Universidade do Minho
Escola de Engenharia

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A Business Analytics Approach Towards Improved Safety Buffer Dimensioning

Outubro de 2023

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UMinho | 2023

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Dissertação de Mestrado
Mestrado em Engenharia e Gestão Industrial

Trabalho efetuado sob a orientação de
Professora Doutora Maria do Sameiro Carvalho
Professor Doutor João Nuno Gonçalves

Outubro de 2023

Direitos de Autor e Condições de Utilização do Trabalho por Terceiros

AGRADECIMENTOS

A presente tese de mestrado marca o fim de uma jornada de dezassete anos, repleta de crescimento pessoal e de descoberta científica. Nada daquilo que alcancei teria sido possível sem o apoio incondicional e todas as aprendizagens que recebi da minha família, amigos, professores e outros colegas, com quem tive o privilégio de me cruzar ao longo dos anos. No entanto, enquanto aqui me encontro a expressar o meu obrigada a cada um de vós, existem algumas pessoas que devem ser particularmente mencionadas.

Primeiramente, gostaria de partilhar a minha profunda gratidão pela orientação, disponibilidade, paciência e conhecimento que a Professora Maria do Sameiro Carvalho e o Professor João Nuno Gonçalves tiveram a generosidade de me oferecer. Obrigada por acreditarem no meu potencial e por segurarem sempre a luz ao fundo deste longo e, por vezes, escuro túnel. Ambos me mostraram que, com a dose certa de motivação e perseverança, todos os obstáculos podem ser ultrapassados.

Gostaria, também, de aproveitar esta oportunidade para agradecer a todos aqueles com quem tive o prazer de contactar na COINDU e que direta ou indiretamente participaram neste projeto, especialmente a minha orientadora na empresa, Andrea Costa, que sempre prontamente procurou esclarecer as minhas questões e partilhar comigo a sua experiência profissional. Em geral, obrigada a todos vós, todos me ensinaram algo, quer a nível pessoal, quer a nível profissional.

Por último, não há como agradecer o suficiente à minha Família, aqueles que sempre me puseram em primeiro lugar, investiram na minha educação, me ensinaram a distinguir o certo do errado e que me encheram de amor e gratidão por tudo aquilo que nos é dado. Muitas pessoas contribuíram para este meu marco, mas, sem vocês, é certo que não o teria alcançado e, por isso, estou e estarei eternamente grata. Apesar de ter recebido de todos vocês algo especial, tenho a certeza que me vão perdoar por te destacar a ti, Vó. Embora já não estejas connosco para te mostrar a tese terminada, ou até mesmo estas palavras de agradecimento, quero que saibas o quão fundamental foste para alcançar este marco, já que tão paciente e carinhosamente criaste a pessoa em que me tornei. Sei que, neste momento, a partir do teu novo lar, te encontras orgulhosamente a celebrar esta minha conquista, por isso espero que também celebres com enorme orgulho o *teu* papel nesta caminhada. Muito obrigada, Vó!

ACKNOWLEDGEMENTS

This Master's dissertation marks the end of a seventeen-year journey of personal growth and scientific discovery. Nothing of what I have accomplished today would have been possible without the endless support and the lessons learnt from my family, friends, teachers, professors and other colleagues, with whom I have had the privilege to cross paths. Nonetheless, as I thank to every single one of you, there are a few people who deserve to be particularly acknowledged.

Primarily, I would like to express how deeply grateful I am for the guidance, availability, patience and knowledge offered to me by both my advisors, Professor Maria do Sameiro Carvalho and Professor João Nuno Gonçalves. Thank you for believing in my potential and for always holding the light at the end of this long and, at times, very dark tunnel. You both showed me that, with enough motivation and perseverance, there is nothing one cannot tackle.

At COINDU, I would like to express my heartfelt thanks to everyone who directly or indirectly played a role in this project, especially my company advisor Andrea Costa, who always, very diligently, answered my questions and shared her personal expertise. All of you taught me something that I will always carry with me in my professional and personal life.

Lastly, I cannot thank enough to my Family who always put me first, invested in my education, taught me right from wrong and filled me with love and appreciation for what we are given. A lot of people contributed to this milestone, but without you I would certainly not have achieved any of this and, for that, I am truly grateful. From all of you I received something special, but I am sure you will forgive me for only setting you, Vó, apart. Even though you are no longer with us so that I can show you the completed dissertation, or even this acknowledgement, I want you to know how fundamental you were to it, since you patiently and kindly raised me to be the person I am today. I know that, from your eternal abode, you are proudly celebrating this accomplishment and so I hope you proudly celebrate the role *you* played in it. Thank you so much, Vó!

Declaração de Integridade

Declaro ter atuado com integridade na elaboração do presente trabalho académico e confirmo que não recorri à prática de plágio, nem a qualquer forma de utilização indevida ou falsificação de informações ou resultados em nenhuma das etapas conducente à sua elaboração.
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I hereby declare having conducted this academic work with integrity. I confirm that I have not used plagiarism or any form of undue use of information or falsification of results along the process leading to its elaboration.
I further declare that I fully acknowledge the Code of Ethical Conduct of the University of Minho.

UMA ABORDAGEM BASEADA EM BUSINESS ANALYTICS PARA A MELHORIA DO DIMENSIONAMENTO DE BUFFERS DE SEGURANÇA

Resumo

Este projeto de dissertação foi desenvolvido na empresa COINDU COMPONENTES PARA A INDÚSTRIA AUTOMÓVEL, S.A. (Joane), no âmbito do Mestrado em Engenharia e Gestão Industrial. Este trabalho pretende funcionar como um estudo preliminar para a definição de políticas de gestão de inventário de matérias-primas baseadas em dados reais sobre incertezas na procura e no fornecimento dos materiais, bem como avaliar a adoção separada e conjunta de stock e *lead time* de segurança. Adicionalmente, como a COINDU ainda se encontra em transição rumo a processos de tomada de decisão suportados por dados, este projeto pretendeu, também, assinalar as principais vulnerabilidades encontradas no sistema, no que concerne à partilha de informação e ao armazenamento e tratamento de dados.

De modo a cumprir com estes objetivos, a avaliação histórica do nível de serviço e da qualidade do fornecimento dos materiais foi priorizada, tendo-se efetuado um grande trabalho de recolha e tratamento de dados antes dos seus resultados terem sido analisados num Report elaborado em Power BI. Esta análise foi restrita a materiais pertencentes à classe A na análise ABC da empresa.

Este diagnóstico inicial permitiu destacar os grupos de mercadorias de Couro, Tecidos e Vinil como os mais vulneráveis a flutuações de curto prazo na procura e com níveis de serviço inferiores a 90%. Posteriormente, alguns materiais pertencentes a estas categorias foram selecionados para testar um DSS capaz de simular e comparar o desempenho de diferentes políticas de gestão de inventário.

Para matérias-primas associadas a produto acabado com procura e capacidade de produção alocada mais voláteis, verificou-se que as políticas atuais revelam ser pouco eficazes, pois levam à manutenção de níveis de stock demasiado baixos para reagir a aumentos abruptos da procura dos materiais - níveis de serviço inferiores a 60%. Adicionalmente, para as condições simuladas, os *buffers* de *lead time* de segurança garantiram o cumprimento total da procura ao menor custo possível, assim como períodos de revisão mensal de inventário foram preferíveis à revisão semanal atualmente em vigor na empresa.

Por último, relativamente às vulnerabilidades de métodos *data driven*, destacam-se a não disponibilização de informação relevante nos sistemas e a não standardização do formato de ficheiros entre plataformas.

PALAVRAS-CHAVE

Business Analytics, Buffers de Segurança, Gestão de Inventário, Incertezas na Procura e no Fornecimento, Informação

A BUSINESS ANALYTICS APPROACH TOWARDS IMPROVED SAFETY BUFFER DIMENSIONING

Abstract

This dissertation project was carried out at COINDU COMPONENTES PARA A INDÚSTRIA AUTOMÓVEL, S.A. (Joane), as part of the Masters in Industrial Management and Engineering program. Its main goals were to serve as a preliminary study in the formulation of raw materials inventory management policies based on real demand and supply uncertainty data, as well as in the evaluation of the joint and separate adoption of safety stock and safety time buffers by the company. Because COINDU is still transitioning towards a data-driven decision making mindset, this project is also meant to signal its system's main vulnerabilities, concerning information sharing, data storage and data treatment.

In order to fulfil these goals, assessing raw materials' historical service levels and supply quality was of top priority, accomplished only after intensive data gathering and treatment stages that led to the creation of a Power BI Report to better understand the obtained results. Because of the wide range of materials used by the company and the short lifespan of this dissertation, the scope of this evaluation was restricted to materials classified as A-type items in COINDU's ABC analysis.

After a preliminary system diagnosis, Leather, Textile and Vinyl were signalled as the groups of materials with service level performance inferior to 90% and more vulnerable to short-term demand fluctuations. A small sample of materials belonging to these categories was then chosen to test a DSS capable of simulating and comparing the performance of inventory management policies.

The main conclusions reached by this study revealed that, for raw materials associated with end-items with extremely volatile demand and production capacity allocation, current inventory management policies tend to be quite ineffective, since they lead to inventory levels too low to account for sudden demand fluctuation, which ultimately translated into service levels below 60% for most of the analysed items. Moreover, for the conducted simulations, safety time buffers outperformed all other buffering strategies, ensuring total compliance with each material's weekly demand at the lowest cost, while monthly inventory review periods were preferred over the company's weekly review policy.

Lastly, in terms of data driven approaches' vulnerabilities, two key issues were highlighted – sensitive information not being available in information systems and lack of file format standardisation across platforms.

KEYWORDS

Business Analytics, Demand and Supply Uncertainty, Information, Inventory Management, Safety Buffers

CONTENTS

ACRONYMS AND ABBREVIATIONS

ABI	Adaptive Business Intelligence
BI	Business Intelligence
BOM	Bill Of Materials
BWE	Bullwhip Effect
CAD/CAM	Computer Aided Design/Manufacturing
CPS	COINDU's Production System
DSS	Decision Support System
EDA	Exploratory Data Analysis
EDI	Electronic Data Interchange
ERP	Enterprise Resource Planning
GUI	Graphical User Interface
ID number	Identification Number
IDT	Information and Digital Technologies
IoT	Internet of Things
IT	Information Technologies
JIT	Just-in-time
KPI	Key Performance Indicators
LT	Lead Time
MOQ	Minimum Order Quantity
MPS	Master Production Schedule
MRP	Material Requirements Planning
OEM	Original Equipment Manufacturer
"PA/SA"	"Produto Acabado/Semi-Acabado" (End-Item/Semi-Finished Good)
POS	Point-Of-Sale
PO	Purchasing Orders
RFID	Radio-Frequency Identification
SAP	Systems Applications and Products in Data Processing
SCRM	Supply Chain Risk Management
SIAP	Support to Production's Integrated System - "Sistema Integrado de Apoio à Produção"

WIP	Work In Process/Progress

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1. INTRODUCTION

This dissertation is the result of a six-month internship at COINDU COMPONENTES PARA A INDÚSTRIA AUTOMÓVEL, S.A. (Joane), as part of the Masters in Industrial Management and Engineering program. It works as a preliminary study for revising inventory management policies of current raw materials and assessing dynamic safety stocks or safety time approaches. In this chapter, the research motivation, objectives and methodology are presented, as well as a document overview.

1.1 Research Motivation

Today's global market is not only particularly dynamic, but also highly and increasingly volatile. Whilst trying to run their supply chains as efficiently as possible, companies fight to maintain their competitiveness, meet customer requirements and be prepared to face disruptive events of any nature (at an internal or external level) (Gonçalves et al., 2020 and Shekarian & Mellat Parast, 2021). In fact, the last few years have been plagued by situations like these (from wars to natural disasters, and even a world pandemic), which only intensified other common sources of risk in supply chains, such as replenishment delays and demand uncertainty (Howells, 2020 and Nezamoddini et al., 2020).

However, even without these extraordinary circumstances, the need alone to meet customer requirements in a highly competitive global market has always introduced a degree of unpredictability in daily operations, pertaining to product demand, supply, transportation and manufacturing activities with short term (increase, reduction, cancelation or forward-backward movements of orders, for example) to long term consequences (such as price volatility) (Gonçalves et al., 2020).

