP, which has been built with the intention of combining the best practices from former planning models. In total, the demand-driven method of planning material requirements combines different practices and principles from MRP, DRP, Theory of Constraints, Lean, Six Sigma, and innovations (Miclo et al., 2019, p. 168; Butturi et al., 2021, p. 463; Ptak & Smith, 2019, p. 52), as implied in Figure 4.

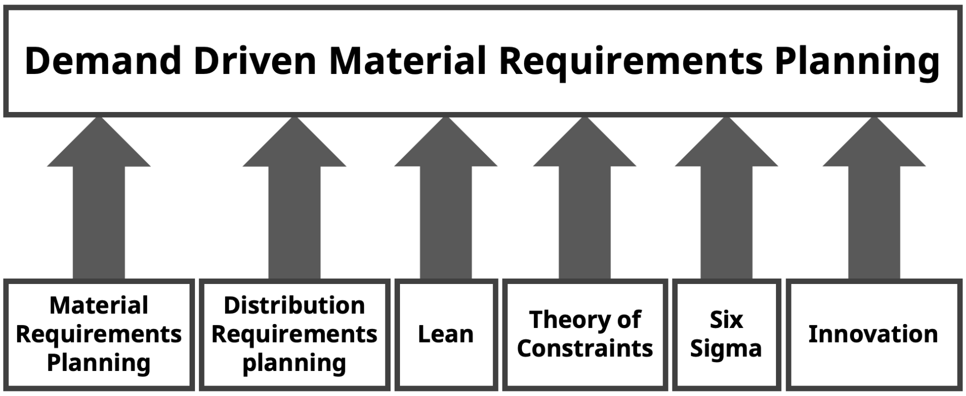

Figure 4. Methodological foundation of DDMRP (adapted from Ptak & Smith, 2019, p. 52).

In DDMRP the flow of materials is ensured by establishing the "position, protect, and pull" environment (Ptak & Smith, 2019, p. 53). The environment is formed over five steps: strategic inventory positioning, buffer profiles and levels, dynamic adjustments, demand-driven planning, and visible and collaborative execution (Ptak & Smith, 2019, p. 53; Azzamouri et al., 2021, p. 440). The five components are discussed more thoroughly in the following sub-sections of this chapter.

2.2.2 Strategic inventory positioning

At the core of strategic inventory positioning is the ability of purchasers to effectively get the right quantity of each of the needed materials at the right moment for production to use (Ptak & Smith, 2019, p. 57). While the bullwhip effect (see Figure 2) causes distortion in the supply chain as implied before, Ptak and Smith (2019, p. 57) propose decoupling points as a solution for the nervousness created by MRP's nature of forcing dependency between factors (Ptak & Smith, 2019, p. 27). These decoupling points are defined to be buffers that are used to ensure that when BOM is changed, the demand variety is not transferred to all the lower-level items. An example illustration of decoupling points in a simplified BOM can be found in Figure 5.

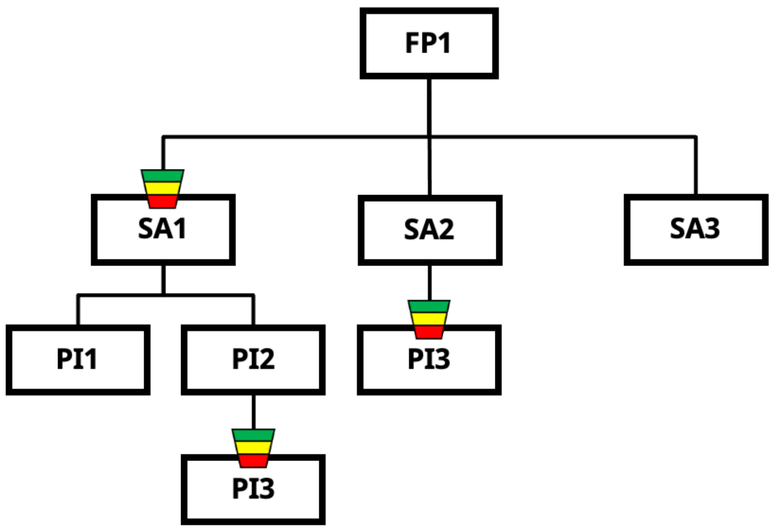

Figure 5. BOM with decoupling point positions (adapted from Jiang & Rim, 2017, p. 2).

The simplified BOM in Figure 5 includes the Final product 1 (FP1), Subassemblies 1-3 (SA1, SA2, SA3), and Purchased items 1-3 (PI1, PI2, PI3). When the variability is passed throughout the BOM, the decoupling points reduce the impact of it. For instance, if PI3 had a purchasing LT of 150 days, and the agreed MLT of FP1 would be around 30 days, an unexpected demand for FP1 would cause problems if PI3 was purchased without any buffer. The same equation is the basis of conventional MRP safety stock. The dynamic buffer is however different from the static safety stock, as are discussed in a further part of this text.

Ptak and Smith (2019, p. 71) argue that more advanced inventory positioning can be done for an environment with vast material structures that use shared components across different BOMs of final products. When the BOM is extended, the more easily it is affected by bad planning, variability, and the bullwhip effect. Thus, it is imperative to emphasize the cruciality of decoupling point selection, since Ptak and Smith (2019, p. 58) argue that the selection ultimately affects the ROI of a production facility.

The selection of decoupling points can be guided by six key factors: customer tolerance time, market potential LT, sales order visibility horizon, external variability, inventory leverage and flexibility, and critical operation protection (Ptak & Smith, 2019, p. 58). The first two factors are subject to further examination when the aim is to implement the demand-driven operating model in all parts of the organization, as they address to final product delivery lead time level on which customers are either no longer willing to wait, or willing to pay more. Alternatively, sales order visibility horizon and external variability are indeed factors that need to be addressed in the scope of this research. To simplify, the less visibility to the sales order horizon and the more external variability there is, the more a decoupling point is needed.

Furthermore, inventory leverage and flexibility, as well as critical operation protection, are factors that are addressed when deciding where the decoupling points should be stationed. Ptak and Smith (2019, p. 60) define inventory leverage and flexibility as points in BOM or a distribution network that provide the best LT compression for a company in order to meet business requirements. Also, critical operation protection is described to stand for identifying areas with e.g., limited capacity, possible quality disruptions, or amplified variability. Bayard et al. (2021) state that decoupling points are not new concepts but have been studied as the order penetration point.

As this study focuses mainly on defining the scope of materials that should be purchased with a demand-driven planning method, the focus is on the replenished parts. Also, prior research on the topic of DDMRP has addressed buffering only purchased materials, as Bayard et al. (2021) found in their study that buffering only purchased items can provide decent results.

2.2.3 Buffer levels, profiles, and dynamic adjustments

Buffers in DDMRP are certain points inside the overall flow of material in the supply chain that absorb variability in the form of a “dynamic safety stock”, that can be easily distinguished from a conventional safety stock, as it protects and promotes flow better (Ptak & Smith, p. 234). According to Ptak and Smith (2019, pp. 97–98), buffer profiles are sets of parameters that can determine the behavioral characteristics of a buffer. The characteristics can be divided into item type, LT, and variability. Furthermore, the buffer profiles assist in deciding how much inventory should be kept in the buffer.

The main idea behind buffering is to address the problem of having either too little or too much inventory. If the stock level is too low, it leads to material shortages from production, leading to production delays, expediting the production with costly overtime work, costly priority shipments (Ptak & Smith, 2019, p. 95), and possible contractual penalties (Preliminary interviews, May 2023). Alternatively, excess stock levels compromise cash flow, efficient usage of warehouse space, and use of recourses (Ptak & Smith, 2019, p. 95; Preliminary interview, May 2023). Consequently, Ptak and Smith state that the optimal range of inventory is thus between the two disadvantageous points, as described in Figure 6, in which the inventory loss function is illustrated.

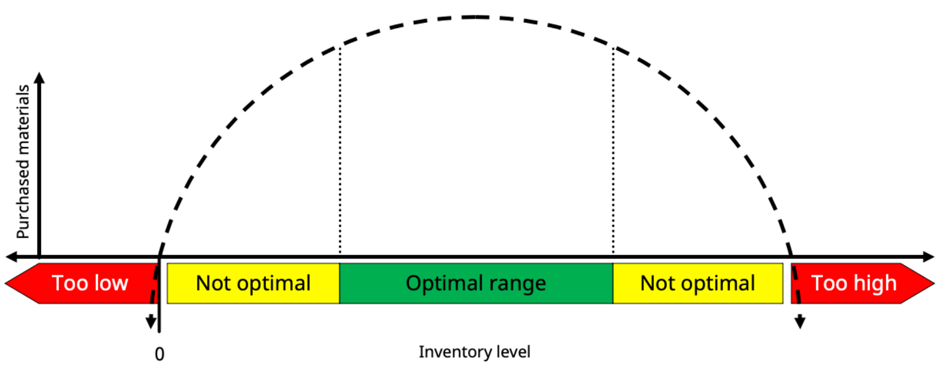

Figure 6. Taguchi inventory loss function (Ptak & Smith, 2019, p. 9).

When the decoupling points are identified, a buffer is placed there to absorb shocks, compress lead times, and propose purchase order generation. The idea is to keep the inventory level in the optimal range (see Figure 6) as efficiently as possible. There are three different types of buffering methods when it comes to DDMP: replenished parts, replenished override parts, and min-max parts. (Ptak & Smith, 2019, p. 96).

The buffer levels are delineated with summing three buffer zones together, which are the green zone, the yellow zone, and the red zone (Ptak & Smith, 2019, p. 97). For each buffer zone, there is a predetermined role as implied in Figure 7, where the buffer zones are displayed in a way they commonly are in the existing literature (e.g., Ptak & Smith, 2019; Duhem et al., 2023, p. 5). In addition, at the top of each buffer zone is a certain level that is referred to as the top of green, the top of yellow, and the top of red (TOG, TOY, TOR). The top levels of each buffer are subject to required actions that are done to ensure that the inventory level stays in the optimal range.

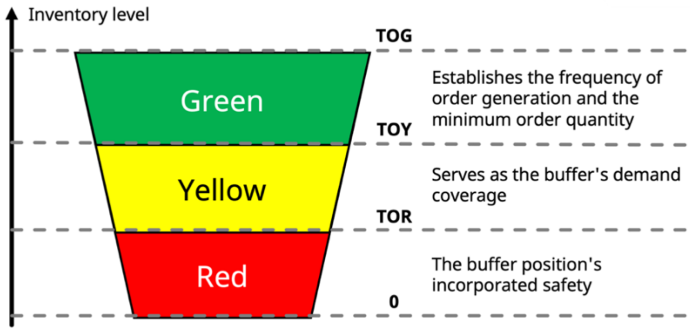

Figure 7. DDMRP buffer zones and purposes (adapted from Ptak & Smith, 2019, p. 98; Duhem et al., 2023, p. 5; Favaretto et al., 2022, p. 6).

The red buffer acts as the safety buffer of the entity and is designed to protect the inventory against supply variability. The yellow buffer on the other hand covers demand during the LT of the purchased item. Finally, the green buffer zone acts as a protector against unexpected demand surges. The buffer levels are not fixed, and thus the top levels of each (TOR, TOY & TOG) can alter based on demand, supply, and LT changes. (Ptak & Smith, 2019, p. 97). The equations for the buffer levels are implied in Table 4.

Table 4. Buffer equations (Pekarcıkova et al., 2019, p. 54).

Buffer level	**Equation**
Green	The smallest of: • Order cycle x ADU • DLT x ADU x LTF • MOQ
Yellow	• DLT x ADU

Buffer level	Equation
Red	Red Zone Base + Red Zone Safety • DLT x ADU x LTF (Red Zone Base) • LTF x Red Zone Base (Red Zone Safety)

In DDMRP, all items are divided into buffer profiles based on their specifications. The breakdown is done between three different factors: item type, LT, and variability. The factors are likewise divided into segments that eventually define the buffer profile for the material (Ptak & Smith, 2019, pp. 98–100). To simplify, a purchased item with as small buffer levels as possible would be characterized by low demand and supply variability, short lead time, high availability, low value, non-criticality, and high substitutability. On the other hand, the buffer is increased at each level according to the different levels of the aforementioned factors. The buffer levels are adjusted dynamically if the variabilities, lead times, and other specifications change.

When the item types are segmented, the minimum designations that must be defined are manufactured, purchased, and distributed (Ptak & Smith, 2019, p. 99). As this study focuses solely on purchased items, manufactured, and distributed items are left out. Therefore, in the later parts of this text, all example items are referred to as PI1, PI2, PI3, and so on. For the lead time, the segmentation is also done into at least three different segments, which can be divided into long, medium, and short LTs (Ptak & Smith, 2019, p. 99). To divide the third factor – variability – into segments, a minimum number of three segments are defined. The variability is at minimum divided into high, medium, and low demand variability (Ptak & Smith, 2019, p. 101).

When put together, these attributes form a minimum of a 3 x 3 x 3 three-dimensional table of possible buffer profiles that can be used to categorize purchased parts. Since this study concentrates on purchased items, the table of different buffer profiles shrinks to the size of 3 x 3 with two dimensions. In Table 5, the different equations for buffer profiles are listed. There are apparently no clear or universal rules on how the ranges of LT and variability factors should be parametrized, but the determination is more case-related and should be approached with the specific characteristics of each case company or factory. The parameterization of DDMRP is discussed more in the following parts of this text.

Table 5. Buffer profiles (adapted from Ptak & Smith, 2019, p. 104).

	Low variability	**Medium variability**	**High variability**
Short LT	SLT + LV	SLT + MV	SLT + HV
Medium LT	MLT + LV	MLT + MV	MLT + HV
Long LT	LLT + LV	LLT + MV	LLT + HV

When deciding on what ranges the LT and variability categories determined in Table 5 should be divided, the LTs of the purchased parts are divided into the three categories by multiplying ADU with decoupled lead time (DLT). The distribution is further explained in Table 6, where long LT is formed over parts that have 20-40% of ADU x DLT, medium LT with 41-60% of ADU x DLT, and short LT with 61-100% of ADU x DLT. These calculations to distribute the parts and form the LTF (see Table 6) is recommended by Ptak and Smith (2019, p. 100).