Notwithstanding, the primary goal of supply chain management remains the same – to efficiently link and integrate manufacturers, warehouses and stores, so that the final product is produced and distributed at the right quantities, to the right locations, at the right time, while satisfying service levels requirements and minimising total system-wide costs, from transportation and distribution to inventories of raw materials (Simchi-Levi, 2000).

For decades, in order to achieve these goals, the manufacturing industry followed the so-called '*just-in-time'* (JIT) philosophy (Masters et al., 2021), prioritising cost-efficiency and collaborative mentality (Ivanov & Dolgui, 2022). As a result, companies became inclined towards keeping low inventory levels and outsourcing non-core functions (design, production, logistics or even information services, to name a few) which meant expanding their supply chains to multiple locations (Masters et al., 2021; Nezamoddini et al., 2020; Tang, 2006) and, consequently, increasing their vulnerability to social-economic cycles such as the one we are currently undergoing (Nezamoddini et al., 2020 and Tang, 2006). Additionally, despite enhancing efficiency and cost savings, the adoption of low levels of inventory in JIT systems makes them particularly vulnerable to supply disruptions, equipment failures and delays (Nezamoddini et al., 2020).

This new, challenging reality, however, has made companies less tolerant of risk and uncertainty (Gonçalves et al., 2020), leading to a change in corporate strategy towards '*just-in-case*' policies that aim to increase their resilience and prepare them for any eventuality (Masters et al., 2021 and Shekarian & Mellat Parast, 2021). In fact, supply chain resilience has received burgeoning attention in recent years, since its purpose is to identify strategies that allow supply chains to react to disruptions while recovering to their original state or evolving to a new one more functional than the former (Shekarian & Mellat Parast, 2021).

Furthermore, '*In modern supply chains, information replaces inventory*' – meaning accurate information about inventory levels, orders, production and delivery status, throughout the supply chain, provides a great opportunity to improve the way supply chains are designed and managed (Simchi-Levi, 2000). As emphasised by Simchi-Levi (2000), information (i) reduces the variability in the supply chain; (ii) helps suppliers make better forecasts and account for promotions and market changes; (iii) enables the coordination of manufacturing and distribution systems/strategies; (iv) offers tools for locating items so that retailers can better serve their customers; (v) allows retailers to rapidly react and adapt to supply problems; and (vi), lastly, provides for lead time reductions.

Unfortunately, even when the demand of a particular product may not vary much, it is natural to have inventory and back-order levels fluctuating significantly throughout its supply chain (Simchi-Levi, 2000). This phenomenon is named Bullwhip Effect (BWE) and is defined as the increasing variation of the order quantity from downstream members to upstream members in a supply chain (Chiang et al., 2016). As a result, it is easy to understand that the more upstream a player is in a supply chain, the more vulnerable it becomes to receiving distorted demand information and, ergo, the harder it gets to know its real needs and to control its inventory levels.

In Material Requirements Planning (MRP) systems, supply and demand uncertainty are tackled via buffering strategies, which, in practice, translates into the adoption of safety stock or safety time (Guide & Srivastava, 2000 and Silva et al., 2022).

Although safety stock remains the most popular buffering technique amongst researchers and practitioners, plenty of studies have tried to better understand under which circumstances each strategy should be used instead of the other, in order to minimise materials' holding costs and to maximise service levels. However, most research in this field does not consider the simultaneous existence of supply and demand uncertainty, neither does it combine both buffering techniques into one inventory management policy (Guide & Srivastava, 2000; Silva et al., 2022; van Kampen et al., 2010).

Nonetheless, Silva et al. (2022) have recently developed a Decision Support System (DSS) that explored the trade-offs between inventory-related costs and service level requirements, by combining safety stocks and safety lead times. Their results encouraged the use of both buffering techniques under particular circumstances, namely on products with low delivery frequencies or increasing demand variability.

Inspired by their work, in this dissertation, we also intend to study the benefits of using safety stock together with safety time, including efficiency improvements in raw materials inventory management and service levels, in a company whose core business is the production of seat covers for vehicles – COINDU. Moreover, we aim to answer the following research questions:

- Do dynamic safety buffers improve the overall system performance?
- Which technique, safety stock or safety time, is the most appropriate to ensure a good trade-off between inventory holding costs and service levels?

1.2 Research Objectives

The main purpose of this dissertation is to be a preliminary study on the definition of raw materials inventory management policies based on real demand and supply uncertainty data, collected from COINDU's information systems. Thus, inspired by the contributions made by Silva et al. (2022), we intend to understand if the adoption of hybrid safety buffers, combining safety stock and safety time, can improve the system's current performance, regarding its holding costs and service levels. To this end, it is essential to understand:

- How raw materials are currently managed and what the main inventory policies in place are;
- What the company's key challenges are with regard to supply and demand uncertainty, and what strategies it has in place to cope with them;
- How finished products' needs are translated to raw materials' necessities and production orders, how the different parties involved in this process interact;
- How information is shared, internally as well as between the company and its clients and suppliers;
- What information is available to conduct a historical performance assessment of the suppliers' deliveries and the raw materials' service levels.

Fulfilling these objectives allows oneself to better understand how the system operates and helps signalling materials with poor supply performance, frequent stock-outs or high inventory levels (and, consequently, higher holding costs and obsolescence risk), which would very much benefit from new inventory management policies.

Since this dissertation constitutes the groundwork for future company research and tool development, we also intend to underline the main difficulties and system vulnerabilities that will be found, concerning information sharing, data storage and data treatment – key topics when dealing with business intelligence, data analytics, and decision support systems.

All of this work is expected to provide some evidence that the adoption of new, dynamic policies and the development of intelligent tools that capture both supply and demand fluctuations will make the company less vulnerable to supply disruptions and demand variation, hence improving its resilience towards market uncertainty.

1.3 Research Methodology

The development of this project follows the '*Action Research*' methodology inasmuch as its fieldwork allows the researcher to address real practical concerns and problems faced by the company, as well as to create knowledge or theory about the actions taken to solve them (Coughlan & Coghlan, 2002 and O'brien, 2001).

'*Action Research*' is, therefore, '*learning by doing*', as the researcher works alongside members of the system, in order to study a specific problem and to find appropriate solutions that will help it evolve towards what is regarded as a desirable direction (O'brien, 2001). Cooperation and co-learning are paramount among all parties involved, while the researcher must also ensure that the executed intervention is based on theoretical considerations (Coughlan & Coghlan, 2002 and O'brien, 2001).

Furthermore, it should be kept in mind that this methodology is a cyclic process, one that requires continuous adjustment to new information and events. There are also no restrictions to how data is collected – all methods are valid if properly discussed and agreed upon by all members of the workforce (Coughlan & Coghlan, 2002).

Additionally, Susman & Evered (1978) identified five key recurring steps in the '*Action Research*' process – 'Diagnosing' (to identify a problem within the system); 'Action Planning' (to consider different courses of action to solve the problem previously found); 'Action Taking' (to select the course of action);

‘Evaluating’ (to study the consequences of the actions taken), and ‘Specifying Learning’ (to identify general findings).

Complying with this framework, primarily, it was performed a system diagnosis, focused on raw materials inventory management policies, its main challenges and cross-functional interactions with other departments, as well as an analysis to its information sharing and data storage practices.

Parallel to this work, it was carried out an overview to the theoretical background information that supports fundamental concepts to this study, with the help of primary (theses), secondary (books, journals, newspapers) and tertiary (online databases) bibliographic sources.

After having a clearer depiction of the system’s current status, the action plan includes analysing the service level performance of key materials (A-type items in the company’s ABC analysis), its holding costs and stock-out consequences. Materials flagged in this initial assessment were evaluated in terms of supply uncertainty (replenishment delays or non-compliance with ordered quantities), noting that the acquired information was used to optimise safety stock and safety time levels.

The ‘Action Taking’ stage implied data collection, treatment and analysis from the company’s main information systems (SAP and SIAP, Support to Production’s Integrated System - “*Sistema Integrado de Apoio à Produção*”) and important local files. The new inventory management policies under study followed periodic-review systems (R, s, S). All major results, especially those from the service level and supply diagnosis to class A materials are presented in a Power BI Report, a Business Intelligence tool that visually allows for a better understanding of data, turning it into valuable information that supports decision making.

In addition to the new inventory and service levels, inventory management costs before and after the optimisation process were compared, as means to evaluate the performance of the suggested policies. These results, combined with all the diagnostic work, helped to understand part of the system’s current performance, the potential of dynamic safety stocks in this environment and what the work ahead will entail if the company, indeed, chooses to follow the example provided by Silva et al. (2022) and continue down the path of implementing a DSS to uphold the determination of safety buffers for raw materials.

1.4 Document Overview

This Master’s dissertation includes six main chapters, for the purpose of dividing the developed work in its major discussion topics. Starting with the present chapter, the reasons behind this study are properly explained, as well as its objectives and the followed methodology in order to achieve them.

On the other hand, the second chapter encompasses a thorough literature review on (i) supply chain and MRP systems; (ii) the adoption of safety stock and safety time buffers as means of protection against uncertainty; (iii) the role of Industry 4.0 and information in this research field, (iv) and, lastly, on Big Data and Business Intelligence.

After laying the groundwork for this project, chapter three introduces the company where this study was conducted (COINDU Joane), emphasising its supply chain positioning and manufacturing process, before moving on to the system's performance diagnosis, which is already part of chapter four, where current logistical processes concerning raw materials management are well described, as well as a historical analysis to service levels and supply quality is performed.

The study of new inventory management policies was carried out in chapter five, where a decision support system was conceived and the behaviour of a certain group of raw materials' inventory levels was tested for periodic-review systems (R, s, S). Additionally, the joint and separate combination of safety stock and safety time buffers was also under assessment. The results of this analysis are properly discussed in this section.

Finally, chapter six summarises this work's main findings and contributions, not just on a raw materials inventory management perspective, but also in terms of the vulnerabilities found in COINDU's system. Additionally, this section outlines what should be the direction of future research, in case the company is interested in continuing its journey towards data-driven decision making.

2. BACKGROUND

This chapter encompasses a literature review of the main topics related to this dissertation. Supply chain management and MRP systems are the first discussed subjects, followed by the two most popular means of protection against uncertainty in MRP production systems – safety stock and safety time. Afterwards, the role of Industry 4.0 and information in supply chain and operations management is clarified. Additionally, an overview of Big Data, Business Intelligence and Adaptive Business Intelligence is also presented.

Lastly, it is added a final notes section interrelating the key discussed topics with the research project itself.

2.1 Supply Chain Management and MRP Systems

The scientific community defines a supply chain as a network of interconnected players (for example, suppliers, manufacturers, distribution centres and retailers) that share one common goal – to add value to their customers or markets, while operating at the lowest possible cost and assuring the delivery of their products, services and information (Nezamoddini et al., 2020 and Silva et al., 2022) . In a setting like this, one's success rests on their interactions with others, and managing these interactions is what defines supply chain management (Silva et al., 2022).

Meeting customers' requirements in a highly volatile and competitive market such as today's involves dealing with uncertainty related to product demand, supply, transportation and manufacturing activities, which creates the need to develop new techniques - most of them studied by the risk management field - capable of addressing these phenomena and their repercussions throughout the supply chain (Gonçalves et al., 2020). Supply chain risk management (SCRM) aims, therefore, to identify, assess and monitor disruption risks in a supply chain network, in order to moderate their negative effects and assure the continuity and profitability of operations, by promoting collaboration and coordination between supply chain partners (Shekarian & Mellat Parast, 2021).

Industrial settings that plan and control their production by means of Material Requirements Planning (MRP) systems appear to be rather vulnerable to demand and/or supply risks, as a consequence of timing and/or quantity uncertainties (Guide & Srivastava, 2000). Nonetheless, MRP systems are quite popular in the industrial real world, with their appropriate use being restricted to dependent demand items – items that are a part of an end item, commonly referred to as the items bellow the end item in its product structure (Guide & Srivastava, 2000).

To correctly calculate the materials' needs, MRP systems use data from Master Production Schedule (MPS), Bill of Materials (BOM), inventory levels and lead time estimates (Koh et al., 2002 and Molinder, 1997). Because MRP systems are well defined as a set of back scheduling techniques, they use this data to determine the latest start date for all the materials of one end item, which, thereupon, leads to the calculation of their needs (Koh et al., 2002 and Molinder, 1997).

This logic shows that MRP systems were designed to operate within stable and predictable manufacturing environments (Koh et al., 2002), which, in theory, should avert the need for strategies that deal with any kind of uncertainty (Guide & Srivastava, 2000). However, as previously described, uncertainty is an established fact in daily operations, that is to say finding ways to cope with this unreliability, while preserving a system's performance, is not as much a matter of choice as it is a matter of necessity (Guide & Srivastava, 2000).

On the one hand, customer demand is typically forecasted as it is not known in advance (Syntetos et al., 2016), which implies that there is always a degree of uncertainty (Guide & Srivastava, 2000 and Syntetos et al., 2016) in the volume, product type or timing of incoming orders that can, ultimately, cause changes to operational production plans (van Kampen et al., 2010). Furthermore, insufficient or distorted demand information about orders or demand quantities also contributes to demand variability (Shekarian & Mellat Parast, 2021) and it is one of the main causes of the so-called Bullwhip Effect (BWE) – Figure 1. In fact, even though it is the final customer demand that sets the entire supply chain in motion (Syntetos et al., 2016), it is often found that orders to suppliers have a greater variance than the actual sales to buyers and that this variance tends to be propagated and amplified from downstream to upstream members (Li et al., 2017). This "demand amplification" (BWE) (Bhattacharya & Bandyopadhyay, 2011) can decrease supply chain performance (Chiang et al., 2016), since it leads to several operational problems, such as (i) excessive inventory levels, (ii) insufficient or unnecessary capacity, (iii) product unavailability, (iv) higher supply chain costs and (v) inaccurate production plans (Bhattacharya & Bandyopadhyay, 2011).

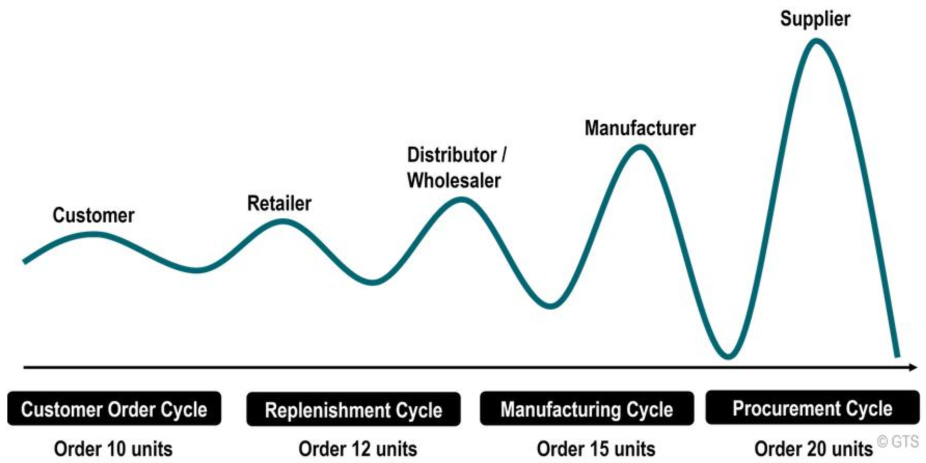


Figure 1: The Bullwhip Effect (Source: Rodrigue, 2020)

On the other hand, supply chains also face supply risks related to time, quality and quantity deviations, as well as other product or information disturbances that involve upstream partners (Shekarian & Mellat Parast, 2021). These uncertainties have many possible sources, namely (i) poor logistics performance by suppliers or by logistics service providers; (ii) supplier quality problems; (iii) sudden demise of a supplier; (iv) outsourcing and globalisation issues, and (v) replenishment lead time variability (Shekarian & Mellat Parast, 2021).

In MRP production systems, buffering is regarded as the primary means of protection against demand and supply uncertainty, which, in practice, translates into the adoption of safety stocks and safety lead times (Guide & Srivastava, 2000 and Silva et al., 2022).

2.2 Buffering Strategies – Safety Stock and Safety Lead Time

Safety stock and safety lead time are two different buffering strategies that aim to reduce the impact of demand and supply uncertainty in MRP production systems (Silva et al., 2022 and Van Kampen et al., 2010). While the former translates into the additional amount of inventory kept on hand, in order to face short term demand and supply variability (Silva et al., 2022 and van Kampen et al., 2010), the latter is defined as the difference between the optimal planned lead time and the on average lead time over the planning horizon (Molinder, 1997), which, in practice, entails planning order releases and scheduling their receipt earlier than required and established in the requirements plan normally obtained by the MRP system (Silva et al., 2022) – Figure 2. Although both safety stocks and safety lead times are dimensioned according to the level of uncertainty expected to impact production, it is worth noting that safety stocks increase system responsiveness, whereas safety lead times improve its flexibility (van Kampen et al., 2010).

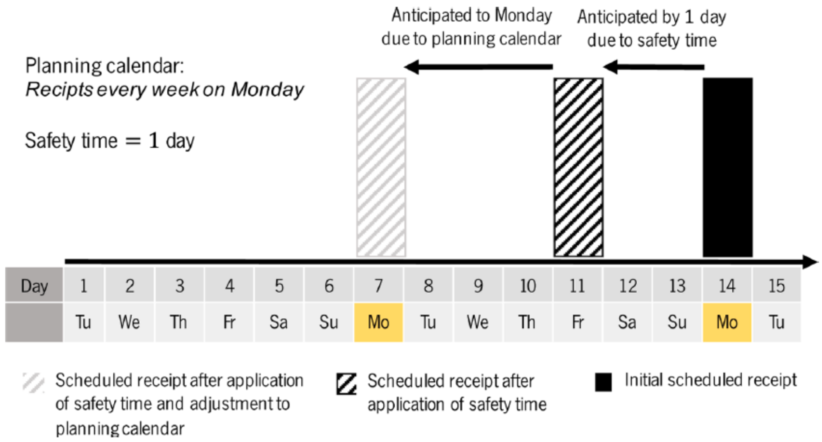


Figure 2: Possible Implications of using Safety Lead Time (Source: Silva et al., 2022)

Over time, despite safety stock's popularity amongst researchers and practitioners, many studies tried, unsuccessfully, to ascertain under which circumstances one methodology should be used instead of the other, while simultaneously minimising inventory holding costs and maximising service levels. Nevertheless, most of these works not only disregard the joint consequences of supply and demand variability and the possible benefits of combining safety stocks and safety lead times, as they are also mainly theoretical and based on very restrictive scenarios, not tested in real production settings (Guide & Srivastava, 2000; Silva et al., 2022; van Kampen et al., 2010).

Whybark & Williams (1976) conducted the first systematic study on buffering decisions in MRP systems, using a simulation experiment that allowed them to compare safety stock and safety lead time performance in single-stage production systems that faced demand and supply risks, caused by quantity and timing uncertainties (Guide & Srivastava, 2000; Koh et al., 2002; Molinder, 1997; Silva et al., 2022). They concluded that, when facing timing uncertainty, safety time should always be adopted, regardless of the level of uncertainty involved (Guide & Srivastava, 2000; Koh et al., 2002; Molinder, 1997; Silva et al., 2022). On the contrary, after using a simulation approach to better understand lead time uncertainty of purchased parts in multi-stage systems, Grasso & Taylor (1984) suggested the adoption of safety stock over safety time (Guide & Srivastava, 2000; Koh et al., 2002; Molinder, 1997; Silva et al., 2022).

In its quest for the best strategy to achieve a target service level at a minimum cost, the work of Etienne (1987) considered all types of demand and supply uncertainties. The results supported the idea that, in MRP production systems operating under quantity variability, safety time should be disregarded as the primary buffering technique, whereas in products with sparse delivery schedules, also affected by timing variability, safety time proved to be the better choice. Furthermore, it is carefully underlined that no buffering method is capable of assuring the superior performance in every single scenario (Guide & Srivastava, 2000 and Silva et al., 2022).

A few years later, Buzacott & Shanthikumar (1994) developed analytic models for single stage production systems, while proposing the adoption of continuous MRP systems instead of the traditionally periodic ones. Their studies upheld the use of safety time only when demand is well forecasted over the production lead time, otherwise safety stock should be the preferred buffering method. It is worth mentioning, though, that this analysis did not include any kind of supply uncertainty (Guide & Srivastava, 2000; Silva et al., 2022; van Kampen et al., 2010).

Molinder (1997) chose to simultaneously optimise, via simulated annealing, the safety buffers and the constant order quantity within an hypothetical MRP system, with the intent to analyse the influence that different lead time and demand variation coefficients would have in the optimal buffering choice and, subsequently, in the system's stock out cost and inventory holding cost ratio. The conclusion was reached that, when demand variability increased, safety stock was the best option. However, before high levels of both demand and lead time variability, safety time should be adopted instead. Moreover, these results support the work of Whybark & Williams (1976), suggesting the adoption of safety stocks when facing quantity variability and the adoption of safety lead times when dealing with timing uncertainty scenarios (Molinder, 1997).

By analysing a real multiproduct industrial setting via a simulation study, van Kampen et al. (2010) tried to understand the effectiveness of safety stocks and safety lead times, in the presence of both demand and supply uncertainties. To assess the impact of each buffering technique, they measured the system's performance along two different dimensions – delivery performance and average inventory level. Their findings supported the conclusions taken by Molinder (1997) – to cope with high demand variability, safety stock is the advisable alternative; if uncertainty is mainly in supply, safety lead time allowed for better results and, lastly, when the system faces both demand and supply uncertainty, safety time should be adopted, although it must be kept in mind that this strategy generally leads to a higher level of inventory than the one expected with a comparable level of safety stock.

A completely different perspective on the matter was presented by Silva et al. (2022) who, instead of, once again, analysing the separate performance of safety stocks and safety lead times, chose to optimise them jointly and understand their impact on materials' holding costs and the achieved service levels. For that purpose, they developed a hybrid bi-objective optimisation model, embedded in a DSS that recommends the optimal buffering strategies for components with different supply, demand and MRP dynamics (Silva et al., 2022). It is noteworthy that this study was conducted in a real and complex industrial setting – a company in the automotive electronics business, with multi-component and multi-supplier considerations, a single-stage system and both demand and supply uncertainties.

The results of this study allowed the researchers to suggest the combination of both buffering strategies in two different instances – on materials with low delivery frequencies (sparse delivery schedules) or when demand variation increased in the system. Moreover, if demand was overestimated, especially for A-type components, safety stock seemed to prevail over safety time. Lastly, when it came to supply uncertainty, combining safety stock and safety lead time proved, once again, to be the optimal strategy whenever supplier delays increased (Silva et al., 2022).

All in all, the overview presented in this section outlines the main studies on the adoption and dimensioning of safety stocks and safety lead times as a primary means of protection against demand and supply uncertainties in MRP production systems.

In fact, it is noticeable that, throughout the years, several researchers tried to comprehend which buffering strategy was the most appropriate under different circumstances, but only focusing on theoretical and less realistic scenarios. The ones that actually based their work on industrial case studies, oftentimes simplified the problem by disregarding some type of uncertainty. And most of them overlooked the potential of combining both buffering techniques. By restricting their approaches to a mindset of one policy instead of the other, they ignored the potential of a joint buffering strategy that could more dynamically react to different sources of variability in production systems, while achieving target service levels at minimum cost. Therefore, the work of Silva et al. (2022) constitutes a major breakthrough in this field, considering it not only offers a refreshed view of a broadly discussed topic as it combines its new approach to a DSS capable of providing guidelines to decision-makers, in what concerns the optimal parameterization of safety inventory buffering techniques.

2.3 Industry 4.0 and Information

So far, it has been ascertained that companies all over the world face incredibly challenging market conditions and that, if they wish to prevail over the others, they must find new strategies to deal with the different types of uncertainty that disrupt their supply chains. Buffering techniques play an important role in achieving this, especially in MRP production systems, with the adoption of safety stock and safety lead time.

Nonetheless, dimensioning these buffers relies heavily on the level of understanding decision makers have of the uncertainties they face, which ultimately relates to the strategies in place to signal and quantify such variations.
One could think that living in the information era would make this job much easier, but, surprisingly, the ever increasing amount of data generated and collected, is not always the most reliable, nor is it often structured in the best way, which presents new challenges to practitioners who want real-time data access to support their decision-making.
Having this in mind, the following sections allow for a better understanding of what Industry 4.0 is and the changes it has brought to the industrial world, in general, and to the supply chain management field, in particular. Big data and Business Intelligence are two other topics also discussed.