Table 6. Recommended LTF ranges (Ptak & Smith, 2019, p. 100).

LT category	**Definition**
Long LT	20-40% ADU x DLT
Medium LT	41-60% ADU x DLT
Short LT	61-100% ADU x DLT

To address the variability factor that divides variability into categories (see Table 7), some other factors have to be examined. According to Ptak and Smith (2019, pp. 101–102), the variability of supply must be calculated based on sourcing, variance of delivery dates from actual dates of delivery, and possible disruptions. The calculation of variability can be expressed mathematically with standard deviation for each material. The distribution of the VF and recommended segments can be referred to in Table 7. High variability is 61-100% of the safety base, medium variability is 41-60% of the safety base, and low variability is 0-40% of the safety base.

Table 7. Variability factor ranges (Ptak & Smith, 2019, p. 104).

Variability category	**Definition**
High Variability	61-100%+ of safety base
Medium Variability	41-60% of safety base
Low Variability	0-40% of safety base

Both LTF and VF can have a value that is between 0 and 1. For the LTF, the smaller the value, the bigger the safety. Alternatively, the higher the value of VF, the higher the variability. All the buffers and zone levels can be calculated with the factors visible in Table 8. From the factors visible in Table 8, at least when considering the situation of the CPF, the least change in the values is with LTs, LTFs, and MOQs. Consequently, the variables behind the dynamism of the safety stock are ADU and VF. This is another part of the DDMRP environment which is affected by the level of material flow.

Table 8. Buffer profile factors (Ptak & Smith, 2019, p. 111).

<table>
<tr><th>Part feature</th><th colspan="4">Buffer Profile Assignment</th></tr>
<tr><td>Average Daily Usage (ADU)</td><td rowspan="4">x</td><td rowspan="2">Lead Time Factor (LTF)</td><td rowspan="4">=</td><td rowspan="4">Buffer & Zone Levels</td></tr>
<tr><td>Lead Time (LT)</td></tr>
<tr><td rowspan="2">Minimum Order Quantity (MOQ)</td><td rowspan="2">Variability Factor (VF)</td></tr>
<tr></tr>
</table>

When compared with MRP safety stocks, DDMRP strategic buffers are first and foremost dynamic in nature. Furthermore, when a safety stock is determined, the actual stock minus the safety becomes the new zero-position that the MRP inevitably tries to net against (Ptak & Smith, 2019, p. 234). Behind this equation is the idea that the inventory level of an item should never go below the determined safety stock level. In DDMRP however, penetration into the inventory's safety level, which is the red zone, is seen as an act of routine (Ptak & Smith, 2019, p. 234). While the safety measures have been found to be more beneficial to be static on some occasions, the control of the buffers with ADU has been argued to possibly be sufficient (Martin et al., 2023, chapter 5).

In the scope of DDMRP, as in the scope of every material planning method, the introduction, ramp-down, and transition of products are critical processes that must be planned thoroughly. When introducing a new product, DDMRP utilizes demand adjustment factors (DAFs) to control the strategic buffers and real-time demand signals, sidestepping the pitfalls of relying on non-existent historical data (Ptak & Smith, 2019, pp. 133–134). This ensures rapid adaptability to unpredictable demand patterns without overstocking. Conversely, during product deletion, DDMRP's approach is to methodically reduce buffers based on waning demand signals, ensuring minimal leftover inventory and mitigating obsolescence risks (Ptak & Smith, 2019, p. 135). This is also done with the help of DAFs.

When there is a transitioning, whether it's between product versions or suppliers, it is streamlined in DDMRP. As demand shifts, buffers are dynamically adjusted, preventing stockouts of the outgoing version and excess of the new. This real-time adaptability can ensure smooth transitions without financial setbacks. In essence, DDMRP's focus on real-time demand and strategic buffering offers a nimble approach to product introduction, deletion, and transition, minimizing risks and optimizing supply chain responsiveness (Ptak & Smith, 2019, pp. 136–137).

2.2.4 Demand-driven planning

Demand-driven planning is the fourth component of DDMRP and is argued by Ptak and Smith (2019) to be a proven method of generating purchase orders. In the middle of purchase order generation is the net flow equation. The net flow equation is the single factor providing the purchaser with a signal of purchase order generation in demand-driven planning (Ptak & Smith, 2019, p. 149). The net flow position equation is as follows:

$$Net\ Flow\ Position\ (NFP) = On\ hand + On\ order - Qualified\ demand. \quad (1)$$

In the equation, the on hand refers to the physically available stock of the item, whereas the on order refers to the quantity of which the material has been purchased but has not yet arrived in the inventory. When on-hand and on-order stock quantities are summed up, the qualified demand of the current day is extracted from the value. The qualified demand includes the sum of requirements that are due on the current date or past due date, and qualified demand spikes. Consequently, the equation calculates the current inventory position of each day it is calculated. The net flow should be calculated daily on the decoupled positions. (Ptak & Smith, 2019, pp. 149–150).

In the context of DDMRP, the shift to actual demand represents a transformative approach to supply chain management. Traditional systems often rely on forecasts (Miclo et al., 2019, p. 167), which can be error-prone (Louly et al., 2008, p. 5442; Thevevin et al., 2020, p. 2) and lead to overstocking or stockouts. DDMRP, however, prioritizes real-time demand signals, ensuring that production and procurement decisions are directly aligned with current market needs (Ptak & Smith, 2019, chapter 9). This emphasis on actual demand, coupled with strategic stock buffers, has been argued to result in a more agile, responsive, and efficient supply chain, reducing inventory costs and enhancing customer satisfaction.

Within the framework of DDMRP, the concept of "qualified order spikes" emerges as a crucial consideration for supply chain professionals. Qualified order spikes refer to sudden and significant increases in demand that exceed the expected consumption pattern. The qualified spikes are then calculated into the net flow position (Dessevre et al., 2023b, p. 2). Unlike random fluctuations, these spikes are substantial enough to potentially disrupt the established buffer levels and lead to stockouts if not addressed promptly. According to Ptak and Smith (2019, pp. 151–157), DDMRP handles such order spikes by first distinguishing between "normal" demand and these exceptional spikes. This differentiation is vital to prevent the system from overreacting to every minor fluctuation, which could lead to unnecessary adjustments and inefficiencies.

Once an order spike is qualified, DDMRP recommends a two-fold approach: first, to satisfy the immediate spike from the available buffer, and second, to adjust replenishment quantities to restore the buffer to its optimal level. The advantage of DDMRP lies in its ability to maintain a balance. While it ensures that strategic buffers absorb most demand variabilities, it also recognizes and responds to qualified order spikes, ensuring that the supply chain remains agile and resilient. This approach not only prevents potential stock-outs but also ensures that the system doesn't overcompensate by producing excess inventory, thereby optimizing both responsiveness and cost efficiency. (Ptak & Smith, 2019, pp. 151–157)

Two questions define the timing and quantity that need to be determined when a purchase order is created. Traditional MRP calculates the timing based on the demand (requirement date), GR time, LT, scheduling margin key, and safety time. In demand-driven planning, the timing of placing a new PO is determined with TOY. When the net flow reaches the TOY level, a need for a PO is proposed by the system (Dessevre et al., 2023a, p. 741) (see Figure 8). The quantity on the other hand is determined by the visible demand, lot size, MOQ, and other factors when it comes to MRP. DDMRP defines the order quantity of the new PO to match the quantity of the green buffer. Thus, the newly created PO should move the net flow position to TOG (Figure 8). In classic DDMRP, the net flow equation is calculated continuously and thus recommends a new order to be created as soon as the net flow reaches the level of TOY. Azzamouri et al (2022) have assessed also periodic DDMRP compared to the classic one, which revises replenishment based on a specified review period.

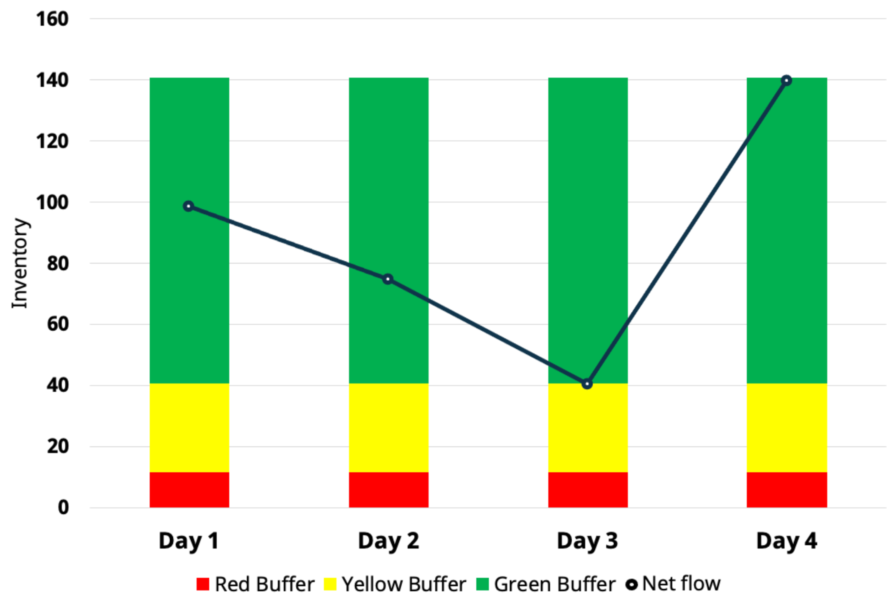

Figure 8. Simplified purchase order creation indication with net flow (adapted from Ptak & Smith, 2019).

According to Ptak and Smith (2019, p. 185), MRP and DDMRP in some cases do not differ from one another. In fact, the two methods are identical within certain parameters. If the decoupling points are efficiently established for some parts in the BOM, the items between the decoupling points are dependent on the final product in the same way they would be in MRP. This consideration is subject to further research since the BOM-related decoupling is not in the scope of this study.

2.2.5 Visible and collaborative execution

MRP has exception messages that indicate what should be done to POs for the SKU's inventory to maintain the desired level. These exceptions account mainly for rescheduling the delivery date either in or out or canceling the position in full. When a DDMRP system is used to control the material flow of a company, the exception messages are substituted by buffer status alerts. These alerts are divided to buffer status alerts and synchronization alerts, and further into current on-hand alerts, projected on-hand alerts, material synchronization alerts, and LT alerts. A description of the basic execution alerts is implied in Figure 9.

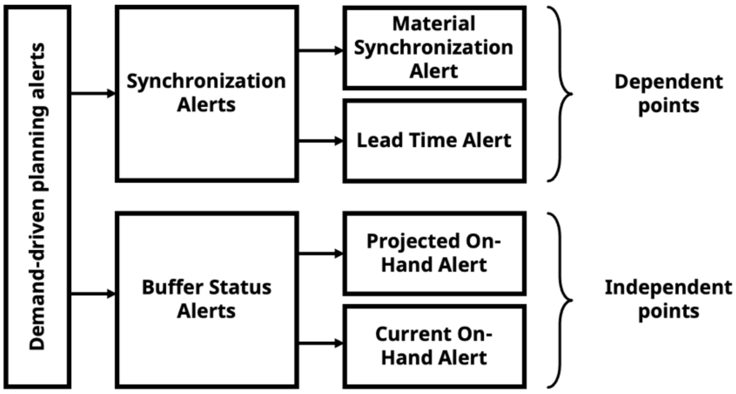

Figure 9. DDMRP basic execution alerts (adapted from Ptak & Smith, 2019, p. 208).

Buffer status alerts can be divided into current on-hand alerts and projected on-hand alerts. The first one shows what replenished positions are undergoing issues relating to only the on-hand perspective. These alerts message when it can be identified a certain PO should be immediately advanced. On the other hand, projected on-hand alert calculates possible criticalities in the buffer based on both supply and demand information. The alert considers the inventory that is available today and projects the on-hand status for all independent days that will come.

As implied in Figure 9, synchronization alerts can be divided into material synchronization alerts and lead time alerts. Material synchronization alerts are usually triggered when supply levels fall short of the required. This can be triggered with for example time frames in which the demand is significantly heavier than usual. Moreover, the synchronization alert can be triggered if a promise date of a PO is postponed by a supplier (Ptak & Smith, p. 225). The latter can be seen as a similar alert as the exception message of "reschedule in" in MRP. Alternatively, lead time alerts are execution alerts for items that are not strategically buffered.

In conclusion, the visible and collaborative execution focuses on current and projected integrity of decoupled point buffers, with a focus on the promotion and protection of material and information flow.

2.3 DDMRP suitable materials and tools to identify them

2.3.1 General characteristics of DDMRP suitable materials

As stated previously in the text, DDMRP has emerged as a revolutionary methodology within supply chain management, with potential implications for various industries. However, due to the nature of today's SCM environment, DDMRP is most likely not able to be implemented in a generalized way (see Azzamouri et al., 2021, p. 447; Butturi et al., 2021, p. 468) to all materials. Furthermore, when evaluating the performance of DDMRP in a complex context, there is no proof of how the method works (Azzamouri et al., 2021, p. 447).

The specific characteristics of the materials involved play an essential role when it comes to the applicability and success of DDMRP method. Moreover, it has been identified that the complexity of parametrization can affect critically the applicability of the method (Butturi et al., 2021). Shofa et al. (2018) conducted a study with a material that has the characteristics of e.g., 1313 ADU, a LT of 45 days, and variability factor of 50%. According to the study, the item performed better under demand-driven planning than MRP over the course of 180 days. Miclo et al. (2019) however, argue that DDMRP is especially effective for materials with higher demand variability. In addition, materials with very short LTs could possibly be better to buy with conventional MRP systems, since there would be little to no benefit from additional buffers. Furthermore, Butturi et al. (2021, p. 468) argue that the application of DDMRP to raw material procurement can become challenging if the LTs are protracted and cannot be tied to effective demand over long time ranges.

When deciding the aforementioned decoupling points in demand-driven planning, Ptak and Smith (2019, p. 57) identify the most effective points to be in specific locations inside the BOM and the supply chain. For example, if some purchased items are not directly on the path of the decoupled lead time chain of any final products, there is really no need to buffer and decouple the positions as no benefit could be generated for the parent item (Ptak & Smith, 2019, p. 73). If unnecessary decoupling is done, Ptak and Smith note that in such cases the buffer stock would need to be funded inefficiently with working capital with no visible benefit. In cases like those described, the DDMRP method would just work similarly to MRP. The buffer positioning is also highly case sensitive, as Benavente et al. (2022) have identified in their text that in industries that are usually affected by production stops due to the unavailability of raw materials that are at the bottom of the BOM, buffers have been positioned only to purchased items.

One objective of this study is to determine what are the characteristics that indicate a specific purchased item should be included in demand-driven planning. The existing literature does not contribute to the objective by stating clear boundaries to the occasion or excluding some purchasing items categorically. Some individual case studies and simulations on DDMRP parametrization have however been done with a limited scope. Therefore, there is a lack of direct information regarding the general characteristics of materials that are suitable for purchasing and managing with the DDMRP approach. There have been indicators of the wide suitability of DDMRP, as Favaretto et al. (2023, chapter 5) found in their study that if the parameters are set right, DDMRP can manage efficiently the inventory of materials regardless of the length of the LT.

2.3.2 Tools for identifying materials suitable for DDMRP

As mentioned previously, there are no fixed delimiters for material characteristics that would state DDMRP-suitability for different material groups. Moreover, no calculating model exists that could be used to identify DDMRP-suitable materials in the way required by the case company. However, there are some tools that could be used to set the parameters for DDMRP using historical and future data. For example, Damand et al. (2022) built an algorithm that contributes to optimizing DDMRP parameters. The objective of the algorithm is to help DDMRP optimize on-time deliveries and average inventory simultaneously through correct parametrization.

While the process of excluding a specific portion of materials from the scope of DDMRP planning is crucial, so is the parametrization of the materials that are chosen to be purchased with the DDMRP method. Lahrichi et al (2022, p. 9) argued that there is not a sufficient amount of theoretical work on the topic of DDMRP parametrization. Some studies however address the problem. According to Damand et al (2022, p. 19), a tool developed in their study can be used by a manager to fix DDMRP parametrization based on historical data of the previous year. This can be done to optimize the buffer positions, levels, and other DDMRP-related parameters. However, a tool of this nature does not align with the objectives of this study. Consequently, the absence of an identification tool forms a clear research gap.

2.4 Implementation of DDMRP in SCM

While DDMRP has been widely studied in the field of SCM, the lack of generalizable literature related to the implementation of the system in a real-world context is clear, apart from studies conducted by e.g., Kortabarria et al. (2018), and Ihme and Stratton (2015). This deficiency has been also acknowledged by Orue et al. (2020, chapter 1), and by Azzamouri et al. (2021, p. 452). Despite the missing literature, DDMRP has been argued to be a system that has been developed from practice (Bagni et al., 2021, p. 521)

As defined, DDMRP represents a novel approach to supply chain management, promising enhanced operative performance and efficiency. Some companies have implemented the method to assess their challenges and have reportedly benefitted from DDMRP implementation by having improvements in on-time delivery, reduction of stock-outs, and lower inventory levels (Miclo et al., 2019, p. 166). However, despite the burgeoning evidence supporting DDMRP's efficacy its integration and implementation remain subjects of extensive debate and investigation. This chapter analyzes the challenges associated with the implementation of DDMRP and its integration with existing systems, based on the literature and practitioner perspectives.

Though DDMRP shows considerable promise, its implementation comes with challenges. For example, the economic impact caused by implementing DDMRP is not general information (Benavente et al., 2022, p. 43), which can be a struggle in the implementation process. This absence of academic discourse is an issue for companies with vast and complex BOMs aiming to incorporate DDMRP into their supply chain management protocols, as they battle with logistical issues, such as the positioning of buffers (Achergui et al., 2021). Selective buffering - applying buffers where needed and removing them where unnecessary (Miclo et al., 2019, p. 178) - further complicates the implementation process.

Furthermore, there are technical obstacles to DDMRP implementation. Even though software solutions like Asprova and SAP claim DDMRP compliance, practitioners often struggle to integrate DDMRP parametrization into their software systems (Duhem et al., 2023, p. 3). There is a clear need for more refined implementation methods to assist companies in successfully incorporating DDMRP into their operations. The integration of DDMRP with traditional methods is another significant challenge. Organizations are often hesitant to abandon their existing systems, rendering it crucial to understand how DDMRP can coexist with traditional methods (Azzamouri et al., 2021, p. 452). Evaluating DDMRP performance in cooperation with other methods can also help determine its optimal implementation conditions and scope of use (Azzamouri et al., 2021, p. 452). However, there is a dearth of published results on DDMRP integration, further blocking comprehensive understanding (Duhem et al., 2023, p. 2).

The scarcity of concrete DDMRP applications reported in academic literature limits the validation of its implementation and integration strategies (Butturi et al., 2021, p. 469).

This paucity underscores the need for more empirical studies to confirm the purported benefits of DDMRP and furnish concrete guidelines for its implementation and integration. Furthermore, no established calculation method or tool using historical data has been developed thus far (Duhem et al., 2023, p. 4), indicating a significant gap in DDMRP methodology that needs addressing to facilitate more widespread and effective implementation.

Considering the demonstrated benefits of DDMRP in improving supply chain efficiency and performance (The Demand Driven Institute, n.d.), it is essential to overcome the challenges associated with its implementation and integration. The lack of detailed literature and guidance on DDMRP implementation and the complexity of integrating it with existing systems represent considerable limits. However, with further research and development of more refined implementation methods and effective integration strategies, DDMRP could revolutionize supply chain management. This would enable more organizations to leverage its potential benefits, fostering operational efficiency and resilience in an increasingly complex and unpredictable business environment.

2.5 Identified research gaps

As was found reviewing the literature related to the topic, the business environment has made a movement toward a more volatile, uncertain, complex, and ambiguous nature, also defined by the term VUCA-world. It was identified that the conventional inventory planning systems were not designed to operate in such a world, leading companies to face increasing issues in material planning and management. DDMRP was identified to be a promising method of material planning while incorporating certain difficulties in the implementation and parametrization phase. Also, the locating of decoupling points was found to be a critical exercise, since faulty strategic positioning can lead to compromising the positive effects promised by DDMRP.

A conspicuous gap in current research revolves around the absence of tools to adeptly identify materials that would be beneficial to be replenished using the DDMRP model. However, it is worth noting that certain tools pertaining to the parametrization of DDMRP have been created. This suggests a relatively more well-addressed dimension of the model's implementation. Consequently, while there remains a pronounced need for comprehensive tools in one area, the presence of tools in another facet signifies a step towards a more holistic understanding and application of the DDMRP framework.

Another research gap that was identified during the literature review is the clear generalized boundaries between which the characteristics of purchased materials could be put when implementing the demand-driven replenishment method. This might be due that the preparatory steps of implementing DDMRP were found to not be generalizable to different companies, but that every integration of the method must be done individually with the specific nature of the case company in mind.

3 Research methodology

This part of the research thesis outlines the methodology used for the empirical part of this research. The objectives are to specify the empirical method, the applied research strategy, and the scientific approach. Additionally, comprehensive descriptions of data collecting, organizing, and applied statistical analysis methods are provided. Finally, the concepts of validity and reliability are used to assess the quality of this research.

3.1 Research design

This study's empirical portion was carried out using a single-case study research design and mixed methods research method as an empirical methodology, which created the research strategy. According to Chumney (2015), mixed methods as a research methodology is defined by the use of both qualitative and quantitative methods in the research process. The use of this methodology was justified by the nature of the study’s research questions (see Figure 10). Research question 1 can be specified to be exploratory by nature, and the research method chosen to address the question was picked to be mixed methods, incorporating preliminary interviews and quantitative data analysis.

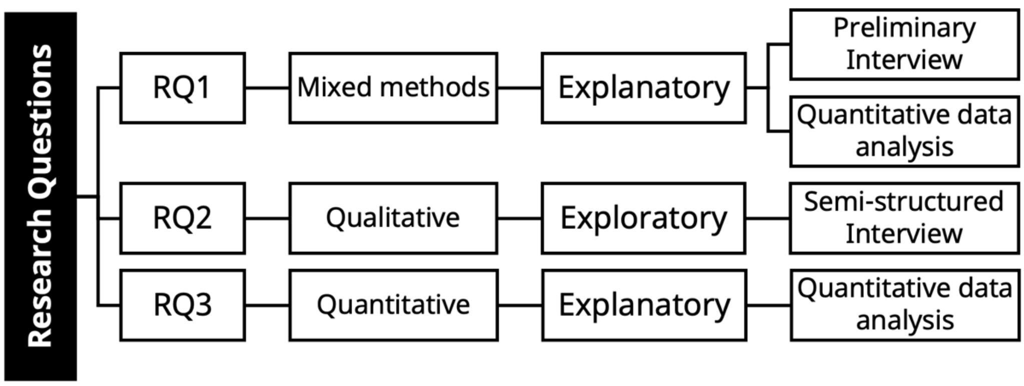

Figure 10. Methodological design of the research based on the research questions.

Likewise, RQ2 is exploratory by nature, proposing the use of qualitative methods. The objective of building a tool to identify the DDMRP-suitable materials dictates the direction of the methodology to be qualitative since an in-depth review of the subjective need for the features of the tool was seen as beneficial. RQ3 is yet again explanatory by nature, which led to conducting the research with mainly quantitative research methods.

According to Chumney (2015) and Mitchell (2018), the research method of a study is usually determined more by the nature of individual research questions, and the expected outcomes. Additionally, the choice of research methods is case-sensitive and thus requires analysis of the nature of the research questions. As for the RQ2, the objective of finding needed features for the tool requested by the case company shifted the methodology toward the usage of qualitative methods, since the needed features were somewhat subjective opinions, rather than numerical facts that could have been extracted from quantitative data. Alternatively, research questions 1 and 3 intended to find out specific characteristics of materials and financial effects, which both relied on numerical data. For the RQ1 however, the case-specific attributes for suitable materials were mapped out with aid of qualitative methods, shifting the methodology toward mixed methods.

3.2 Data collection and sampling

Since the data collection was done with semi-structured interviews which are qualitative by nature and with collection of quantitative data from the case company's ERP, the use of mixed methods was substantiated. Consequently, to sufficiently assess the research questions and objectives, both a qualitative viewpoint of the topic and a quantitative data collection were required. As stated previously in Figure 10, the data collection method incorporated in the research was determined by the nature of each research question. Furthermore, the sampling was also done based on the requirements of each research question and the objectives of the study.

For the RQ1, the mixed nature is perceived, leading to addressing the question with both qualitative and quantitative data. Data was collected first as a part of the preliminary interview, and the answers were compared to data collected from the ERP of the CPF. According to Chumney (2015), mixed methods are often used in this order (qualitative first, quantitative second) with research questions that are exploratory by nature.

The sample of the quantitative data to address RQ1 consisted of a sample that was formed from all purchased items that were specified with a material number in the CPF and had historical usage data and future requirements. This exclusion was based on the recognition that an analysis relying on consumption cannot be meaningfully conducted with materials lacking the necessary consumption data. The outline for the sample was also done to materials with the most usual MRP profiles, which were CO06, CO08, CO09, and CO11. This exclusion was validated by the fact that other profiles in the existing processes of the CPF are not capable of being purchased with the current DDMRP software used by the case company. After the outlining, the total quantity of SKUs in the sample was counted to 10 841.

After the initial material selection, the subsequent step involved the extraction of consumption data from the ERP system of the CPF. This dataset formed the foundation for the analysis and comprises records of material consumption over the review period. After the consumption data was fetched, the data collection process extended to the extraction of monthly inventory levels from the ERP system. Specifically focusing on the end of each month in the review period, this dataset provided data on inventory levels at predefined intervals. This approach was motivated by the constraints within the ERP system.

Following the collection of material consumption and inventory level data, the delivery reliability and annual quality notifications for each material were fetched from the case company's system. Both data sets were later used in the assessment of the research problems, forming an adequate measure for calculating the CDAFs for each sample material. The delivery reliability data was gathered from the review period from each external supplier of the CPF. Furthermore, annual quality notifications were calculated from all rejective external quality notifications that had been created in the case company's ERP between the beginning of July 2022 and the end of June 2023. This time frame deviated from the review period of other measures since it was more simple to calculate annual quality notifications based on annual data, rather than two quarters.

All mandatory master data of the sample materials needed to calculate the DDMRP simulation are listed in Table 9. The data attributes described in the table form the minimum required data scope that is needed to calculate the buffer levels, and ultimately whether purchasing a sample material with the DDMRP method would potentially have reduced the inventory level of the material.

Table 9. Required master data attributes that were used in the calculations.

Name	Definition
Material number	A number that specifies a PI, crucial for part identification
Effective lead time	Purchasing LT + transportation time
Fixed lot size	Proportions that must be when ordering
Minimum order quantity (MOQ)	Minimum quantity of a material in a PO
Delivery reliability of supplier 1.1.-30.6.2023	What percentage of deliveries during the review period were delivered on time
Annual quality notifications	The number of rejective quality notifications issued for a material during the past year
Consumption 1.1.-30.6.2023	How much a material was used for production during the time frame?
Average inventory 1.1.-30.6.2023	How much stock were there during the time frame?

To address RQ2, qualitative data was collected with semi-structured interviews. The interviews were conducted with respondents from the purchasing department of the CPF. The invitation was sent to a portion of the members of the purchasing department all of which had some prior knowledge about DDMRP. Following the sampling, an individual timeslot of about 15 minutes was booked with each respondent. The interviews were conducted in a hybrid form, using both live interviews and remote video calls using

Microsoft Teams as software. The interviews were conducted fully in Finnish to ensure perfect understanding since all respondents had Finnish as their native language. All interviews were recorded.