2.3.1 Digitalization and Industry 4.0

In the literature, digitalization has been defined as the use of computer and Internet technology to increase the efficiency and effectiveness of the economic value creation process, which leads to not only changing business processes and company products, as well as processes across entire supply chains (Núñez-Merino et al., 2020). Such profound changes paved the way to what is now known as digital transformation (Núñez-Merino et al., 2020).
In effect, this new broader term encompasses the joint use of both traditional and innovative information technologies (IT), connected via the Internet itself, which gave rise to the concept of Information and Digital Technologies (IDT) (Núñez-Merino et al., 2020). Applying IDT to the manufacturing industry in its quest to improve efficiency and effectiveness levels has led to its digital transformation and, consequently, to the birth of Industry 4.0 (Núñez-Merino et al., 2020).
The term Industry 4.0 was first used in 2011, during the industrial Hannover Fair, to summarise how the concepts of cyber-physical systems apply to industrial production systems (Barros, 2023). Although in its essence Industry 4.0 stands for the introduction of IDT in the industrial world, in order to achieve higher operational, productivity and automation levels (Barros, 2023 and Núñez-Merino et al., 2020), amongst researchers, its formal definition varies depending on the academic research field (Ivanov et al., 2021).
From an operations management perspective, Ivanov et al. (2021) define Industry 4.0 as "an integrity of technologies, organizational concepts and management principles underlying a cost-efficient, responsive, resilient and sustainable network, data-driven and dynamically and structurally adaptable to changes in the demand and supply environment through rapid rearrangement and reallocation of its components and capabilities". It is noteworthy that this definition links the concepts "resilient" and "adaptable" to

"data-driven", emphasising that the knowledge required to make systems more flexible should be derived from data about their performance.

Industry 4.0's technologies include tools such as Electronic Data Interchange (EDI), Computer Aided Design/Manufacturing (CAD/CAM), Industrial Simulation and Enterprise Resource Planning (ERP) (Núñez-Merino et al., 2020), alongside more advanced IDT – Cyber-physical systems, Internet of Things (IoT), that allows not only humans to communicate via the Internet, but also objects and devices (human-to-things and things–to–things communication techniques) (Pal & Yasar, 2023); Blockchain, Artificial Intelligence, Cloud Computing and Big Data Analytics, the last of which being particularly relevant in the operations management field (Ivanov et al., 2021 and Núñez-Merino et al., 2020).

Furthermore, in their work Ivanov et al. (2021) identified five key research areas and disciplines related to Industry 4.0. As shown in Figure 3, Artificial Intelligence is one of the major research areas, whereas Supply Chain and Operations Management, Industrial Engineering and Data Science are included in the disciplines' category.

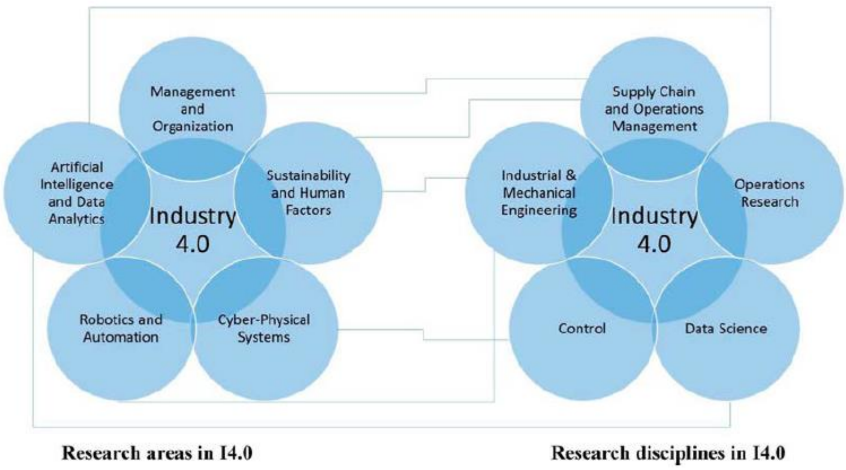


Figure 3: Research Areas and Disciplines in Industry 4.0 (Source: Ivanov et al., 2021))

2.3.2 Information Technologies in Supply Chain Management

Information is power and there is no exception to this rule in supply chain management. Abundant information (i) reduces the variability in the supply chain; (ii) helps suppliers make better forecasts; (iii) enables the coordination of manufacturing and distribution systems/strategies; (iv) offers tools for locating items so that retailers can better serve their customers; (v) allows retailers to rapidly react and adapt to supply problems; and (vi), lastly, provides for lead time reductions (Simchi-Levi, 2000).

IT plays an important role in increasing supply chain effectiveness, since it helps creating an information trail parallel to the one physically made by the product (Simchi-Levi, 2000). Even more traditional IT tools still manage to find a place in today's hyperconnected world, including EDI and ERP systems.

Although it has been around since even before the Internet reached business domain, EDI has been properly adapted to web environments and has continuously helped improving the communication between customers and suppliers; business partners and organisations (Núñez-Merino et al., 2020). In simple terms, it allows the exchange of large volumes of information (data exchange) between partners, by using electronic transactions, when performing purchasing, shipping and other types of deals (Núñez-Merino et al., 2020 and Simchi-Levi, 2000). This computer-to-computer data exchange involves documents interchanged in a standard electronic format, so that computers are able to read and understand them (EDIbasics, 2023). As a result, it is no surprise that EDI contributes to reduce errors, costs and the time needed to send out information, ultimately translating into faster decision making, improved relationship between business partners and increased supply chain efficiency (EDIbasics, 2023 and Núñez-Merino et al., 2020).

Regarding ERP systems, they constitute a common database for all business functions (Simchi-Levi, 2000). As they present information visually, they make its interpretation easier to understand and communicate, which improves the management of real-time operations and processes (Núñez-Merino et al., 2020).

With the dawn of Industry 4.0, information is now more than ever generated, integrated, transmitted and processed throughout all supply chains, in order to support the decision making process (Núñez-Merino et al., 2020). Digitalized supply chains and operations' concept includes its control with real-time data, dynamic resource allocation, the improvement of forecasting models, using Big Data; and the combination of optimisation, machine learning algorithms and agent-based modelling for supply chain resilience (Ivanov et al., 2021).

Thus, it comes as no surprise that operations management activities and their decision-support methods are expected to be significantly transformed by the bedrock principles of Industry 4.0 (Ivanov et al., 2021), as it is clear the adoption of these new technologies, principles and methods is designed to make supply chains more autonomous, dynamic, flexible and precise (Núñez-Merino et al., 2020).

2.4 Business Analytics and (Adaptive) Business Intelligence

2.4.1 What are Big Data and Big Data Analytics?

The term Big Data simply translates to an incredible amount of data, so much so that the processed datasets are too large to fit into the memory of the computers used to conduct this task (Sanders, 2014). This kind of data comes from different sources, such as point-of-sale (POS); radio-frequency identification (RFID); EDI or ERP systems, in different formats, for example, numerical, text or voice (Choi et al., 2018 and Sanders, 2014).

Big Data is traditionally described by the following five variables (5Vs):

- **Volume:** Data is everywhere. Nowadays, virtually all companies have IT systems that generate huge amounts of data, about almost anything. In supply chains, manufacturers and retailers collect data from POS, RFID, ERP systems and even equipment sensors (Sanders, 2014). The amount of data generated has increased and will continue to increase exponentially with the spread and development of IDT, which challenges the capacity of existing storage devices (Nguyen et al., 2018 and Sanders, 2014).
- **Variety:** As aforementioned, data can come from many heterogeneous sources, in structured, semi-structured and unstructured formats (Nguyen et al., 2018). Sensors, POS and RFID are examples of sources of structured data, whereas text and voice messages, social networks feeds and blogs are sources of unstructured data (Sanders, 2014).
- **Velocity:** The speed of data generation and delivery (Nguyen et al., 2018). Companies capture exponentially growing volumes of transactional data, as well as information about their customers, suppliers and operations, all of this enabled by IoT (Sanders, 2014). Moreover, plenty of data is generated unintentionally, as a by-product of other activities, creating digital trails that can be captured, monitored and analysed (Sanders, 2014). To sum up, companies collect data with increasingly greater granularity and frequency, not just about customer transactions, but also their behaviour and personal information (Sanders, 2014).
- **Veracity:** Many data sources contain a certain degree of uncertainty and unreliability. This dimension relates to data quality and level of trust (Nguyen et al., 2018).
- **Value:** The process of revealing underexploited value to support decision-making (Nguyen et al., 2018).

Other elements can also be associated with Big Data, such as **“variability”**, **“complexity”** and **“decay”**, the last of which referring to the declining value of data over the course of time (Sundarakani et al., 2021). Indeed, time-critical situations require high volumes of data to be instantaneously processed, so the decay of data is an exponential function of time (Sundarakani et al., 2021).

Nevertheless, one should keep in mind data itself is quite worthless without proper analytics. Thus, Big Data Analytics brings to use advanced analytics techniques to extract knowledge from vast amounts of data, by exhibiting it for meaningful interpretation that will drive business decision-making processes (Nguyen et al., 2018 and Sundarakani et al., 2021).

But how does Big Data and Big Data Analytics relate to Supply Chain and Operations Management? Simply put, it all comes down to problem-solving capacity (Sanders, 2014). Operations management employs scientifically sound analytical methods to help make optimal or near-optimal decisions for organisations, a task naturally associated with the use of data (Choi et al., 2018). To solve problems in this field, there is a need for computing algorithms based on statistical and mathematical models and, as a result, big data analytics and its techniques should be regarded as one of the most prominent recent developments in this field (Choi et al., 2018). Bearing in mind that inventory control/management is a critical topic in operations management, the influence that Big Data has on supply chain and logistics management becomes quite clear (Choi et al., 2018).

In order to process big data, there are several and not mutually exclusive techniques that can be used, namely:

- **Statistics:** It aims to provide a scientific framework to collect, analyse and draw inference and conclusion. It can be used in data analytics, even though standard statistical methods are usually not versatile enough to fit some of the big data requirements, including its need to deal with heterogeneous and unstructured data (Choi et al., 2018).
- **Machine Learning:** It provides algorithms that allow computers to discover knowledge and make decisions by learning from the given data (Choi et al., 2018). In Big Data Analytics, machine learning methods have to be improved for both the supervised and unsupervised learning approaches (Choi et al., 2018). Note that, in supervised learning, the datasets used are labelled, meaning that they are designed to train or “supervise” algorithms for classifying or predicting outcomes accurately, hence allowing the model to measure its accuracy and to learn over time (Delua, 2021). On the other hand, an unsupervised learning approach uses machine learning algorithms to analyse and cluster datasets, which translates into the discovery of hidden patterns

in data without the need for human intervention, ergo being known as “unsupervised” (Delua, 2021).

- **Data Mining:** The process of extracting insights from a given dataset by identifying patterns and relationships that can help solve business problems (Choi et al., 2018 and Stedman, 2021). Typically, data mining models are developed based on machine learning and statistics (Choi et al., 2018). These techniques and tools enable companies to predict future trends and to make more informed business decisions, so it is no wonder that data mining is the cornerstone of business intelligence and Big Data Analytics (Choi et al., 2018 and Stedman, 2021).
- **Optimisation:** A standard analytical approach to find the optimal or near-optimal solutions in quantitative decision-making problems (Choi et al., 2018). Genetic algorithms, simulated annealing, particle filters and other evolutionary algorithms are well-developed ways to get good solutions in a reasonably short time (Choi et al., 2018). Computational optimisation in Big Data Analytics faces challenges related to (i) computational memory and time; (ii) convergence (optimisation reaching a stable point at the end of the process when no further improvements are expected) (Brownlee, 2021); (iii) identification of globally optimal solutions and the need of real-time optimisation (Choi et al., 2018).

In Operations Management, data mining and machine learning techniques are used in areas such as risk analysis, transportation management and forecasting (Choi et al., 2018). In particular, forecasting typically relies on historical data, market information and expert advice (Choi et al., 2018). The fact that information is now available from so many different sources can, for example, help sense demand behaviour, which consequently improves demand forecast accuracy (Choi et al., 2018 and Nguyen et al., 2018).

Additionally, inventory control also takes advantage of Big Data Analytics (Nguyen et al., 2018). In this field, the standard technique used is optimisation, since analytical optimisation models are well established in inventory management, as it is the case of the base-stock policy (Choi et al., 2018).

2.4.2 Big Data Analytics - Challenges

Big Data Analytics faces several challenges, not just from the data and computing side, but to its adoption as well. From the data side, there should be noted the massive amount of data points, the presence of complex data and the existence of high uncertainty (Choi et al., 2018), all of these directly related to three out the 5Vs already presented – volume, variety and veracity.