According to George (2022), the sampling of semi-structured interviews can be done with convenience sampling, which refers to picking a specific set of participants that are easily accessed. The sample size for the interviews was formed with the convenience sampling method, which resulted in a total of 13 respondents from the sample universe of members of the OP of the CPF who have some knowledge about DDMRP. According to Robinson (2013, chapter 3), in convenience sampling, respondents who meet the required criteria are picked for the sample as long as the sample size quotient is filled up. As 13 is the total quantity of personnel in the operative purchasing department of the CPF that have some degree of experience in the topic of DDMRP, it was justified as a sample size. Table 10 shows the descriptions of the interview respondents, including the designation, experience, and DDMRP knowledge of each interviewee.

Table 10. Semi-structured interview respondents.

Respondent	Designation	Level of expertise with DDMRP
Respondent 1	Purchaser 1	Low
Respondent 2	Manager 1	Advanced
Respondent 3	Manager 2	Advanced
Respondent 4	Manager 3	Advanced
Respondent 5	Development engineer	Medium
Respondent 6	Material availability manager	Low
Respondent 7	Purchaser 2	Low
Respondent 8	Purchaser 3	Medium
Respondent 9	Purchaser 4	Medium
Respondent 10	Supply chain expert	Low
Respondent 11	Purchaser 5	Low
Respondent 12	Purchaser 6	Medium
Respondent 13	Purchaser 7	Medium

Furthermore, the semi-structured interviews had a package of seven predetermined questions that formed the basis of the interview, leaving room for follow-up questions and discussion. The questions of the interviews are listed below in Table 11. First, the prior knowledge of each respondent about the topic was mapped out with a question about previous experience with DDMRP. Secondly, a total of five questions was asked regarding the design, target audience, and functionalities of the identification tool. To sum up and end the interview, a vast open-ended question was asked to figure if the respondent had anything more to say in order to contribute for the cause. Depending on the respondents' answers and viewpoints, some follow-up questions were asked. In addition, the topic of DDMRP or an interview question was explained in more detail if a respondent was not able to understand an individual question. However, if a respondent did not answer a question during the interview, no answer was forced out but rather considered as an answer regardless.

Table 11. Semi-structured interview questions.

Index	Questions	Questions in Finnish
1	What is your level of knowledge and previous experience with DDMRP?	Mikä on tietotasosi ja aiempi kokemuksesi DDMRP:stä?
2	Could you describe the features you would expect in a tool for identifying DDMRP-suitable materials?	Kuvailisitko yleisiä ominaisuuksia, joita odottaisit DDMRP:hen soveltuvien materiaalien tunnistamiseen tarkoitetulta työkalulta?
3	For whom should the tool on DDMRP suitability of materials be designed?	Kenen käyttöön työkalu materiaalien sopivuudesta pitäisi olla suunniteltu?
4	How important would it be to have the tool integrated into an existing system?	Kuinka tärkeää olisi saada työkalu integroitua osaksi jotain jo käytössä olevaa järjestelmää?
5	What type of user interface would you find most helpful in this tool?	Minkälainen käyttöliittymä olisi mielestäsi hyödyllisin tässä työkalussa?
6	How would you see yourself using such a tool?	Miten näkisit itse hyödyntäväsi tällaista työkalua?
7	Is there anything else you would like to share on this topic?	Onko sinulla jotain muuta aiheeseen liittyvää mitä haluaisit kertoa tässä yhteydessä?

When collecting data with interviews, research ethics must be considered. While the interview questions were not sensitive by nature, the anonymity of the respondents was crucial regardless. To address the ethical point of view, a consent of recording was gotten from each respondent before starting the recording. Also, the recordings were not stored longer than is needed for the research process, and the storing was done properly.

RQ3 is also explanatory by nature, and a quantitative method was required to form a tangible answer. The sampling for resolving the problem imposed by RQ3 was the same as the outcome of RQ1. This was done since the sampling was already efficiently done by identifying PIs that were performing inventorially better when the planning was done with the DDMRP method. Consequently, the data collected was the same sample of PIs that are the outcome of RQ1.

3.3 Data analysis

After sampling, data collection, and data verification, the analysis of the data was done with different methods depending on the data and related research questions and problems. Data related to RQ1 and RQ3 were analyzed with the help of an Excel sheet that included relevant calculations. RQ2 on the other hand, consisted of an in-depth analysis of the interview results. For the quantitative calculations, the system used was a computer using Microsoft Windows 10 Enterprise (64-bit) as software that has 16,0 GB of RAM and an 11th generation Intel(R) i5-1145G7 2,60 GHz processor. The calculation sheet consisted of five different sub-sheets that included raw consumption data, total usage of each material in the specified time frame, raw stock data for each material, average stock value in the same time frame for each material, and the sheet that included all the basic material master attributes for each material and also calculated the DDMRP potentiality and savings in the average stock level that could have been in the specified time frame if DDMRP was utilized.

On the raw data sheet, all consumptions to qualified orders for all CPF materials were listed, including the material number, date of consumption, and quantity of consumption. As implied previously, the data was filtered to be only from the time frame from the beginning of January 2023 to the end of June 2023. The time frame of the analysis was determined with the intention that it was not too long nor too short. According to Ptak & Smith (2019, p. 105), a too short period over which the ADU calculation is done can lead to overreactions and possible symptoms of the bullwhip effect. Thus, the review period was agreed with representatives of the CPF to be six months.

Furthermore, the raw data was fetched to the Consumption sheet to gain a comprehensive table from which the ADU and variability could be calculated efficiently. Image 1 shows the basic structure of the usage table, where on the top row material numbers are listed, and on the left-hand column, all dates in the time range are listed. The rest of the table was formed from cells that contain the consumed amount of each material on each date listed.

	Material								
Date	**PI1**	**PI2**	**PI3**	**PI4**	**PI5**	**PI6**	**PI7**	**PI8**	**...**
1.1.2023	0	0	0	0	0	0	0	0	...
2.1.2023	37	3	0	0	0	0	0	0	...
3.1.2023	0	0	0	0	0	0	0	0	...
4.1.2023	0	0	0	0	4	2	12	0	...
5.1.2023	0	0	0	0	5	0	0	0	...
6.1.2023	0	0	0	0	0	0	0	0	...
7.1.2023	0	1	0	0	0	0	0	0	...
8.1.2023	18	0	0	0	0	0	0	0	...
9.1.2023	30	0	0	0	4	0	0	0	...
10.1.2023	37	1	0	0	4	2	12	0	...
11.1.2023	0	0	0	0	0	0	0	0	...
12.1.2023	16	2	0	0	10	0	0	0	...
13.1.2023	0	0	0	0	0	0	0	0	...
14.1.2023	29	0	0	0	0	0	24	8	...
...	...	...	...	...	...	...	...	...	...

Image 1. Consumption sheet.

Stock quantities for each material at the end of each month in the period were listed on the Average Stock Quantity sheet. Finally, the average was calculated. Image 2 shows the structure of the Average Stock Quantity sheet. On the leftmost column of the sheet all the sample materials were listed. After that all months of the review period were listed on the first row to form the table of all month-end stock quantities of each sample material. Consequently, on the last column (also visible in Image 2), the average was calculated by summing up all the inventory quantities and dividing the sum by the number of the inventory quantities.

	Month						
Material	**01.2023**	**02.2023**	**03.2023**	**04.2023**	**05.2023**	**06.2023**	**Average**
PI1	216	718	598	454	542	498	504,33
PI2	85	81	81	65	49	41	67,00
PI3	110	120	85	87	199	197	133,00
PI4	138	134	86	100	84	112	109,00
PI5	16	14	26	22	27	26	21,83
...	...	...	...	...	...	...	...

Image 2. Average inventory level sheet.

For RQ1, data was analyzed by aligning qualitative findings from preliminary interviews and observations together and verifying the results with quantitative data analysis. The data analysis was done with the Excel sheet that calculated the suitability of each sample material with the help of formulas implied in Table 12. For each formula, the text between the parenthesis refers to the data that was used to calculate the calculation implied in the second column. For example, in the calculation of standard deviation, the word *consumption* refers to all the numbers that were listed under each PI in the consumption sheet. The rounding of the values of the buffer zones was done due to the integer nature of variables regarding the matter (Lahrichi et al., 2022, p. 9). Finally, the LTF and VF were calculated with the parametrization used by the CPF. The formulas of LTF and VF are not in Table 12 to avoid long chains of IF formulas. The definition and ranges of LTF and VF are implied in the literature review (see Table 6 and Table 7).

Table 12. Excel calculations.

Calculation	**Excel formula**
Standard deviation	=STDEV.P(consumption)
ADU	=AVERAGE(consumption)
CoV	=Standard deviation/ADU
Lead time factor (LTF)	
Variability factor (VF)	
Green zone	=ROUND(MAX(LT*ADU*LTF;MOQ;DOC*ADU);0)
Yellow zone	=ROUND((LT*ADU)+(CDAF yellow*ADU);0)
Red base	=ROUND(LT*ADU*LTF;0)
Red safety	=ROUND(Red base*VF;0)
Total red zone	=(Red base + Red safety) + (ADU*CDAF red)
On-hand target	=Red zone + 0,5*Green zone
Average inventory 1.1.-30.6.2023	=AVERAGE(inventory levels)
DDMRP potentiality 1.1.-30.6.2023	=IF(On-hand target<Average inventory; “YES”; “NO”)

To address the volatility of each materials supply environment, two new additional attributes were designed during the research. The attributes were included in the simulated buffers by adding them to the cycle day adjustment factors (CDAF) in the calculation sheet. The first attribute was vendor unreliability which was multiplied by CoV, and the second was annual quality notifications (AQN), multiplied by the ADU. Both were included in CDAF red and only the first one in CDAF yellow.

To justify the usage of these attributes, the requirement for additional buffering must be addressed. Uncertainty and unreliability are mandatory to be addressed in the calculations since it is a crucial factors in ensuring material availability. Supply chain uncertainty can be estimated based on historical delivery reliability data, which consists of the percentage of deliveries from a supplier that have arrived in time. To form the unreliability attribute, the delivery reliability has been inverted, i.e., subtracted from 100 percent. Furthermore, it is multiplied with the CoV since it illustrates the relation between standard deviation and ADU, and consequently the variability. The greater the variability, the more critical the unreliability of a vendor is.

The AQN measure counts all pieces of a SKU that have been rejected by the CPF during the past year. This number was then multiplied by ADU. The reason behind the calculation is that the more daily usage for a material there is, the more critical role a rejected piece plays in the bigger picture.

Data from the semi-structured interviews were mainly used to find an answer for RQ2. The data collected from the interviews were analyzed by comparing each individual answers with each other to form an in-depth understanding of what is required from the identification tool. Due to methodological restrictions, the findings of RQ1 were required before the data analysis for RQ3 could be conducted. The data was analyzed with the help of the same Excel calculation sheet, incorporated with additional calculations, that counted the possible cost effect of purchasing the sample materials with the DDMRP method.

The cost effects addressed mainly the savings of inventory value. The analysis of the financial effects on the inventory values was done by inserting two additional rows to the calculations implied in Table 12, target inventory value, average inventory value 1.1.-30.6.2023, and savings. Inventory values were calculated by multiplying the inventory quantities previously calculated by the unit price of each SKU. Consequently, the savings were calculated by extracting the on-hand target quantity from the average stock value in the review period.

3.4 Validity and reliability

The validity and reliability of a research methodology are fundamental to ensuring the accuracy and credibility of research findings. These two aspects are ensured through appropriate sampling and the use of up-to-date data. As this research incorporates different methods, methodological validity and reliability are also dependent on the different research methods. For instance, the validity of interviews is not assessed similarly to the validity of statistical analysis (Creswell & Creswell, 2018). In this context, the validity is first assessed from the point of view of all research methodologies, after which, the reliability is examined similarly.

The validity of quantitative research is crucial as it ensures that the research measures what it intends to measure (Creswell & Creswell, 2018). On the other hand, to ensure the validity of qualitative research, the credibility, transferability, dependability, and confirmability of the research must be considered (Shenton, 2004). While validity can be seen as a matter of quality in research, it is also important from the perspective of research ethics. If the validity is compromised in the process of data collection and data analysis, the claims made later in the course of the research can be invalid, leading to the spread of false information (Creswell & Creswell, 2018).

However, the symbiotic relationship between the two research methodologies is only one aspect of how well-mixed methods research is assessed. The discovery of new or distinctive insights that are made possible by the use of this methodology is another essential quality criterion in mixed methods research (Fàbregues & Molina-Azorn, 2017, chapter 3). In addition to validating its value, the creation of these unique insights through the use of mixed methodologies research promotes it as a convincing option for a research methodology.

In the context of mixed methods research, the validity and reliability of both the quantitative and qualitative components of the research must be considered. It must be ensured that the quantitative data is valid and reliable, and that the qualitative data is credible, transferable, dependable, and confirmable (Creswell & Creswell, 2018). The data used in this research can be presumed valid since it was gathered directly from the databases of the case company. However, it must be noted that there is a possibility, even if not significant in every case, that for instance, the material data fetched from the case company’s systems was in one way or another faulty.

In conclusion, the validity and reliability of a research methodology are crucial for ensuring the accuracy and credibility of the research findings. These aspects were ensured through appropriate sampling, which is described in the sampling section of this chapter, the use of up-to-date data, and the careful planning and execution of the research methods. By ensuring the validity and reliability of the research methodology, the research produces valid and reliable research findings that contribute to the body of knowledge in the field of industrial management.

4 Case study results

The findings of the empirical research are reported in this chapter, which is formed by four subchapters, followed by some multi-stage subsections. The results and answers found for the research questions are addressed chronologically in this chapter. Within this chapter, a detailed exposition of the empirical data is provided, replete with insightful interpretations and discussions.

4.1 Materials suitable for Demand-Driven MRP

4.1.1 Introduction to RQ1 Findings

The first objective of this thesis was to address the question of what purchased materials could be beneficially purchased by incorporating the DDMRP methodology. The benefit is referred to in this text as “DDMRP-suitability”, and materials of which inventory levels would decrease if planned with DDMRP as “DDMRP-suitable”.

The identification of DDMRP-suitable materials was made with the help of quantitative data, observations, and a calculation sheet. All purchased materials of the CPF were analyzed with the help of the calculation sheet that used basic DDMRP equations to evaluate if a purchased material would be beneficial to be purchased with the DDMRP method. Altogether, the data was collected from the case company’s ERP, after which it was analyzed to find characteristics for materials that would not have been potential for consideration of replenishing with DDMRP.

To answer RQ1, the data collected from the CPF’s ERP system was analyzed. The data was analyzed by simulating the buffer levels and average inventory levels all CPF materials would have had at a specific point. The buffer levels were simulated as if they would have been on July 1st, 2023, with an ADU calculated by data from the preceding six months. The DDMRP suitability of each material was assessed by determining conditions under which materials would outperform conventional MRP average inventories.

The findings included that about 57 % of the sample materials could have been beneficial to be purchased with DDMRP in the review period. Figure 11 shows the distribution between materials with DDMRP potential and materials with no DDMRP potential. The potential materials are marked with the color black and account for 57,1 % of all the sample materials, which was a total of 4 001 SKUs. Rest of the materials, a total of 3 008 SKUs (42,9 %) were outlined as not potential. The rest of the sample materials were excluded from this calculation because the counting was impossible due to lack of consumption in the review period. The potentiality was determined by dividing the number of materials that could have had lower inventory levels in the review period with the expected average inventory calculated with the DDMRP buffers by all sample materials.

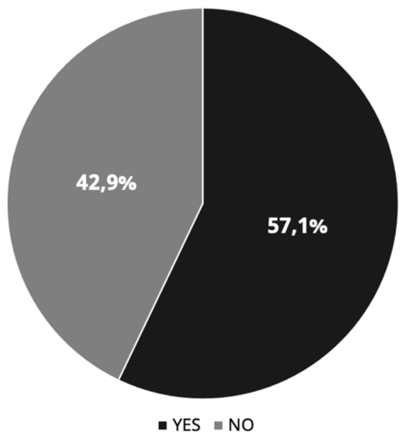

Figure 11. DDMRP potentiality of the sample materials.

4.1.2 List of Conditions Identified

After the values were calculated, the materials that were beneficial to be purchased with the DDMRP method were identified by assessing the ones with lower expected inventory than the actual average inventory from the first half of 2023. This observation led to the fact that there are no categorical groups that can be excluded from the DDMRP scope, but that the individual attributes of each material determine the suitability. If only the mass was analyzed the result that can be drawn is that as ADU increases, so does the potential savings. This conclusion can be drawn from Figure 12, which shows a trendline that suggests just that when the sample materials are analyzed on a large scale.

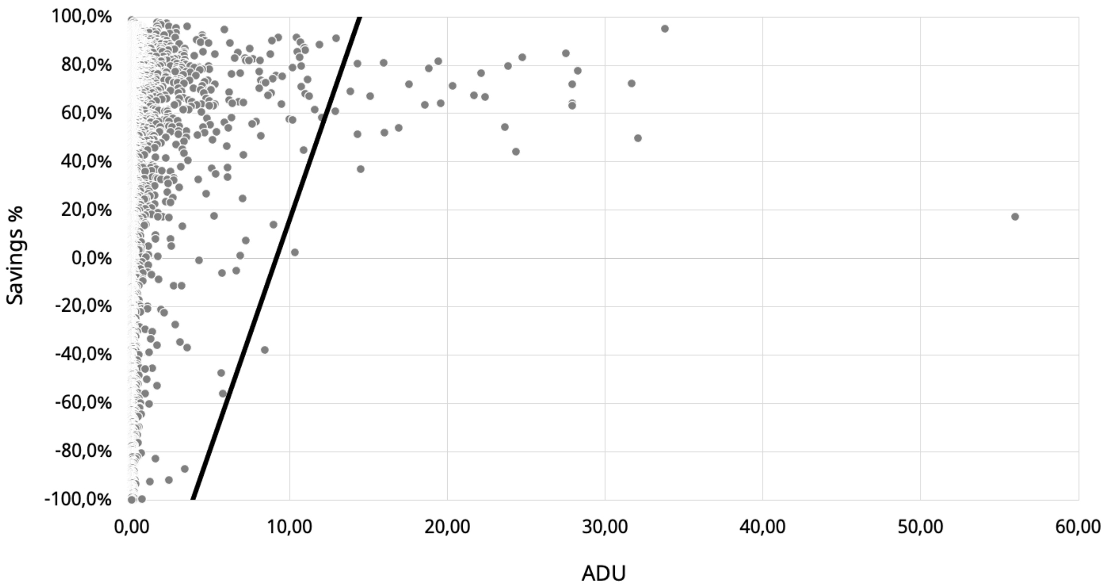

Figure 12. ADU related to percentual savings.

However, this finding cannot be generalized because of another discovery. For example, PI1 (see Figure 13) could only be beneficial to be purchased with DDMRP if the ADU was below 0,037. However, when it is above that level, there are no savings, but the increasing buffer levels make the stock value higher than when purchased with conventional MRP. This is due to the long LT of the example material, which increases the buffer when ADU increases.

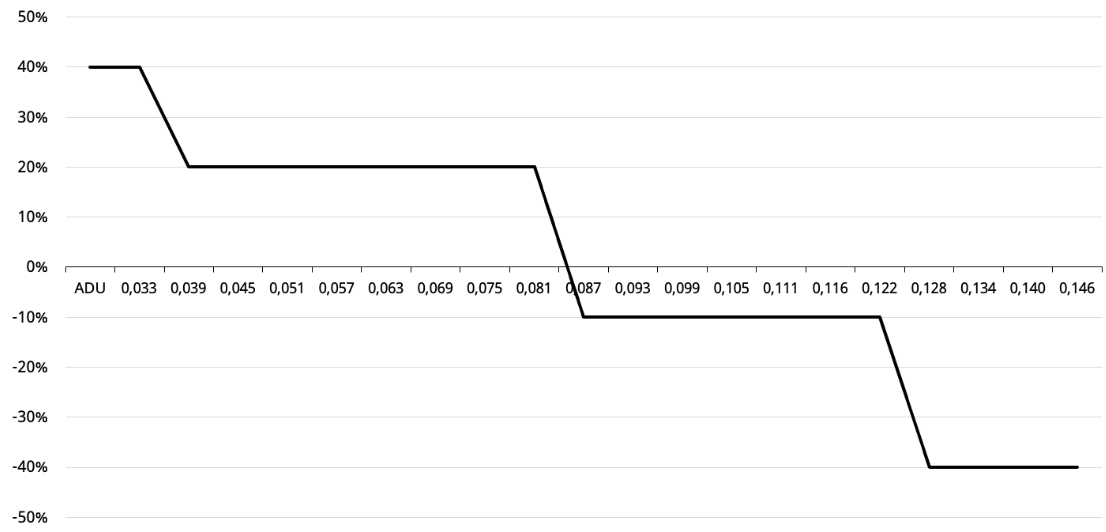

Figure 13. Percentual savings dependence on ADU of an example SKU.

The savings act as implied in Figure 13 due to the equations that are used in demand-driven planning to determine the buffer levels. To simplify, the math behind the analysis comes down to limited attributes that make up the buffers in DDMRP. These are mainly DLT, ADU, LTF, and VF. Furthermore, the assessment of whether the expected average inventory is below the actual measured average is based on the buffer zone calculations.

One result that arose from the quantitative data was the distribution of percentual savings on materials with different lead times. For example, the data suggests that items with short lead times have slightly less potential to be included in the DDMRP scope than materials with long lead times. Figure 14 shows that with most LT segments, that are divided into 20-day ranges, the suitability is between around 70 and 90 % of the materials. The remaining amount is either not suitable or the suitability is not able to be calculated. In addition, it was found that in the two LT segments that are under 40 days, the bigger portion of materials (over 50 %) would not have provided any savings to the average inventory value in the review period. Moreover, it must not be forgotten that although some of the materials are not declared as “DDMRP-suitable” in this thesis, there are no disincentives that would make the materials strictly unsuitable. The materials just would not have provided potential savings with demand-driven planning during the review period.

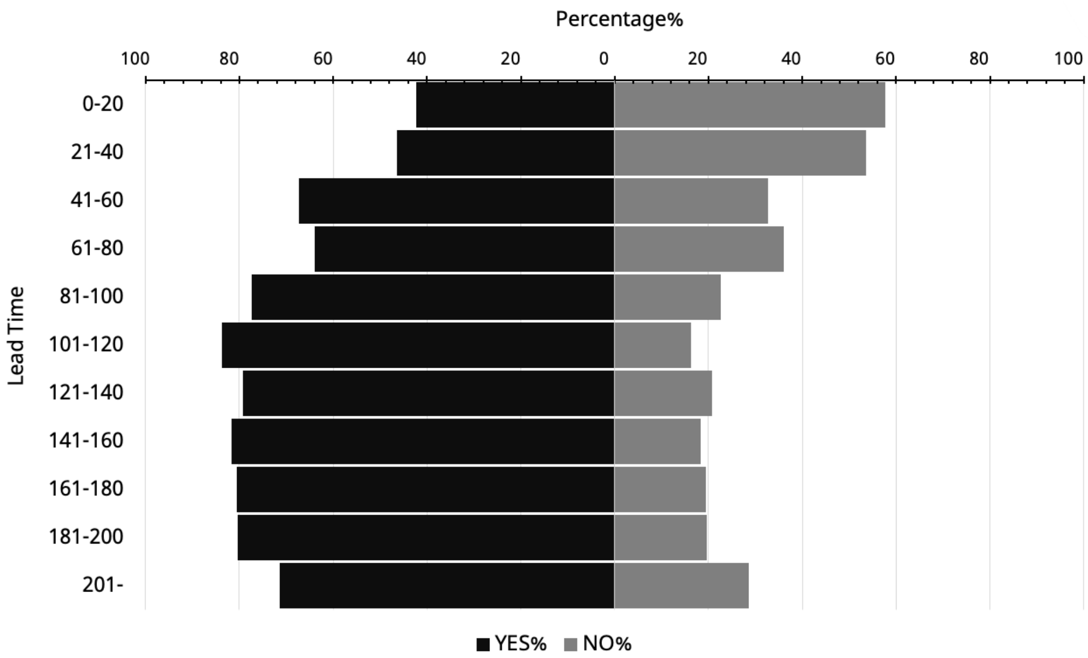

Figure 14. Distribution of DDMRP-suitability on LT ranges.

4.1.3 Explanation of the characteristics

In Table 13, two similar materials are compared to each other. It can be interpreted that although both have same LTs, and similar CoVs, there is a clear difference in the on-hand targets and buffer zones. The material on the left has close to triple the ADU the material on the right column has, which consequently leads to increased buffers.

Table 13. Comparison of two similar materials.

Material number	PI1	PI2
DLT	60	60
MOQ	0	0
Unreliability %	0,33 %	0,33 %
Standard Deviation	0,84	0,27
ADU	0,20	0,07

Material number	**PI1**	**PI2**
CoV	424,19	407,40
Green zone	3	1
Yellow zone	41	13
Red zone	32	11
On-hand target	33,62	11,50
Average on-hand 1.1.-30.6.	50,8	11
DDMRP potential	**YES**	**NO**

One potential reason for the excessive inventory that has been kept for the material on the left is that as the ADU is higher, there has been pressure to keep the stock levels higher to ensure there is enough pieces of the material to cover the consumption. However, it seems that the inventory levels have been overcompensated at least during the review period, leading to the conclusion that the inventory level of the material would have had benefit in the review period from demand-driven planning.

4.1.4 Analysis and Summary of RQ1 Findings

As the idea is to optimize the stock levels, the more the capital tied to inventory would be reduced with demand-driven planning the more beneficial would it be for the material to be purchased with the DDMRP method. On the other hand, optimization means that there should be no risk of the stock falling below zero since that scenario is harmful to the overall business. Thus, another condition that is evaluated is the average coverage of the average stock level that would be with the DDMRP method.

The evaluation of average coverage can be further justified by the fact that one of the fundamental features of DDMRP is to make forecasts irrelevant, preventing the information bullwhip effect. Consequently, this would mean that if the average coverage of the inventory is below the DLT, there would be no condition to use DDMRP in the purchasing process of the material. However, as the yellow zone in DDMRP buffer zones incorporates the lead time in the buffer, by multiplying LT with ADU, there should not be a situation where the inventory would go below zero during the purchasing LT of an item.

A case in which this could happen would require a visible increase in ADU that would be easy to notice beforehand, by the demand spike evaluation for instance.

During the preliminary interviews (May, 2023), the availability of source lists was brought up. However, there is really no need for one, since the responsible planner chooses the correct source each time the system recommends a PO to be created. The findings of RQ1 suggest that one feature of the identification tool should be to not recommend a material as DDMRP suitable if the ADU is projected to increase above the beneficial level soon.

Due to the dynamic nature of DDMRP, there are no clear limits to generalizing whether the materials they limit should always be purchased with DDMRP or not. Rather, each material purchased should be viewed individually and set the appropriate values for them. It was found that about three out of four materials that are purchased by the CPF have the potential to lower inventory levels by planning replenishments with a DDMRP-software.

Also, although attributes of a material such as having a source list, a scaled price, or a MOQ were speculated to be determining factors in the suitability of materials during the preliminary interviews, no evidence was found that would support this viewpoint. Rather, these attributes were found to be irrelevant from the perspective of DDMRP-suitability. However, as identified in the preceding parts of this text, for any material planning system to work properly, accurate data is a necessity. Furthermore, if the parametrization and buffer positioning are done incorrectly, the potential benefits of DDMRP are compromised.

4.2 Tool for Identifying Materials for Demand-Driven MRP

As stated in the preceding parts of this text, one objective of this research was to develop a tool that is used to identify DDMRP-suitable materials by the OP department of the

CPF. The development was done by first adapting the calculation sheet used in the methodological phase of RQ1 and then by collecting qualitative data with semi-structured interviews. In this sub-chapter, the qualitative findings are first analyzed, after which the functionalities of the tool are described with the help of findings from quantitative analysis of RQ1 results and the development of a logic that outputs the recommendation to act as a support for decision-making.

4.2.1 Qualitative findings

The semi-structured interviews as defined in prior parts of this thesis were conducted with 13 respondents from the purchasing organization of the CPF. Altogether, the sample consisted of six operative purchasers, three managers, and four employees with roles in some development functionalities. Some of the respondents had an advanced level of knowledge about DDMRP, some a moderate level of knowledge, and the leavings a low level of knowledge. As the interviews included a question to determine the level of expertise of the respondent in the field of the subject area, the answers were stressed accordingly.