Regarding computing challenges, many existing methods are not flexible enough, nor scalable to adapt to big data requirements (Choi et al., 2018). Moreover, they also struggle to cope with huge-dimensional problems (Choi et al., 2018).

To overcome these shortcomings, there are some useful strategies commonly followed, including:

- **Divide and Conquer:** To break down big data into multiple pieces, small enough to be solved one by one. The final analysis is obtained by combining the separate results (Choi et al., 2018).
- **Distributed and Parallel Processing:** To process data by multiple parallel and distributed computing systems. It is consistent with the divide and conquer concept, but, in this case, the dataset is being analysed at the same time by multiple distributed processors, which makes this method extremely flexible (Choi et al., 2018).
- **Statistical Inference:** It includes statistical sampling and relationship establishment between samples and the population. This helps to justify if it is enough to process a smaller sample from the big data population instead of the entire dataset (Choi et al., 2018).
- **Feature Selection:** Its main idea is to determine a subset, from the big dataset, that is good enough to represent its core features, implying a reduction of the input variables (features) to a more relevant selection (Choi et al., 2018 and Menon, 2023).
- **Heuristics:** These are developed to find near-optimal solutions and identify bounds by numerical methods, within a reasonable timeframe (Choi et al., 2018).

Nonetheless, although Big Data Analytics is expected to enhance supply chain performance, its adoption by companies can still be considered in its infancy. Nguyen et al. (2018) presented (i) the lack of understanding its implementation; (ii) the inability to identify suitable data; (iii) low acceptance, "routinization" and assimilation by organisations and supply chain partners, and (iv) data security, as the main reasons for the low uptake.

Devane (2023) and Renner (2021) pointed out other factors that contribute to hamper the transition to Big Data Analytics, namely:

1. **Lack of Visibility and Poor Data Quality:** Data is often incomplete, outdated and fragmented across several systems. A centralised access is crucial to improve visibility, transparency and, consequently, supply chain insights and decision-making (Renner, 2021).
2. **Security, Compliance and Governance Requirements and Restrictions:** Sensitive data is becoming not just incredibly common, but also vital to compete. However, according to a survey from S&P Global's 451 Research and Immuta, 86% of the respondents agree that

"security and privacy rules have become stricter over time, making it harder to access and use data". The complexity involved with ensuring compliance can become a supply chain bottleneck that delays or prevents real-time data access (Devane, 2023).

3. **Lack of Skill and Personnel:** While security, compliance and governance requirements are increasing, the same cannot be said about the people responsible for implementing measures to satisfy them (data suppliers) – data engineers, architects, and so on. Two major problems that relate to this are, once again, delayed data access and unauthorised data use (Devane, 2023).
4. **Lack of Automation:** Adding to the lack of data suppliers, there is a lack of tools to allow them to do their job at the required pace. Indeed, almost as bad as lack of automation is automation that requires substantial human intervention (Devane, 2023).

2.4.3 Business Intelligence and Adaptive Business Intelligence

Hopefully, one can now fathom that data is the new asset for organisations and that its true power is fully unleashed when combined with analytics, since it is only then that one gets meaningful insights and turns information into business intelligence (Sanders, 2014).

Business Intelligence (BI) itself refers to the processes, tools and technologies that enable organisations to make better decisions, take informed actions and implement more efficient business processes (Oracle, 2023 and Stefanovic & Milosevic, 2017). BI capabilities allow companies to collect up-to-date data, present it in easy-to-understand formats (such as tables and graphics) and deliver it in a timely fashion to employees (Oracle, 2023).

Moreover, BI helps companies to understand what happened in the past and why it has happened, as well as to better predict what will occur in the future (Sanders, 2014). As a result, it is no wonder that organisations that manage to answer these questions satisfyingly increase their problem solving capability, thus becoming more competitive (Olszak, 2022 and Sanders, 2014).

Nowadays, it is no longer enough for companies and their supply chains to be cost effective. They must also be (i) agile (respond quickly to disruptions and unexpected changes), (ii) aligned (the interest of all partners needs to be aligned with the global supply network strategy) and (iii) adaptable (evolve over time by adapting their processes to other partners, key customers and changing market needs) (Stefanovic & Milosevic, 2017). Therefore, even the BI concept has evolved into what is called Adaptive Business Intelligence (ABI), representing an adaptable system capable of using advanced forecasting and optimisation techniques to enhance intelligence in strategic decisions (Lopes et al., 2020).

ABI systems aim to answer two fundamental questions – *what is likely to happen in the future?* and *what is the best decision right now?* (Michalewicz et al., 2007). Michalewicz et al. (2007) quite eloquently pointed out that the future of business intelligence lies in systems that can provide answers and recommendations, as opposed to loads of knowledge presented in the form of reports. *'The future of business intelligence lies in systems that can make decisions'* (Michalewicz et al., 2007) and that is the premise behind ABI. The architecture of an ABI system is presented in Figure 4.

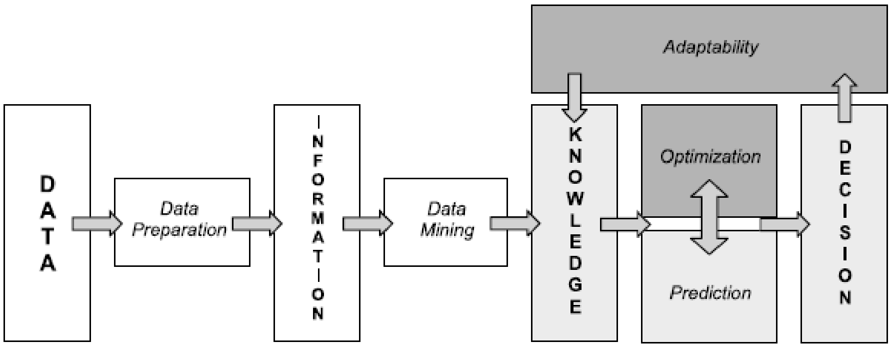


Figure 4: The architecture of an ABI System (Source: Michalewicz et al., 2007)

As shown in Figure 4, ABI systems include elements of data mining, predictive modelling, forecasting and optimisation to recommend near-optimal decisions based on past data, as well as an "adaptability module" for improving future recommendations (Michalewicz et al., 2007). Without this ability to adapt, the system cannot be characterized as "intelligent" (Michalewicz et al., 2007).

In conclusion, real-world business problems have complex constraints, are set in time-changing environments, might have conflicting objectives and where the number of possible solutions is too large to enumerate, can only be properly solved through systems that combine prediction, optimisation and adaptability modules – ABI systems (Michalewicz et al., 2007).

2.5 Final Notes

Throughout this chapter, several key topics related to the work presented in this Master's dissertation were discussed. Indeed, COINDU, as plenty of other companies worldwide, has entered this new Industry 4.0 era by digitalizing its systems and investing in IT tools without taking full advantage of this new way of operating.

IDT not only help connecting processes and making them more efficient, they also increase one's visibility over them, by the intensive data creation and collection associated to their use. This data, when properly treated, can be quite revealing of a company's current status and what future direction it seems to be heading. Data transformed into information is a powerful tool that must be used to support decision-making. Unfortunately, many companies have not yet mastered this transformation and plenty of others have not even acknowledged its potential.

On a different note, COINDU wants to take advantage of the data that they have available to improve its raw materials inventory management, through the definition of new buffering strategies, more suitable to their needs and the levels of demand and supply uncertainty that they face. Hence, this project means not only to improve existing inventory management policies, but also to help the company entering this new path of data-driven decision-making.

Considering the literature review carried out throughout this chapter, it seems clear that safety stock and safety time are two widely discussed topics, as well as the potential of data to obtain information and drive organisations forward. Nevertheless, these research topics still present a few literature gaps that will hopefully be explored by this dissertation.

In regard to the study of safety buffers, even though plenty of researchers tried, unsuccessfully, to ascertain under which circumstances each methodology should be used instead of the other, as Guide & Srivastava (2000); Silva et al. (2022) and van Kampen et al. (2010) pointed out, most of these works not only disregard the joint consequences of supply and demand variability and the possible benefits of combining safety stocks and safety lead times, as they are also mainly theoretical and based on very restrictive scenarios, not tested in real production settings.

Stimulated by the research conducted by Silva et al. (2022) and while trying to positively contribute to close this literature gap, this dissertation studies the use of demand and supply uncertainty data, obtained via COINDU's information systems, to define new raw materials inventory management policies. This uncertainty information is particularly important in the determination of safety buffers that, in this case, include the joint and separate use of safety stock and safety time. This way, we intend to estimate the practical benefits of implementing these buffering strategies in a dynamic, real industrial setting.

On the other hand, when it comes to the IDT field, research related to its ground-breaking opportunities and main applications is often found. In fact, the background work in industry 4.0 and big data highlights the power of turning available information into real business insight, the main techniques used to achieve this, some challenges that might come with big data processing and future business intelligent tools that can be developed.

However, none of this research seems to detail how companies take this next technological step. Most discussed issues refer to practical difficulties that come with Industry 4.0 and big data itself, while few explore the big hurdles that organisations encounter when trying to evolve from more traditional industries, where information is often spread across departments, to new hyper-connected systems, where real-time information is available to all users.

In order to address these shortcomings, this Master's dissertation also details the main hurdles and system vulnerabilities found in the course of this project, as a way of raising awareness to the struggles companies face when starting their journey towards full-system integration and data-driven decision making.

3. COMPANY

This chapter enables one to learn more about the company where the project was developed - COINDU COMPONENTES PARA A INDÚSTRIA AUTOMÓVEL, S.A. (Joane). Initially, the COINDU Group is presented, as well as Joane's production unit. Afterwards, the company's products are properly discussed, along with its supply chain positioning and manufacturing process.

3.1 The COINDU Group

COINDU was founded by António Lourenço, Armindo Gomes and Günter Stichter Senior in Joane, Portugal, in 1988. At that time, its core business was the production of small leather parts, being most operations conducted in Joane, with the exception of commercial operations that were handled by Sevex, the other company held by the Stichter family.

Four years later, COINDU started the mass production of car seat covers, acting as a second-tier supplier for Original Equipment Manufacturers (OEMs) Volvo, Ford, Mercedes, Volkswagen and Chrysler. Its continuous growth led, later on, to the establishment of a new plant in Arcos de Valdevez, Portugal, and the company becoming completely independent from Sevex.

The following years would add big players to their customer portfolio, including Faurecia and Johnson Control, two new clients that prompted the decision to open the first plant outside Portugal – a production plant in Curtici, Romenia.

COINDU's expansion would not stop there, since, throughout the years, not only did other major OEMs and Tier I suppliers become their customers, but also the company itself decided to diversify its product selection by moving outside the automotive industry into the luxury apparel industry and by supplying small leather parts to one of the world's leading international fashion houses.

In 2015, the company continued its internationalisation strategy and opened a new production plant in Tetla, Mexico, while 2019 marked the acquisition of BREE Collections GmbH, a German brand that produces luxury leather goods.

Nowadays, COINDU's headquarters remain in Joane, while maintaining its other production units in Arcos de Valdevez, Curtici and Tetla, as well as customer centres in Germany and China, with a combined workforce exceeding 3.800 employees in total. Its core business is well established as the production of luxury car seat covers for different OEMs and Tier I suppliers (Figure 5). Throughout its history, COINDU has managed to build a solid reputation for the quality of its products and the flexibility of its manufacturing process, the latter being a particularly distinctive characteristic that attracts OEMs looking for suppliers capable of handling highly customisable products.

COINDU is also committed to a series of values, towards its partners and employees, including product **reliability**; **integrity**; **respect** for their global team, rewarding their performance; **responsibility**, not just concerning its employees safety and healthy working environments, but also the environment itself; **sustainability** associated with value creation; and **curiosity/continuous improvement** – "Today is better than yesterday, tomorrow is better than today".

Figure 5: Examples of Seat Covers produced for Aston Martin DBX (left) and Audi Q7 (right) Models (Source: COINDU, 2023)

3.2 COINDU Joane

COINDU's facilities in Joane not only include the company's headquarters, but also its biggest production unit, currently employing over 1.500 workers and with a daily capacity to produce 2.400 car sets. The production is spread between two different buildings, commonly referred to Joane I and Joane II (Figure 6). While Joane I encompasses the so-called *premium* projects – highly customisable seat covers for several bespoke car models -, as well as all of BREE's manufacturing process, Joane II is known as the mass production site –the seat covers from Joane II are produced in much larger quantities than the ones manufactured in Joane I, though still rather customisable.

Figure 6: Aerial View of Coindu Joane I (green) and Joane II (white)

In recent years, COINDU has invested in developing its own production system (COINDU Production System - CPS) by implementing innovative solutions that embrace the challenges of the automotive sector and textile manufacturing, whilst allowing them to meet their customers' expectations. Every time the CPS department starts a new initiative, it is primarily studied and properly tested in Joane. The rollout of new initiatives to the other sites only happens after its local implementation proves to be successful. As a result, COINDU Joane also stands as the company's development centre, performing as the incubator of new solutions designed to uphold its continuous improvement mentality, increase its competitiveness and, consequently, to drive the organisation forward.

3.3 End-Items

Even though COINDU's business also includes the production and retail of fashion leather goods, its main focus remains on the automotive industry. Likewise, the scope of this study is aligned with this main reality, only concerning the production of car seat covers.

The seat covers produced by the company fall into one of the following four categories – mass production and *premium* products, Purchasing Orders (PO) and Service Parts. While the difference between mass production and *premium* products has already been explained, it is important to distinguish PO and Service Parts.

On the one hand, PO are one of a kind orders customers make. In practice, these special requests translate into car seat covers whose part numbers are not included in the range of production references available and are, as a result, treated in a Make-To-Order (MTO) basis. Such orders may be related to the use of a particular material in the seat cover, the addition of personal details or a change in its design. Tests to assess technical changes and airbag performance are also included in this category.

On the other hand, Service Parts concern orders made to replace seat covers that got damaged as a consequence of, for example, car accidents. This type of orders is particularly hard to manage, since (i) it is highly unpredictable for it can be directly requested, at any time, by car dealers and not just COINDU's direct customers; (ii) it is most likely associated with older seat versions that are no longer in production or, in the worst-case scenario, (iii) it may even regard car models that COINDU does not manufacture anymore and whose raw materials supply is now rather scarce. One should note COINDU is responsible to ensure this service several years after the end of a project. Service Parts bring, therefore, plenty of challenges to both production and raw materials management activities.

As PO and Service Parts are managed separately and do not represent the same sales and manufacture volume as mass production and premium items, they will be out of the scope of this project.

3.4 Supply Chain Overview

COINDU can be described as an upstream member in their customers' very complex supply chains, which makes them particularly vulnerable to the BWE. Working with a multitude of suppliers and clients, spread across several geographical locations, while keeping its manufacturing process as flexible as possible proves to be quite a challenge, especially in a market as volatile and competitive as the one typically surrounding the automotive industry. Additionally, the fact that the company works simultaneously with various car makes and models means they must comply with different requirements and its production needs to use a wide range of raw materials, from leather and luxury textiles to thread, airbag materials, foam and vinyl. Figure 7 illustrates the main characteristics of COINDU's supply chain.

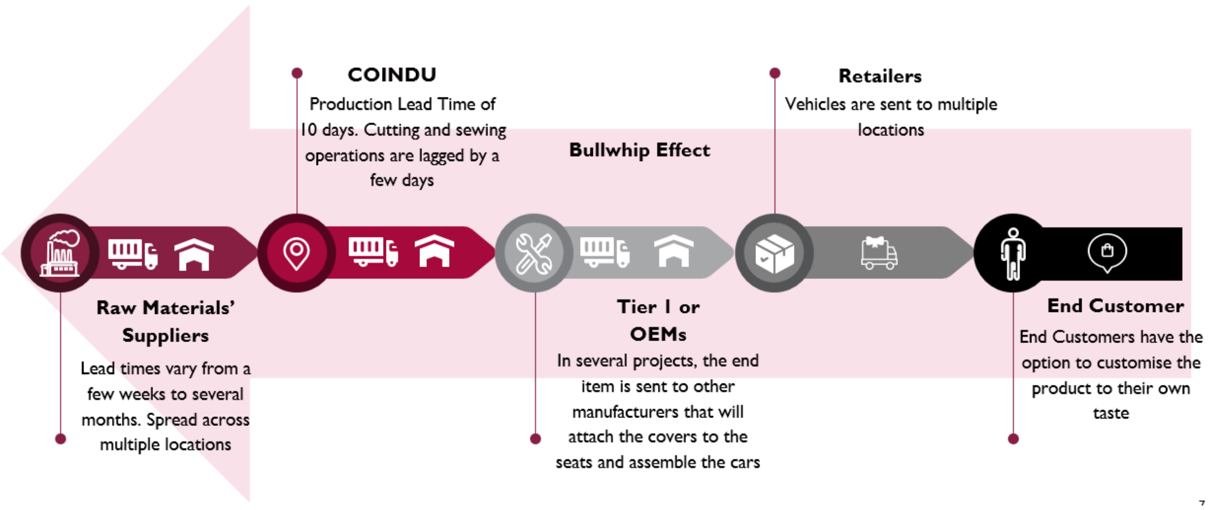


Figure 7: COINDU's Supply Chain Main Characteristics

When it comes to COINDU's raw materials suppliers, most of them are chosen by costumers themselves. If the company believes to have found a supplier capable of providing the same material with similar or even better quality, but at a lower price, the client must verify that the newly produced seat covers follow their standards before authorising the supplier's change.

Moreover, supplier lead time is extremely influenced not just by their location but also by the type of the delivered material. For instance, leather materials have typically the highest lead times because their production process is rather laborious and time consuming. Considering leather materials alone, COINDU deals with lead times that range from four to twelve weeks' time.

With such a big gap between the moment the orders are placed and the time the materials reach COINDU's facilities, the ultimate question revolves around how the company and its suppliers handle demand fluctuation during lead time. Here, the fact that most raw materials' suppliers are chosen by the customer plays an important role, once again.

Some suppliers are in direct contact with the customer, meaning that they have access to the same demand forecast as COINDU and that they already know what should be considered as a real order or as a future prediction. For other suppliers, COINDU is responsible for sharing the demand forecast (usually for the next three to four months) and to define what should be regarded as an actual order.

Sometimes, end item demand fluctuation may force the company to reach out to the supplier and increase the requested quantities during the lead time window. In these circumstances, the supplier may be able to comply with this request, should they have enough stock on hand. If not, however, the supplier, COINDU and the customer must agree on a delivery plan to cover the additional demand.

On the contrary, when the minimum order quantity (MOQ) is too large in comparison to the company's estimated needs, COINDU is forced to order this amount, but asks for phased deliveries - to receive this quantity over time and not all at once, which allows them to better manage their warehouse space limitations.

These limitations also forced the company to outsource the warehousing of their materials, in order to save space and reduce costs with an extra warehouse of their own, although transportation from the supplier is always COINDU's responsibility. This third-party warehouse is located nearby COINDU's facilities and allows for speedy deliveries, whenever the materials are needed for production. Nevertheless, this strategy cannot be used in all projects, especially those where the customer pays the company to keep a minimum quantity of raw materials in stock on site.

The transformation of raw materials into car seat covers takes about 10 days – five days for cutting and auxiliary operations and five others for sewing and quality control procedures. Cutting and sewing operations are lagged by a few days, meaning there is a delay of a few days between one and the other - a piece that is being sewn on a Monday has ideally been cut on the previous Wednesday or Thursday, the latest. The manufacturing process itself is explained in greater detail in section 3.5.

Focusing on the end-items themselves, they may either be collected by the customers at COINDU's facilities or the company may be held responsible for their direct delivery to them. In some other cases, COINDU must firstly send them to distribution centres in Europe before customers can get them by their own means or they can even request COINDU to transfer the products to their facilities, following the JIT philosophy.

As previously mentioned, overtime, COINDU has managed to attract new customers and to establish long lasting partnerships. For this reason, nowadays, the company works directly with several OEMs and Tier I suppliers, responsible for attaching the covers to the seats and to assemble the cars. Evidently, it is only after this stage that the vehicles will be ready to be sent to car dealers and retailers across multiple locations in Europe (in the case of COINDU, Portugal customers) and to ultimately reach the end customer.

3.5 Manufacturing Process

The manufacturing process of the desired car seat covers is determined by the main material used in its production, meaning that if the end-item is meant to be a leather upholstery, it will have a more intricate process than a textile or vinyl upholstery. Figure 8 highlights the fundamental operations associated with the manufacturing process of the different types of seat covers.

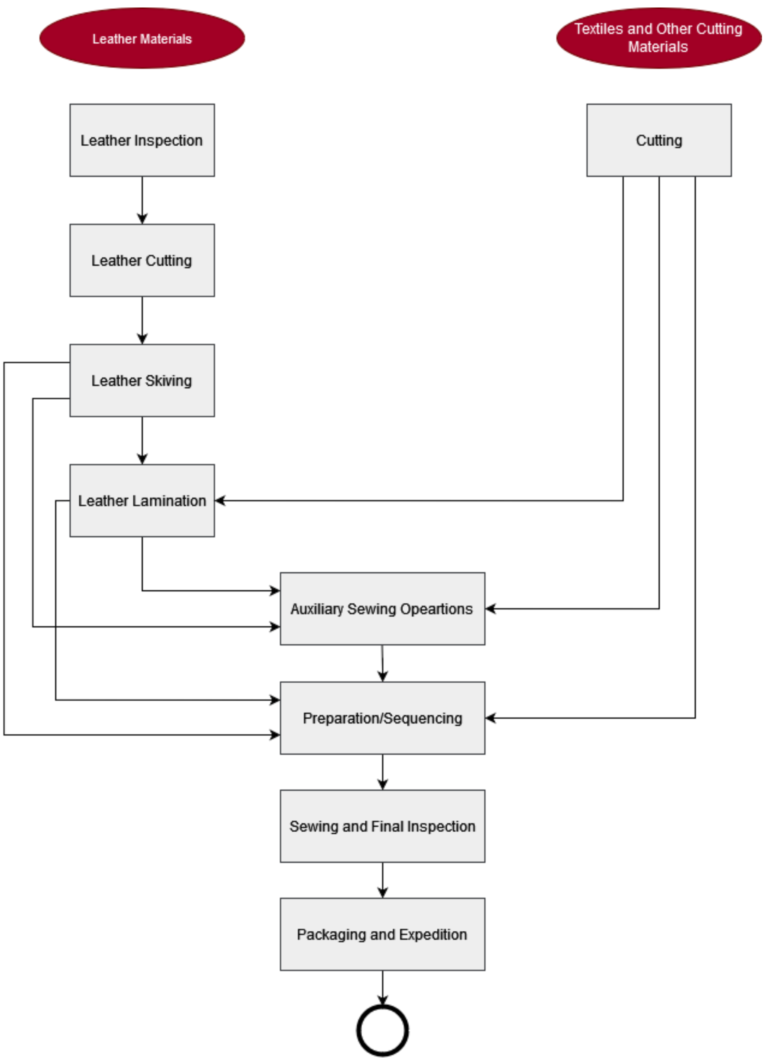


Figure 8: Manufacturing Process

In regard to leather materials, they must undergo a thorough inspection before being used in production. During this procedure, the workers verify the leather quality and look for defects that might impact the following operations. The defects found fall into different categories, ranging from less to more severe damage. Each severity level is linked to unique standardised symbols that the workers draw on the leather, so that, during the leather cutting stage, machines and operators distinguish the areas that can be used to produce certain seat parts from those which are not up to code and will go to waste. After being properly cut, all leather pieces must be skived, which translates into having their edges thickness reduced, so that they become more flexible.

Depending on the role that the leather parts play on the seat design, they might undergo the lamination process. In practice, however, skiving and lamination operations happen in adjacent workstations, which implies that, although some pieces will not undergo the latter transformation, they all move along this station. Leather lamination consists in applying a material to the surface of a leather piece, in order to enhance its properties. In this particular case, the leather parts are merged with foam to introduce a cushioning feel to the touch.

Textiles, vinyl, foam and other cutting materials are not as heavily inspected as leather, transitioning, therefore, more quickly to the cutting operation and from there to lamination, auxiliary sewing operations or preparation/sequencing stages.

Auxiliary sewing operations encompass a series of transformations that may happen to the pieces, depending on the car seat's final design. These transformations include embossing, embroidery and perforation. Embossing involves pressing a design or pattern onto the material, using heat and pressure, whereas embroidery uses needlework to stich the patterns directly onto the surface. Perforation consists in the process of creating small holes (perforations) on the materials surface. These holes can either be decorative or functional if, for example, the covers will be used for heated seats.