As a result, the interviews varied a little with the answers, and some specific trends and findings were discovered. In Table 14, the distribution of relevant factors discovered from respondents' answers is listed to form a clear picture of the answers. For example, respondents 1, 7, 8, 11, 12, and 13 emphasized the simplicity of the tool when they were asked about desired features for it. Moreover, the variability of the answers was moderate, despite the fact that some individual answers differed clearly from others.

Table 14. Answers from the semi-structured interviews by topic.

	Features				Target audience					Integrability				User interface				Utilization			
Respondent	Simplicity / user friendly	Data based identifica-	Data accuracy	Grouping	OP department	SP department	Production	Individual planner	Everyone	Important	Not must have	SAP	PowerBI	Similar to SAP	Simplicity	Report	One-dimensional an-	Not often	No use in own role	Frequent usage	Mass speculation
1	x				x	x				x		x		x				x			
2		x						x			x		x		x		x				x
3		x	x					x	x		x	x	x				x			x	x
4		x							x	x						x				x	
5					x	x			x		x				x					x	
6		x	x		x				x	x		x							x		
7	x		x				x	x	x	x		x			x		x	x			
8	x							x	x										x		
9		x	x	x		x		x			x	x				x				x	
10					x		x			x				x				x			
11	x	x	x	x	x	x					x	x			x						x
12	x	x						x	x	x		x			x				x		
13	x							x	x	x		x							x		

The results interpreted from the qualitative data collected with the interviews include different aspects that are considered when the tool for DDMRP suitability identification is developed. To begin with, the tool should be available for everyone in the case organization to use, even though the main target group that will be using it might consist of only individual planners and line managers. Consequently, the nature of the tool can be defined as strategic, as the purpose is to identify materials that would potentially benefit from demand-driven planning.

The logic behind the tool is that the output is not trusted blindfolded, but rather used as a helpful opinion to assist in decision-making. This means that the final decision of utilizing DDMRP as a planning system for an individual PI is made by the responsible employee in the CPF based on knowledge of the environmental factors of the supply network. For instance, if the tool shows a clear potential for buying a PI with the DDMRP method, there is a possibility the nature of the supply network for that specific material is not optimal (Author’s observations; Preliminary interviews, May 2023).

When it comes to the overall user interface of the identification tool, integrability was found to play an important role in the entity. In the interviews, it was argued e.g., that if the tool is separated from existing systems that are regularly used in the OP department of the CPF, there would not be as much usage for it. On the other hand, integration was seen as a secondary requirement for the tool by some respondents, functional implementation being the primary one. When these two viewpoints are examined in the light of other responses, it can be stated that functionality is a more important factor than integrability, which was not seen as a mandatory feature.

According to the responses, the integration of the tool into the case company’s existing ERP solution SAP is highly requested. However, based on timely constraints and observations made by the author, the tool would be better off integrated with Microsoft PowerBI, which is also incorporated into the operations of the CPF. The tool is integrated into a material planning report that lists all PIs that are defined in the CPF. PowerBI can best address the CPF’s needs when it comes to the identification tool of DDMRP-suitable materials. This is because e.g., it is simple and highly user-friendly, and also regularly used by the target audience. Also, the report can provide one-dimensional answers with high accuracy, as identified as requirements for the tool.

4.2.2 Development of the tool

On top of the findings from the interviews, this sub-chapter addresses the logic behind the calculations that tell the user of the tool whether the material considered is beneficial to be replenished with the DDMRP method. At the end of this sub-chapter, Figure 15 displays the basic data model that is behind the calculations. The basic logic is based on the master data of a purchased item that the tool fetches from the case company’s ERP system. The algorithm then provides an answer on whether the materials master data implies potential benefits from demand-driven planning or not.

The calculation of savings for each material during the last six months acts as a foundation for the tool that identifies materials that would be beneficial to purchase with the DDMRP method. In a nutshell, the tool is integrated into a PowerBI report of the CPF that is regularly used by the OP department. The report includes all materials of the CPF, and every planner can use the tool to analyze materials that are under their responsibility. In addition, the supervisors can use the report to assess different developmental challenges on a larger scale. As found with the semi-structured interviews, this is the arrangement most suitable for the needs of the CPF.

Material number	Planned del. time	GR time	Effective LT	Source list exists	MOQ	On-hand target	Average stock qty 1-6.23	DDMRP potential based on last 6 months
PI1	120	15	141	yes	260	16,7	20,8	**YES**
PI2	60	10	74	yes	336	5,2	7,8	**YES**
PI3	90	43	150	yes	112	2,5	1,3	**NO**
PI4	120	41	177	yes	2000	2,5	4,3	**YES**

Image 3. User interface of the identification tool.

Image 3 shows the appearance of the identification tool as it can be in the PowerBI report in the future. For clearance, some irrelevant columns have been taken out of the picture. The main focus of the tool is highlighted with thicker outlines in the last two columns. These two right-most columns consist of DDMRP-potentiality, and the level of benefit that would be possible to get if the PI was planned with DDMRP.

As agreed with the case company, this research provides solely the general logic of the identification tool, as well as the calculations and selection of the data. Consequently, the research does not include any configurations with PowerBI. The data model that can be used as the base of the report is provided in Figure 15. In the figure, the general logic and the relations of the data are described. Also, a sum icon can be found before every aspect that is calculated. Furthermore, all attributes that can be excluded from the visible table are placed between parentheses.

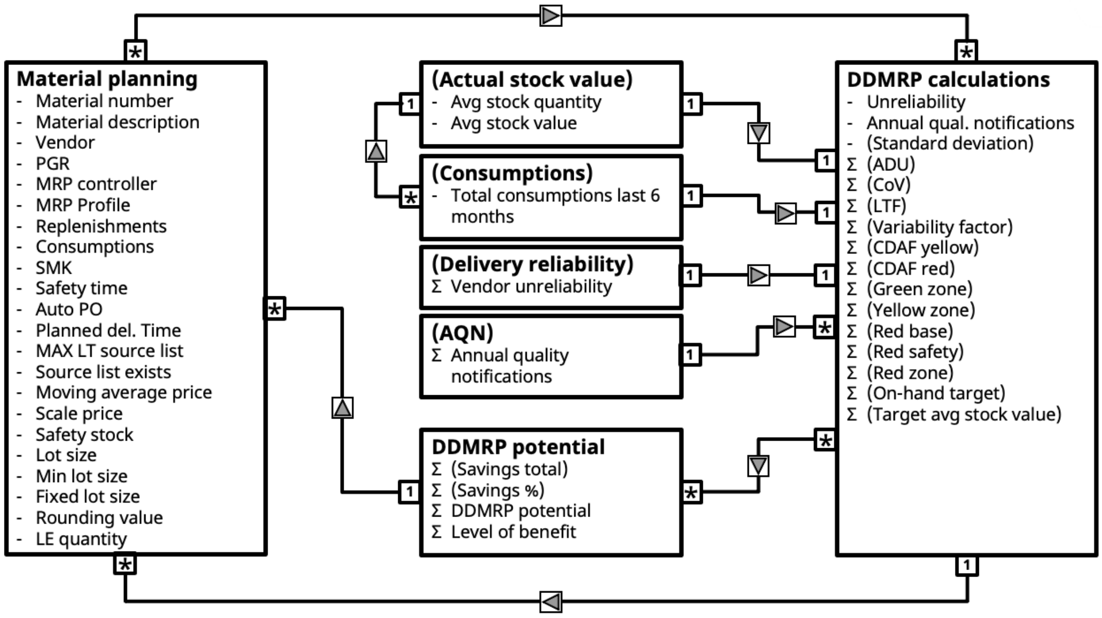

Figure 15. The data model of the identification tool.

4.2.3 Analysis and Summary of RQ2 Findings

To conclude, RQ2 delved into the accessibility and usability aspects of the studied tool, as interpreted from the insights gathered through semi-structured interviews. The findings prominently suggest that the tool in question has the potential to act as a support tool for decision-making in the OP department of the case company. A notable consensus among the interviewees is the unanimous agreement that accessibility is a central consideration for the tool. This aligns with the contemporary emphasis on democratizing data access within organizations, ensuring that tools are easily accessible to all relevant personnel. The implications of this finding underscore the importance of user-centric design and the need for intuitive interfaces that facilitate ease of use.

Moreover, the study's exploration of the tool's usability has revealed a relevant point of integration, which is the inclusion of the tool within a PowerBI report. This revelation carries valuable implications for streamlining the decision-making process, as PowerBI reports can serve as a hub for data-driven insights. By integrating the tool in this context, the case company can harness the synergy between data visualization and practical decision-making. This integration takes advantage of the strengths of both the tool and the PowerBI platform, leading to a collaborative and efficient solution.

It's worth noting that the groundwork for the practical implementation of the tool has been laid out in the previous chapter through the implied data model. This serves as a foundation for the case company to effectively translate the conceptual framework into a working PowerBI tool. This shift from theoretical findings to practical development underscores the real-world applicability of the research findings. Finally, the study's culmination in the development of the PowerBI tool by the case company substantiates the research's objective of providing a comprehensive tool to address the research problems.

4.3 Change of purchasing costs when DDMRP is implemented

4.3.1 Introduction to RQ3 Findings

The change in overall purchasing costs is dependent on various factors such as market volatility, the business environment of the CPF, and the output level of the production facility. Thus, no absolute number caused by the improvements can be stated in this thesis. However, the potential savings in average inventory levels caused by demand-driven planning on a specific time range in the past can be calculated. Consequently, the potential savings in average inventory levels is how the RQ3 is addressed in this research. Furthermore, other aspects of the financial impact originating from DDMRP implementation are assessed by estimations.

As stated in the methodology section, the inventory levels that were evaluated during the research were from the period between January 1 and June 31, 2023. All calculations and results regarding RQ3 have been calculated based on the data that was gathered from the review period. The total reduction of inventory values was found to be around 63 % but a realistic estimation was determined to be 1,4 %.

4.3.2 Effects on Purchasing Costs

When evaluating the potential savings and impact of DDMRP implementation on purchasing costs, the average stock level during the period was compared to the on-hand target value that was calculated with buffer levels created in the research process of RQ1. Simply put, this evaluation is the situation that would have been with the buffers on 1.7.2023 in this case. The focus of this research was on the inventory carrying costs, and potential savings in inventory values to be more specific. An example of the calculated savings is implied in Image 4, where the materials of CPF with the highest moving average prices are listed. In the picture of the calculation sheet, the savings in euros and in percent are listed in the last two columns. The highlight color for positive savings is green and red for negative ones.

Material	On-hand target	Average stock qty 1-6.23	Potential savings %
PI1	16,7	20,8	19,7%
PI2	5,2	7,8	33,9%
PI3	2,5	1,3	-87,5%
PI4	2,5	4,3	42,3%
PI5	2,5	1,0	-150,0%
PI6	4,0	9,0	55,6%
PI7	8,3	19,3	57,3%
PI8	2,7	29,3	90,8%
PI9	3,0	22,2	86,5%
PI10	2,7	5,2	48,4%

Image 4. Potential inventory savings of 10 materials with highest unit price.

Furthermore, this analysis was done for all sample materials to form a throughout picture of the potential savings, and to form the final educated estimate of the total financial benefit of implementing DDMRP. The concept of cost savings related to DDMRP were evaluated by comparing three different scenarios, that could be the next steps for the CPF in implementing DDMRP up to some extent. These scenarios were S1, S2, and S3, which are defined below in Table 15.

Table 15. DDMRP implementation scenarios.

Scenario	Definition
S1	Add PIs with most potential savings to DDMRP scope
S2	Add all PIs from a couple of reliable nearby suppliers with potential savings to DDMRP scope
S3	Add only PIs in strategically correct decoupling points to DDMRP scope

An educated guess and an estimate must be done to evaluate cost savings that could be achievable with DDMRP by the CPF. As stock-outs can be often prevented by using more costly express deliveries for the POs to arrive on time, the rare occasion of longer stock-outs originating by not having certain material available for production to use makes calculating the cost savings difficult. However, as DDMRP can prevent the stock-outs with the dynamic buffers, using priority shipments should be reduced.

4.3.3 Breakdown of Cost Savings

As stated in the preceding parts of this text, DDMRP intends to establish cost savings. Possible cost savings that could arise from demand-driven planning can be divided into four cost components. These components are procurement costs, carrying costs, stock-outs, and excess inventory. Out of the components, procurement costs, stock-outs, and excess inventory are the ones DDMRP has the most potential effect on overall costs. This is because carrying costs can even increase if materials are purchased more frequently, as an outcome of demand-driven planning.

Procurement costs are a sum of all costs related to purchasing the raw materials and components that are used as a production enabler to manufacture the final products of the CPF. If everything related to this component is added up, it can be discovered that not only the purchasing price of a product is important, but the total cost comes from many different directions. For example, the total price of a PI1 with a purchasing price of x includes also – depending on the incoterms – a shipping price of z, and as a fixed cost, the salaries of all employees and managers that work toward ensuring the material availability. During the study, it was also found that the external DDMRP purchasing software used by the case company has an annual license fee.

Stock-outs can be extremely costly since the case company operates in the kind of sector of business, in which a great number of assembly workers are required to be at the site at the time of manufacturing the final products. Thus, if the production stops as a result of a stock-out of critical material, every minute costs money that could be used for something else, also leading to lower profit margins. Moreover, schedules are tight, and contractual penalties and potential reputational damage in case of late deliveries to customers are relatively high. Consequently, savings that could be achieved by avoiding stock-outs are significant.

On the other side of the scale is the excess inventory, which can also be devastating for a business. If inventories are full of material that is not going to be used in production in a while or never again, the cash tied to the physical inventory leads to issues.

The most savings inventory levels in euros were found to be possible to achieve with some key components that have unarguably highest unit prices. However, since the unit price plays such a massive role in the average stock value, it can be declared that a huge impact in euros on the inventory value can be achieved when lowering the average stock levels just mildly when it comes to the materials with high unit costs. Nevertheless, the same components tend to generate big losses in profitability if not available for the production to use at the right moment. Top 10 potential inventorial savings in euros in the review period are implied in Figure 16. The horizontal row indicates the item that is listed, and on top of each bar in the chart, the savings are presented in percent values.

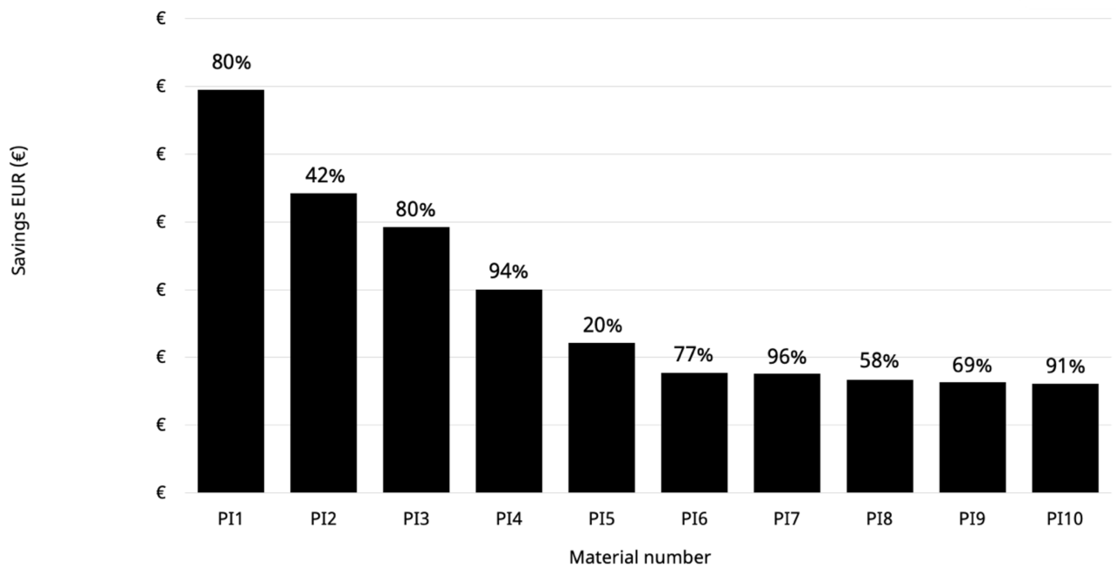

Figure 16. Top 10 potential inventory value savings.

While high unit prices account for the most savings in euros, it was found that the materials with relatively most savings (in percent) were not at all the same type of materials. In fact, the most savings in relation to the inventories managed by conventional MRP were found to be potentially achieved with materials that have a high ADU and consequently have relatively more pieces in stock, as more pieces are needed in the assembly of final products. In addition, the unit price is relatively low. Consequently, it seems that materials that have these characteristics are ought to have high inventory levels since maintaining a safety stock for an individual purchased item with low unit cost appears as a cost-efficient insurance.

However, when many items are planned with the same method of keeping high safety proportions, the financial inefficiencies multiply. For example, the potential savings in average inventory value of PI1 was about 98,5 % (see Figure 17). Figure 17 shows the materials that had the highest relative savings in the review period. On the horizontal axle, the materials are listed and on top of each bar the potential saved monetary value is listed.

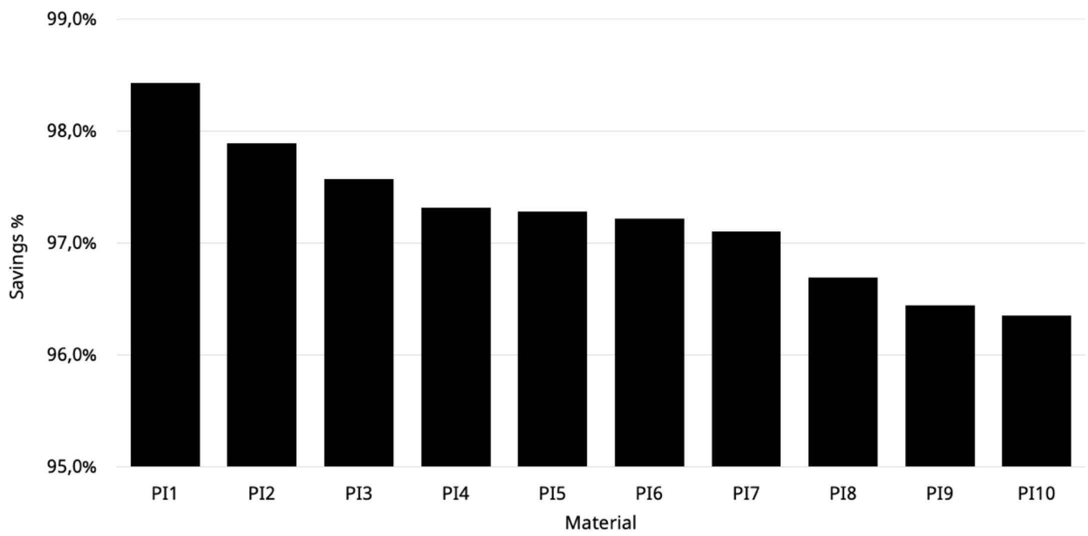

Figure 17. Top 10 materials with relatively highest savings.

The findings strengthen the observation that every material must be assessed individually to comprehensively define the potentiality of DDMRP in the purchasing process. For example, one material from the top 10 savings in euros (see Figure 16) has only 34 % in relative savings, whereas another material on the same list is listed with 91 % savings. The same logic is applicable to the top 10 relative savings (see Figure 17). Some materials with high savings when measured in relatively, have rather insignificant financial impact since the inventory level savings in euros are measured in less than a thousand euros.

Financial impact of each scenario was further assessed trough evaluating different cost-related issues (see Table 16). The scenarios were indexed to ensure the comparability of the different measures. To begin with, the manageability was evaluated since higher masses of SKUs are more difficult to manage especially when first implementing a new method of purchasing. The values were determined with the logic that the higher manageability a scenario has, the more points it gets. The distribution was done with a specification of 0,50 – 0,75 – 1,00 from low to high. S1 had the lowest quantity of SKUs but from eight different suppliers, resulting in 0,75 manageability. S2 had 25 SKUs but only from three suppliers, accounting for relatively easiest manageability. Finally, S3 had an estimated of 100 different SKUs, resulting to 0,5 manageability.

Potential savings were adapted from the calculation sheet with the scope that S1 savings was composed of the potential savings of the top 10 materials, S2 savings of the ones defined in Appendix 2, and S3 savings based on an estimation. According to Demand Driven Technologies (2020), inventory levels are usually lowered by 15 % to 30 % when implementing DDMRP. Based on the assumption that optimal implementation of DDMRP to correct decoupling points would lower the inventory levels by 15 %, S3 was calculated to reduce the inventory level potentially by 15 %.

Finally, the total risk was evaluated by multiplying a potentiality estimate of stock-out related issues with the value between 1 and 5 with a criticality estimate with a value likewise from the range 1 to 5. The indexed numbers that are in parenthesis in Table 16, were founded with dividing the value with the highest value of each category. For example, potential savings of S2 was divided by the highest potential saving, resulting to the indexed value of 0,06. The total impact of each scenario was calculated by summing up manageability and potential savings and extracting total risk from the equation.

Table 16. Scenario evaluation

Scenario	**Manageability**	**Potential savings**	**Stock-out risk**			**Total**
			Potential	Criticality	Total risk	
S1	Medium **(0,75)**	25 % **(1,00)**	4	5	20 **(1,00)**	0,75
S2	High **(1,00)**	1,4 % **(0,06)**	2	2	4 **(0,20)**	<u>0,86</u>
S3	Low **(0,50)**	14,8 % **(0,59)**	3	3	9 **(0,45)**	0,39

The first scenario was achieved to potentially gather the most significant reductions in the total inventory value of the CPF, while simultaneously including the greatest risk of critical stock-outs. Furthermore, the low number of different PIs in S1 contributed to a relatively good level of manageability, lowered by the long LTs and shipping times. Consequently, total indexed impact of S1 was 0,75 + 1,00 - 1,00 = 0,75. Furthermore S2 had a total impact of 1,00 + 0,06 – 0,20 = 0,86, which was deemed as the highest impact. Finally, the total impact of S3 was found to be 0,50 + 0,64 – 0,45 = 0,44. Consequently, S2 was considered the best scenario.

The total financial impact of S2 was estimated by counting all relevant additional costs and savings to monthly cash flow and equity. Costs include the DDMRP software license fee that is paid annually. Positive monthly-based financial impacts include possible decreases in shipment costs and other costs related to insufficient inventory levels. Thus, monthly impacts were estimated to be around 7 %.

For tied capital, the released capital from reduced inventory levels was estimated to be 1,4 %. The reduced inventory was counted based on the savings indicated by the calculation sheet 25 SKUs that are supplied by three nearby suppliers for the CPF. These suppliers were observed to be reliable enough to be included in S2. The calculations regarding the inventory changes with respect to the financial side are visible in Abbreviation 2. Moreover, if the scope of PIs that are purchased with DDMRP is widened further the decrease of capital tied to excess inventory naturally increases.

4.3.4 Limitations and Potential Downsides

Due to restrictions in the calculation tool and data collection, no scale prices were considered in the estimation of the financial effects of DDMRP. Also, due to timely restrictions and limitations of the analysis tool, there is no proof that any of the materials would have held the inventory level above zero throughout the review period. Consequently, if some materials had been out of stock when needed in production, the savings raised from the lower inventory levels would have been reduced or completely overturned.

A potential financial downside for implementing DDMRP is also the fact that if the MM data or other relevant data or parameters are incorrect, the potential savings can turn into a potential increase in inventory levels. In the research, it was found that some purchased items would have potential negative savings on inventory values (i.e., higher inventories) during the review period, which implies that some materials that are not suitable for DDMRP would be better off by purchasing with conventional MRP. An example of this kind of material is presented in Figure 18, where the top ten (by EUR €) potential inventory level-increasing materials are listed. The inventory increase for some materials was measured even in tens of thousands of precents.

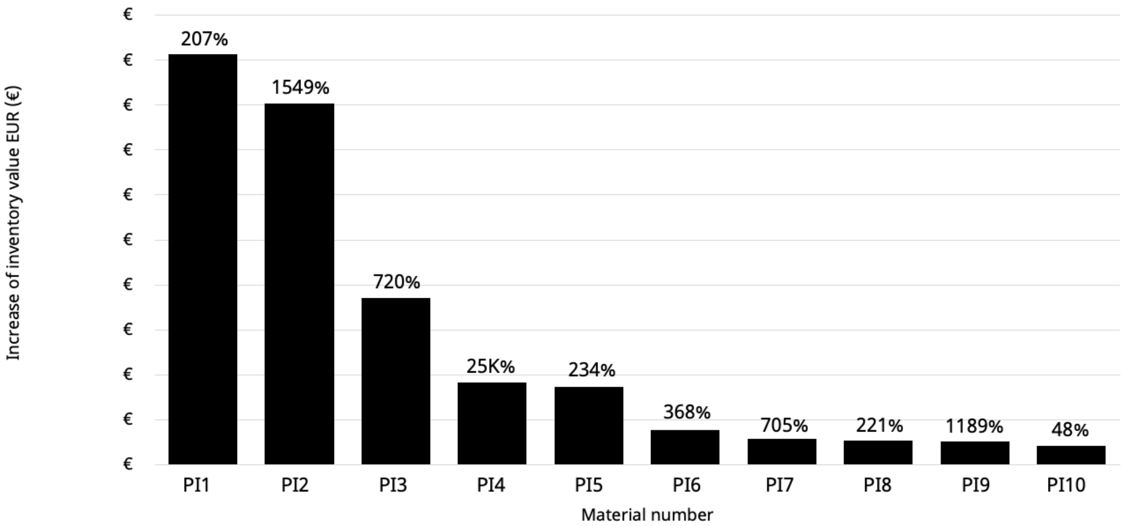

Figure 18. Top 10 inventory value-increasing materials.

While the additional inventory values are quite major, it must be noted that the values in euros are considerably lower than values of the potential savings.

4.3.5 Analysis and Summary of RQ3 Findings

Around 40 % of all analyzed materials were found to be unbeneficial to be purchased with DDMRP in the retrospective analysis.

While it was discovered that if all materials that would have had lower stock levels during the review period had been purchased with DDMRP, the total decrease in total inventory value of the CPF would have been 63 %, the process of moving all 4 001 of these materials in the scope of the external DDMRP procurement system was considered unrealistic. Therefore, a scenario analysis of realistic implementation options was done to evaluate the financial impact of broadening the scope of DDMRP in the CPF. The results suggested that the comprehensively most rational option S2, would result in some additional monthly costs, and 1,4 % of one-off savings in the form of inventory level reductions. However, if the concept of decoupling points is examined throughout, the savings the CPF could face would presumably be higher.

4.4 Analysis of Case Study Results

Limitations that ought to be considered when analyzing the results include the lack of knowledge about whether there is a possibility that the inventory of an individual material could have gone below zero during the review period if the planning was done with the DDMRP method. Moreover, there is always a possibility that for various reasons, the inventories may have been at unusually high levels during the review period, leading to results that can differ from reality.

Moreover, due to time and system restrictions, the calculation sheet was not able to address the unreliability of material with multiple vendors in any other way than by providing a fixed coefficient of 0,01, which is potentially inaccurate in some cases. Also, even if the identification tool were to indicate that an individual material would not have DDMRP potential, there is a chance that it would be beneficial to keep higher inventories for the material if the current situation is unprofitable. Consequently, these could be potential future research topics.

The results suggest that the scope of materials that are purchased with demand-driven planning in the CPF could be enlarged with the help of the identification tool that maps out the potentiality of each material. Furthermore, the results lead to the conclusion that total implementation of DDMRP requires broader research on the topic.

5 Conclusion

This research was done to assist the case company in the process of piloting the demand-driven planning approach in its operative purchasing. The case company desired to get insights into DDMRP as a planning method, with a focus on what purchased materials should be included in the scope of the method, and what would be the financial consequences of purchasing these materials with DDMRP. Consequently, three research questions arose that addressed all the objectives of the research, forming a comprehensive base for solving the research problems.