Despite the path followed by each part until this stage, they all go through preparation/sequencing, before being sewn together. Preparation/sequencing refers to the process of assigning the parts to the end-items' production orders, considering both the production and the delivery plan agreed with the customer. The difference between preparation and sequencing lies in the underlying production control process associated with the end-item that created the need to produce the semi-finished goods. Preparation is related to the so called "PA/SA" (End-Item/Semi-Finished Good) process, which means the reference code that represents the end-item has only one semi-finished good reference code linked to it. This implies that, regardless of the kind of operations underwent by the raw materials until this stage, it is only when all parts of an end-item are ready to move to the sewing stations that they will be assigned a semi-finished good reference code.

On the other hand, the Work In Progress (WIP) process associated with sequencing considers the different transformations applied to the raw materials, meaning that, after each operation, the obtained semi-finished goods receive a new reference code, which implies, in stark contrast to the "PA/SA" process, that one end-item code can be linked to several semi-finished reference codes.

The "PA/SA" process is the oldest of the two and is currently used in end-items with lower demand, whereas high demand products have been transitioning to the WIP process.

After this stage, all parts are ready to be sewn, forming the car seat covers. Note that, although, throughout the process, there are several quality inspection points imbedded in the operations, after sewing, there is a final formal inspection to identify possible defects in the produced covers. In some cases, the customer even requests a second quality check point to the end-item before being cleared to delivery.

The manufacturing process comes to an end with packaging and expedition procedures. It is worth mentioning, though, that each customer has different packaging requirements that must be met – for example, in some projects the seat covers must be hung as opposed to the more traditional approach of being stacked.

4. PROBLEM STATEMENT AND AS-IS PROCESS

The wide range of products manufactured by COINDU and their high customisation levels bring plenty of challenges, not just to the manufacturing process itself, but also to their logistics department. Such challenges are only heightened by the increasing market volatility and product complexity, since today's current trend is for brands to invest more and more in extensive personalisation options that encourage a profound sense of uniqueness and individuality associated with their products.

As a result, COINDU is finding it ever more difficult to balance raw materials inventory costs and their service levels. They are aware that end-item volatility is one of their major issues, but they do not have any strategies put in place to quantify its impact on raw materials service levels or to assess how raw materials needs evolve overtime.

In view of all of this, the company aims to change their *modus operandi* and to start supporting their strategic decisions on real data, retrieved from their information systems (SAP and SIAP). Revising their raw materials inventory management policies seems to be the first step towards this goal.

In order to have a clear picture of the current performance of the raw materials inventory management policies, it is essential to analyse their service levels, as well as the quality of their supply. However, the company does not keep track of these performance measurements, only assessing their inventory management policies using the monetary value of the average stock kept on hand.

Hence, this chapter begins with the description and critical review of the current logistical processes related to raw materials management (sections 4.1 to 4.3), based on several meetings held with department heads and collaborators, as well as official company documentation. Afterwards, sections 4.4 and 4.5 present a historical analysis to service levels and supply quality, respectively, undertaken by using real data from the company's information systems going as far back as 2020. Section 4.6 summarises the main findings uncovered throughout the entire chapter.

4.1 Global Logistical Process

At COINDU, raw materials inventory levels and end-items' orders are respectively managed by the Raw Materials and the End-Item Logistics Departments. Figure 9 illustrates the steps taken by the company from the moment they receive information about their customers' needs to the time production gets underway. It is worth mentioning, though, that each project has its own dynamics and that the diagram shown in Figure 9 only highlights the most important stages of this process - the ones carried out under any circumstance.

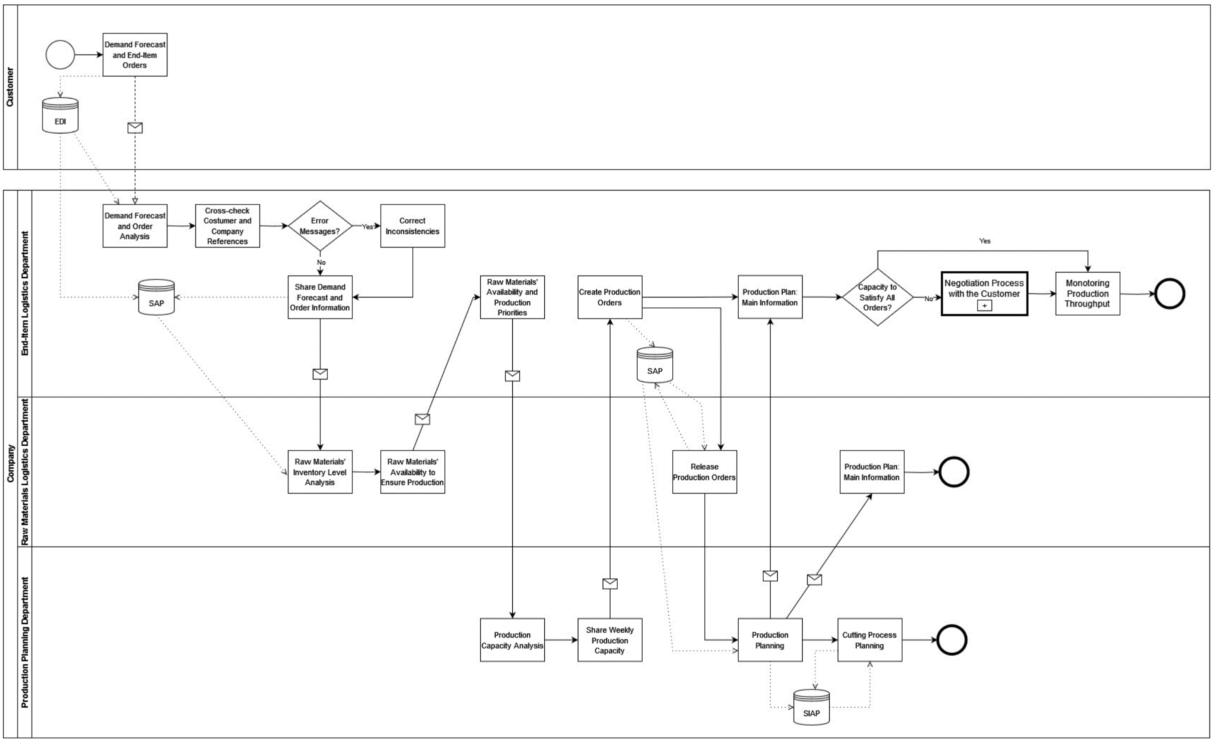


Figure 9: Global Logistical Process until the Beginning of Production

At the start of each week, the customer sends their demand forecast to the company. Although this information is preferably shared via EDI, it can be sent in an alternative or complementary format via email (with an Excel file attachment) to the company's employee responsible for the project, or it can even be uploaded to the customer's online digital platform, in case they have one.

After receiving the demand information, the end-item logistics collaborators must check both the forecast and the orders reported. Ideally, demand for the following ten days is expected to be frozen, that is to say it should correspond to real customer's orders. However, this is rarely the case. Depending on the customer's ability to predict their own needs or their production plans, customer's orders may be confirmed with less than ten days until the requested delivery date.

This problem is heavily associated with the type of customer one is dealing with – OEM or Tier I suppliers. In fact, Tier I suppliers tend to have a rather unpredictable demand, mainly because of their extremely complex production lines. Working with several car makes and models and being responsible for assembling dozens of different vehicles, oftentimes, leads to the need for the rearrangement of their production plans. For example, lack of components in one production line impacts all others, because it delays the production of certain models and pushes the production of others forward, which translates into big and frequent fluctuations of components' needs, including of car seat covers.

The demand information received by the company is specified under their customer's particular internal references, which means that first and foremost the end-item logistics collaborators ought to cross-check these codes with COINDU's reference system. During this stage, some error messages may occur if, for instance, product demand regards new end-items whose references have not yet been created in the system.

After all possible errors are corrected, end-items' needs must be uploaded (in case the customer does not share information via EDI) or updated to SAP (when the customer did not change its EDI, but reported demand changes to the company, using one of the other methods). An email with end-item demand forecast and expected orders is also sent to the Raw Materials Logistics Department. It is based on this information that they must carry out an inventory level analysis and verify planned material receipts for the week ahead. It is noteworthy that before sharing this information, the End-Item Department often works on the data files received from the customer, in order to simplify the information and to make it easier to be understood by their fellow colleagues.

When the weekly availability analysis is concluded, the Raw Materials Department sends its results to the End-Item collaborator responsible for the project, who will attach his production needs to the file, as well as a list of the priority items that have been signaled together with the customer. All of this information is emailed to the Production Planning Department, so they can perform a capacity analysis.

The production capacity analysis must take place at the beginning of the week prior to sewing operations (the week in which the parts start being cut), so that, in the worst case scenario, the production plan is set by that Wednesday without delay.

Information about production capacity is emailed back to the End-Item Logistics Department, so as to create production orders in SAP. These orders are then released by the Raw Materials Department, allowing for the production planning stage. Note that, even though the MRP offered by SAP already proposes which orders should be released each week to comply with end-item demand, these suggestions do not take into consideration production capacity (this information is not available in the system) and, as a result, are presented only as planned and not real production orders.

Production planners will then assign the orders to weekdays and later upload the production plan to SIAP, as well as send the main information to Raw Materials and End-Item Logistics Departments. With the weekly production set, the cutting process may start being planned.

If the company's production capacity does not meet customer demand for that week, it is necessary for both parties to negotiate production priorities and delivery plans, in order not to compromise downstream processes in the supply chain.

The difficulty in fulfilling customer demand does not solely lie in company's production issues. As previously mentioned, demand variability also plays a big role, especially when these fluctuations concern model variants. Variants are different car seat covers that belong to the same car model. For instance, car model A can have two variants associated to it – the regular or the sportive variant. If there are severe short-term demand changes between variants, there will not be enough stock of variant-specific raw materials, because in order for that to happen, the demand increase should have been reported weeks ahead of the order placement. Moreover, it is not unusual for customers to request orders that exceed the contracted production capacity, which also contributes to order backlog.

All in all, this process overview reveals a certain reliance on local files that somehow complete the information available on the system, a topic that will be further discussed on sections 4.2 and 4.3, alongside the inner works of the End-Item and the Raw Materials Logistics Departments, respectively. Nonetheless, it is clearly highlighted how important it is to continuously monitor the production and to make sure that it stays in line with the company and their customer's interests.

4.2 End-Item Logistics Department

In the End-Item Logistics Department, each collaborator is responsible for only one project – one car model and all of its variants. Their responsibility includes managing orders and demand forecast information, taking care of all the tasks related to the creation of production orders, monitoring production throughput, and scheduling end-items' deliveries to the costumer.

End-items' inventory policies do not include safety stocks, unless the costumer has required that a certain inventory level must be kept on hand, either at COINDU or at distribution centres. However, safety time is typically used to anticipate end-item demand and to create a time buffer. The number of days used in this safety buffer depends on how the product reaches the costumer.

For costumers that do not rely on distribution centres and collect the products themselves at COINDU's facilities, end-items' needs are pushed forward five working days in relation to the original pickup date, plus an extra working day to consider expedition procedures. However, if COINDU ensures the transportation between their facilities and the costumer's (no distribution centre involved still), other four to five consecutive days are added to the already mentioned six working days, to cover for the in-transit period.

On the other hand, if the costumer works with distribution centres and is responsible for picking up the seat covers themselves, eleven to twelve days are also considered as safety time – the traditional five working days, plus the four to five representing the in-transit period, plus one more working day for material receiving procedures. In case the company is also responsible for the transportation between the distribution centre and the costumer's facilities, an extra day is added to account for this transfer.

As previously described, COINDU faces a highly unpredictable end-item demand, so it is no wonder that, during this period, demand fluctuates severely and, oftentimes, this buffer is fully employed, if not surpassed. To avoid order unfulfilment, customers may pay for express deliveries (for example, charters) if the delay is caused by a weekly demand variation superior to the value settled in their contract.