Research Question 1, which aimed to determine what conditions must be met for a purchased item to be purchased with the DDMRP method, was addressed with mainly quantitative data analysis with an Excel-based calculation sheet. RQ2 on the other hand, was formed around the intention to sort out what features should a tool designed to identify DDMRP-suitable materials include. Finally, RQ3 helped to assess what are the consequences of deploying the DDMRP method with respect to a financial perspective.

5.1 Results and main findings of the study

The research conducted based on the research questions consisted of different methodological approaches, including interviews and calculations of data gathered from the systems of the CPF. First, the literature review went through existing academic literature on the topics of MRP, DDMRP in general, DDMRP implementation-related issues, and tools that have been developed to support the implementation process. The literature was found to not deal with the type of identification tools as intended as an objective of this thesis. Furthermore, it was found that although implementing DDMRP can bring clear advantages to a company’s operations, the process itself requires a great deal of effort to get the desired result. Moreover, no supporting evidence of the universal applicability of the method to all industrial contexts was found.

After the literature review, the research questions were addressed individually with methodologies most suitable for each question. Regarding material suitability for DDMRP, no delimiting boundaries for material characteristics were found, since the analysis of the sample data suggested that materials that would have performed better with DDMRP during the review period represented almost all different material types. An exception was materials with current procurement modes that limit every requirement to be individual. These materials are not now possible to be integrated in the external procurement software incorporating the DDMRP method that the CPF uses.

However, the inventory levels and usage data, together with an additional buffer determined by the supply chain unreliability of an individual material during the review period defined whether the material would possess the potential to benefit financially from planning the purchasing with the demand-driven method. Based on the results, about two-thirds of the sample materials were found to have saving potential in inventory levels, which accounts for a total of 65,5 million euros in decreased inventory value.

The calculation sheet that was used to get the results to RQ1 and RQ3 formed the basis for the identification tool that was initially developed in the thesis. In addition, results from interviews that were conducted with supply chain professionals from the case company suggested the general user interface of the tool to be easily accessible, and simple, and to act as a supportive instrument in decision-making of the case company. Consequently, the identification tool was defined to be integrated into a current material planning tool of the CPF that is accessible through Microsoft PowerBI.

5.2 Managerial applications

Based on the results, DDMRP should not be implemented solely based on the output of the tool, but a throughout investigation is required. The first option is to test the method with the materials that have the most projected savings. The second option is to ramp up the method with one supplier at a time, including all relevant stakeholders in the process. The third option is to broaden the knowledge of DDMRP in the organization of the CPF by addressing the follow-up research topic of buffer positioning before broadening the scope of materials that are purchased with the DDMRP method. A universal suggestion for the case company, regardless of the direction that is taken regarding the topic, is to ensure that all material data are up to date before taking the concept forward, including making sure the data is kept that way in the future.

Option 1 involves a cautious yet practical strategy for DDMRP implementation. It suggests starting with materials that promise the most significant savings according to the tool's projections. This approach is savings-oriented, as it aims to maximize gains while minimizing potential disruptions. However, a thorough evaluation of the projected savings against actual outcomes is essential before moving ahead. This option could be effective if the tool consistently provides accurate predictions and if confidence exists in its savings estimates. Still, there's a risk of overlooking materials with smaller projected savings that could contribute meaningfully to overall efficiency improvements.

Option 2 centers on a gradual, controlled adoption of the DDMRP method. The idea is to roll out the approach incrementally, beginning with a single or only a few suppliers before expanding to more vast entities. The inclusion of relevant stakeholders ensures a well-informed implementation that addresses potential challenges or resistance. This path is favorable as it manages the risk of disruptive changes and allows the organization to learn from each step, refining the process as it goes. However, it may necessitate a longer timeline to fully realize benefits, demanding close coordination with suppliers.

Option 3 proposes a more comprehensive organizational shift toward embracing DDMRP. Beyond the immediate tool applications, it suggests broadening the organization's understanding of DDMRP through exploring buffer positioning, a subsequent research topic. This strategic move could lead to holistic inventory management optimization. While promising, this option requires a commitment to knowledge sharing and thorough training throughout the organization. The evaluation here rests on the CPF's desire for change and its willingness to commit to the DDMRP methodology.

The second option is suggested to be implemented by the case company since it was found to be the most rational one when evaluated comprehensively, including the assessment of the risk of stock-outs. Regardless of the chosen path, the universal recommendation of ensuring up-to-date data as the beginning step of implementing DDMRP holds substantial weight. This exercise will also help in the current daily operations. The data can compromise advantages brought by DDMRP if not corrected before the implementation.

5.3 Practical implications and study limitations

As the aim of this study was mainly to produce practicable results for the use of the case company, it must be acknowledged that the findings might not be directly applicable to other organizations. Furthermore, the implementation of DDMRP should always be done considering the operating environment of the organization. However, the identification tool and the CDAF parametrization model that takes supply environment unreliability into account contribute better to the field of industrial management, both academic and practical world. This is justified by the fact that the material data used to calculate the potentiality and the CDAF, including LT, ADU, supplier reliability, quality notifications, and consumption data, is presumably widely used across different organizations.

Limitations of the trustworthiness of the results that were brought up in this thesis regarding the results include potential data inaccuracy, specific procurement modes for specific materials that limit the applicability to DDMRP scope that was not visible from the material master data studied, and the fact that the inventory adequacy was not able to be incorporated in the identification tool. Despite the limitations, the findings can be described as precise, since all the calculations done in this thesis are rather simple, decreasing the risk of faulty outcomes.

5.4 Recommendations for Future Research

Future research could include research about implementing DDMRP into the whole process of a production facility, including identification of the decoupling points. In addition, there would be a demand for a tool that would help identify the decoupling points in the BOM of final products. Another research topic that would be of use in the academic context of industrial management would be the determination of the most accurate and beneficial parameters for DDMRP in different market environments.

Another interesting topic is the effect of visible and collaborative execution, when broadened to a wider scale, incorporating Industry 4.0 concepts in collaboration with the DDMRP method. The efficiency of the method might improve if the purchased items were followable throughout a transparent supply chain. Moreover, organizational responsiveness and flexibility might face new levels by integrating DDMRP with the most efficient available technology.

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Appendices

Appendix 1. Dictionary definitions of planning systems

Table 17. Dictionary definitions of planning systems (ASCM Supply Chain Dictionary, 2023).

Planning method	Definition
MRP	"A set of techniques that uses bill of material data, inventory data, and the master production schedule (MPS) to calculate requirements for materials. It makes recommendations to release replenishment orders for material. Further, because it is time phased, it makes recommendations to reschedule open orders when due dates and need dates are not in phase." (ASCM Supply Chain Dictionary, 2023, p. 118)
MRP II	"A method for the effective planning of all resources of a manufacturing company. Ideally, it addresses operational planning in units and financial planning in dollars and has a simulation capability to answer what-if questions. It is made up of a variety of processes, each linked together: business planning, production planning (sales and operations planning), master production scheduling, material requirements planning (MRP), capacity requirements planning, and the execution support systems for capacity and material. Output from these systems is integrated with financial reports such as the business plan, purchase commitment report, shipping budget, and inventory projections in dollars. Manufacturing resource planning is a direct outgrowth and extension of closed-loop MRP." (ASCM Supply Chain Dictionary, 2023, p. 114)
Lean	"A philosophy of production that emphasizes the minimization of the amount of all the resources (including time) used in the various activities of the enterprise. It involves identifying and eliminating non-value-adding activities in design, production, supply chain management, and customer management. Lean producers employ teams of multiskilled workers at all levels of the organization and use highly flexible, increasingly automated machines to produce volumes of products in potentially enormous variety. Lean production contains a set of principles and practices to reduce costs through the relentless removal of waste and through the simplification of all manufacturing and support processes." (ASCM Supply Chain Dictionary, 2023, p. 105)
Six Sigma	"A methodology that furnishes tools for the improvement of business processes. The intent is to decrease process variation and improve product quality." (ASCM Supply Chain Dictionary, p. 188)
Theory of Constraints	"A holistic management philosophy developed by Dr. Eliyahu M. Goldratt based on the principle that complex systems exhibit inherent simplicity. Even a very complex system comprising thousands of people and pieces of equipment can have, at any given time, only a very, very

	small number of variables - perhaps only one, known as a constraint - that actually limit the ability to generate more of the system's goal." (ASCM Supply Chain Dictionary, 2023, p. 204)
DDMRP	"A method for planning material needs that enables a company to build more closely to actual market requirements." (ASCM Supply Chain Dictionary, 2023, p. 51)

Appendix 2. Tool for Identifying Materials for DDMRP

Table 18. Scenario 2 master data.

SKU	Effec-tive LT	MOQ	Unreliability	AQN	StDev	ADU	CoV	LTF	VarF
PI1	132		0,01	6	4,17	0,83	503,52	0,18	0,50
PI2	132	50	0,01	0	3,03	0,71	428,17	0,18	0,50
PI3	66	0	0,02	0	0,19	0,04	498,57	0,25	0,50
PI4	31	36	0,16	0	7,68	2,97	258,37	0,40	0,25
PI5	59	20	0,16	0	2,20	1,14	192,17	0,32	0,25
PI6	31	50	0,16	1	6,72	1,58	425,09	0,40	0,50
PI7	63	0	0,02	0	0,19	0,04	498,57	0,25	0,50
PI8	58	0	0,02	0	0,22	0,05	437,16	0,32	0,50
PI9	31	0	0,16	0	3,36	0,77	437,40	0,40	0,50
PI10	63	0	0,16	0	3,03	0,51	589,26	0,25	0,50
PI11	38	6	0,02	0	3,75	0,98	383,52	0,32	0,50
PI12	29	40	0,16	2	1,84	0,85	216,64	0,40	0,25
PI13	45	32	0,16	0	4,22	1,23	344,30	0,32	0,50
PI14	38	1	0,02	0	0,23	0,06	413,52	0,32	0,50
PI15	55	2	0,02	0	0,21	0,04	465,03	0,32	0,50
PI16	46	0	0,02	0	0,22	0,05	437,16	0,32	0,50
PI17	45	0	0,02	0	0,44	0,06	801,00	0,32	1,00
PI18	98	10	0,01	0	0,44	0,15	294,67	0,22	0,25
PI19	57	10	0,01	1	0,44	0,15	286,96	0,32	0,25
PI20	59	0	0,02	0	0,07	0,01	1341,64	0,32	1,50
PI21	93	0	0,02	0	0,18	0,02	817,77	0,22	1,00
PI22	59	0	0,02	0	0,07	0,01	1341,64	0,32	1,50
PI23	45	16	0,01	0	2,57	1,23	208,84	0,32	0,25
PI24	34	1	0,02	0	0,27	0,07	407,40	0,40	0,50
PI25	38	1	0,02	1	0,63	0,15	419,78	0,32	0,50

Table 19. Scenario 2 DDMRP buffer calculations

SKU	CDAF yellow	CDAF red	Green zone	Yellow zone	Red Base	Red safety	To-tal red zone
PI1	5,14	10,11	50	114	20	10	38
PI2	4,37	4,37	50	97	17	9	29
PI3	8,79	8,79	1	3	1	1	2
PI4	41,23	41,23	37	215	37	10	170
PI5	30,67	30,67	22	103	22	6	63
PI6	67,83	69,41	50	157	20	10	140
PI7	8,79	8,79	1	3	1	1	2
PI8	7,71	7,71	1	4	1	1	2
PI9	69,80	69,80	10	78	10	5	69
PI10	94,03	94,03	9	81	9	5	62
PI11	6,76	6,76	12	44	12	6	25
PI12	34,57	36,27	40	55	10	3	44
PI13	54,94	54,94	32	123	18	9	94
PI14	7,29	7,29	1	3	1	1	2
PI15	8,20	8,20	2	3	1	1	2
PI16	7,71	7,71	1	3	1	1	2
PI17	14,12	14,12	1	4	1	1	3
PI18	3,01	3,01	10	16	4	1	5
PI19	2,93	3,08	10	10	3	1	4
PI20	23,65	23,65	1	1	1	2	3
PI21	14,42	14,42	1	3	1	1	2
PI22	23,65	23,65	1	1	1	2	3
PI23	2,13	2,13	18	59	18	5	26
PI24	7,18	7,18	1	3	1	1	2
PI25	7,40	7,55	2	7	2	1	4

Table 20. Scenario 2 DDMRP suitability

SKU	On-hand target	Avg stck qty 1-6.23	Savings%	DDMRP po-tential	Level of benefit from DDMRP
PI1	63,38	409,33	84,5 %	YES	High
PI2	54,09	227,67	76,2 %	YES	High
PI3	2,84	8,50	66,6 %	YES	High
PI4	188,05	395,50	52,5 %	YES	High
PI5	74,07	145,17	49,0 %	YES	High
PI6	164,68	435,83	62,2 %	YES	High
PI7	2,84	12,27	76,8 %	YES	High
PI8	2,88	8,50	66,1 %	YES	Medium
PI9	73,60	214,83	65,7 %	YES	Medium
PI10	66,81	177,67	62,4 %	YES	Medium
PI11	30,61	134,67	77,3 %	YES	Medium
PI12	63,86	173,17	63,1 %	YES	Medium
PI13	110,39	208,00	46,9 %	YES	Medium
PI14	2,90	21,50	86,5 %	YES	Medium
PI15	3,36	19,17	82,5 %	YES	Medium
PI16	2,88	15,33	81,2 %	YES	Medium
PI17	3,28	47,67	93,1 %	YES	Medium
PI18	10,45	28,17	62,9 %	YES	Medium
PI19	9,48	25,00	62,1 %	YES	Medium
PI20	3,63	7,50	51,6 %	YES	Medium
PI21	2,82	3,83	26,5 %	YES	Medium
PI22	3,63	7,00	48,1 %	YES	Medium
PI23	34,63	122,67	71,8 %	YES	Medium
PI24	2,98	9,67	69,2 %	YES	Medium
PI25	5,13	13,50	62,0 %	YES	Medium