Additionally, this preliminary analysis allowed to identify some other vulnerabilities and challenges faced by this department:

1. **Demand Forecast:** Information about demand forecast and end-items' orders can be received via many sources, in different formats. Even within the same project, the collaborator may need to consult several documents, before having a clear picture of what is required. Demand forecast horizons and their reliability vary between projects, as well as there is a great diversity concerning data treatment and information storage.
2. **Demand Volatility:** The automotive industry is already a particularly competitive sector, traditionally associated with demand variability. Even more so, as previously mentioned, dealing with Tier I suppliers increases the company's exposure to long and short term demand variations. Demand changes between model variants are quite common and significant.
3. **Lack of Visibility:** Especially when working with Tier I suppliers, demand forecast and the orders placed by the costumer do not correspond to the actual car demand on the market. This relates to the BWE and the fact that downstream supply chain members also have their own inventory management policies in place, which implies making their requests based on those and not on actual car demand. Not to mention the fact that, within the company itself, projects with higher production volumes are manufactured following the Kanban methodology. The Kanban process, as it stands today, presents several challenges to the End-Item and the Raw Materials Logistics Departments, including the inability to understand the status of each production order.
4. **Information Management:** Most information is kept on local files (mainly Excel files). Moreover, key information to understand the process evolution is not available in the system - for instance, there is no information in SAP about delivery plans negotiated with the customer or about production's weekly capacity. Data treatment and storage are also not standardised. Some projects might require an incredible amount of manual data processing to improve visibility

over production needs, as it is the case of projects in which seat covers are ordered by car. As production is planned based on seat covers and their parts, these type of needs ought to be translated into part orders, a task done using several excel files that help crossing information.

5. **Project Management:** Each project has its own dynamics - value chain, data processing procedures and interaction between the company and the costumer -, making it difficult to standardise operations.

4.3 Raw Materials Logistics Department

The Raw Materials Logistics Department is organised very differently from the End-Item Department. First of all, it is divided in 'commodities', meaning that each collaborator is responsible for one group of materials, ultimately translating into managing raw materials from multiple projects at the same time.

However, the rest of the company works by project, which makes it necessary to have a raw materials representative that receives the end-items' needs from the End-Item Department, crosses this information with each variants' materials, shares their estimated demand with the department's colleagues, gathers the materials availability analysis made by each one of them and sends it back to the project contact in the End-Item Department. As a result, each raw materials collaborator accumulates two main responsibilities – to manage the group of materials assigned to them and to be the contact person, for at least one project, within the department.

Additionally, it is also possible to split this department's activities into two moments in time – earlier in the week, when raw materials availability is assessed and production orders are released, and, later on, when the long-term needs for each raw material are estimated, one reference at a time.

Another peculiarity surrounding raw materials management concerns the interaction between Joane and Arcos' production units. All raw materials, even those that are not used in any project manufactured at COINDU Joane, must first be registered in Joane's warehouse, before a transportation request prompts their transfer to Arcos' facilities.

Furthermore, and as previously mentioned, supplier lead times vary considerably across all raw materials, which, together with high demand variability, proves to be a challenge in terms of inventory management. For the time being, raw materials' inventory is managed following a 'Dynamic Stock' approach, developed by the company. This method includes the weekly determination of the daily average demand for each material, during the week subsequent to the review point. This result will then be compared to a reference value, according to each group of materials. For that matter, the groups need to be classified into one of five possible categories – Thread, Small Materials, Cutting Materials, Kits (for materials whose cutting operations were outsourced) and Airbag Fabrics. This value comparison follows the logic shown in Table 1 and allows the materials to be categorised as **High**, **Medium**, **Low** or **Exotic** runners (materials daily average demand estimate decreases from High to Exotic categories).

Table 1: Classification into High, Medium, Low or Exotic Runner

	Thread	Small Materials	Cutting Materials	Kits	Airbag Fabrics	**Deviation**
High	Quantity >= 5.001	Quantity >= 1.001	Quantity >= 121	Quantity >= 31	Quantity >= 31	**0,2**
Medium	1.001 <= Quantity < 5.001	301 <= Quantity < 1.001	31 <= Quantity < 121	8 <= Quantity < 31	8 <= Quantity < 31	
Low	301 <= Quantity < 1.001	101 <= Quantity < 301	6 <= Quantity < 31	2 <= Quantity < 8	2 <= Quantity < 8	
Exotic	Quantity < 301	Quantity < 101	Quantity < 6	Quantity < 2	Quantity < 2	

It is, then, based on this classification that materials' safety stock coverage in days is defined (Table 2). High runner materials are expected to be frequently replenished and, as a result, are assigned with the smallest safety stock value – 3 days coverage. The smaller a demand volume a product displays, the more time coverage it will have, so, for Low and Exotic materials, safety stock is set at the maximum value of 8 days coverage.

Table 2: Safety Stock Coverage Assigning

Material Classification	**Safety Stock (coverage)**
High	3 days
Medium	5 days
Low	8 days
Exotic	8 days

Moreover, it is worth mentioning that this inventory management policy is known as 'dynamic' for two main reasons. Firstly because, by quite frequently reviewing the materials' classification into High, Medium, Low or Exotic runners, the company ensures that their classification does not stay the same overtime and that it can, in theory, adapt to expected weekly demand changes. The second reason regards the fact that measuring the safety stock using days of coverage instead of quantities means that the amount of stock to be kept on hand varies accordingly to the expected demand for the period, even if a material's classification remains the same.

Notwithstanding, there are some disadvantages associated with this approach. Although in some aspects it can be considered 'dynamic', in its nature it is rather static. In the presence of a highly unpredictable and volatile market, setting the safety stock in a predetermined number of days that is not periodically revised, may not be the most adequate. The same applies to the rules used to classify the raw materials into high, medium, low or exotic runners. The order volumes that serve as reference have not been updated since this methodology was first implemented (several years ago) and may no longer correctly reflect what could be considered as a high, medium, low or exotic material.

Both of these points strongly highlight the major downfall of this method – since it focuses solely on the expected average demand, it falls short of including demand and supply uncertainties in safety stock calculations. During the course of the review period, it is normal to have demand fluctuations, as well as supplier delays or non-compliance with the ordered quantity, none of which are accounted for while following this approach.

As a matter of fact, although supplier performance is currently assessed using a monthly scorecard that includes categories related to the aforementioned issues, the points scoring system relies heavily on the collaborators' perception of what happens in the course of each month. In other words, if a supplier delays a delivery by a week, without compromising production, it is unlikely to be considered an incident and, therefore, to have any implications on their final score. Of course that, if this is an isolated situation, not recording it does not hold any major implications. However, if there is a tendency for problems like this to occur and there is no historical data to help signalling this kind of behaviour, then not keeping accurate records of supplier's incidents becomes a serious problem.

In addition to these, other challenges regarding the Raw Materials Logistics Department as a whole can be mentioned, namely:

1. Being **organised based on 'commodities'** while the rest of the company works by project. It makes it harder to centralise information and to have a clear picture of raw materials performance by model and car variant.
2. Its **lack of visibility over production**. This problem is, once again, related to the Kanban process. The fundamental problem around Kanban production lies in the fact that it rules over the production orders released by the Raw Materials Department. In other words, in order to ensure the Kanban safety stocks in production, the Kanban process itself generates additional orders, whenever production hits the designated reorder points. The moment this happens, however, is rather unpredictable, as it is the material quantity that the Kanbans will request. These difficulties are intensified by some glitches in SIAP itself and in its integration with SAP, the latter being, at the time, subject to improvement.
3. **Demand variation**, especially related to demand changes in model variants that involve raw materials with big lead times.

4. **Information not being centralised nor accessible**. Important data is not found in the system, as it is the case of weekly production capacity, Kanban's safety stocks or reorder points.
5. **Collaborator dependency**. The inventory management process relies heavily on each collaborator's sensibility, how well they know the suppliers they work with and the relationship they establish with them.

4.4 Raw Materials' Service Levels

4.4.1 MRP Data Treatment

COINDU has a wide range of materials, associated with several projects. As detailed in other sections, each of these projects has its own particular supply chain dynamics. Therefore, and considering the lifespan of this Master's dissertation, the scope of this analysis will remain on materials classified as A-type items in the company's ABC analysis, at the time that this information was originally consulted in SAP's MDO transaction (April 21st, 2023).

The historical service level assessment involved collecting data from the company's MRP transaction (ZPP00007), going as far back as 2020. Although some raw materials were already in use before that year, the COVID-19 pandemic has had such a strong impact in markets worldwide that any data before then was considered to represent a completely different reality to the one faced by the company today.

Because of storage issues, the company's MRP data is split into both of their main systems – MRP data before 2022 can only be found in SIAP, whereas MRP data from 2022 and 2023 is still available in SAP. As a result, it was necessary to extract data from both of these sources to guarantee the desired historical assessment.

Since the company runs its MRP every day, it was also paramount to define the best possible time to represent the week's evolution. During weekdays, production orders are constantly released by the Raw Materials Department and closed by Production, while EDI communication is frequently changing as well. Similarly, on Saturdays, it is not unusual for the company to be operating, as an attempt to increase its production capacity, leaving only Sunday as the finest option to get a clear vision of the company's status at the end of each working week. This also means that data collected on each Sunday paints the company's picture at the start of the following week – its expected orders, its scheduled deliveries, its expected needs and so on -, delivering crucial information to the service levels assessment.

Additionally, and considering the interaction between COINDU Joane and COINDU Arcos, with regard to raw materials' receiving procedures, the ZPP00007 transaction splits the information about their needs and scheduled deliveries by both production units – in COINDU Arcos one can find the information about their needs, whereas their scheduled deliveries are shown under COINDU Joane's centre. Bearing in mind that the company has no standard methods in place to cross this information, and that this work is the first attempt to get some performance measures out of their stored data, the decision was made to restrict this study to Joane's A-type materials, which translates into a total of 63 items.

All collected data required a lot of processing before one could attempt to draw any conclusions from it. This resulted in the development of several algorithms, using R programming language, which ensured the transformation of this data into useful information. Not only that, in the case of the SIAP's records, data needed some extra processing, before being ready to run in the other algorithms. This relates to the fact that the main algorithms were developed based on SAP's records format and that the SIAP data is stored in a slightly different manner. This pre-processing of the SIAP data involved:

- Standardising variable names and date format;
- Filtering MRP data – SIAP's interface does not allow to only select Sunday's records;
- Converting materials' needs and scheduled deliveries into numerical variables (transformation of 'Entrada.Necess' variable).

As some materials had not been used in production until 2022, not all 63 items had their data processed in this stage. More details about this data treatment can be found in Appendix I, including a sample of the used code.

The next phase of the data treatment went underway after making sure that all data files complied with SAP's format. This next stage included the understanding of the different variables and their values, as well as dealing with some problems with the way data had been stored.

Starting with variable understanding, there was a variable selection, based on their relevance to the problem. The variables kept on the dataset were:

- **'Data.MRP':** The date in which the MRP ran and returned the recorded results;
- **'Centro':** Works as a control variable to make sure that all materials refer to Joane's production;
- **'Material':** The company's reference code for each material;
- **'Planeador':** The ID number for the raw materials collaborator responsible for managing the material's inventory;
- **'Depósito':** Another control variable related to inventory location;

- **‘Unid.Básica.Medida’:** Each material’s units of measurement;
- **‘Elemento.MRP’:** An MRP movement. For this analysis, it can adopt six different values - ‘Estoq’, which is the inventory on hand at the time the MRP ran; ‘NecDep’, referring to expected needs that appear on EDI communication, but have not yet been confirmed by the customer; ‘ResOrd’, needs confirmed by the customer that are, as a result, real production orders; ‘Div.Est’/’Div.Pr’, which are scheduled deliveries; ‘AviPed’ that stands for material delivered in the warehouse, but that has not yet been moved to the quality inspection station; and, lastly, ‘LoteQM’ when the material was approved by quality inspection and is ready to enter production;
- **‘Dados.Elemento.MRP’:** When associated with ‘NecDep’ or ‘ResOrd’, represents the item or process generating the material’s needs, whereas if it relates to movements that increase stock on hand, it stands for the order or material batch number;
- **‘Data.Movimento’:** It is normally the same as ‘Data.Disponível’, unless it concerns ‘Div.Est’/’Div.Pr’ or ‘AviPed’ movements. In those cases, it is the moment in which the material has arrived or is set to arrive at the warehouse, but, because of order receiving procedures and the quality inspection process, it is not ready to be used in production. The moment that happens is specified by the ‘Data.Disponível’ variable;
- **‘Data.Disponível’:** The moment an MRP movement happens. This is the date associated with the increase or decrease of the inventory levels.
- **‘Entrada.Necess’:** It represents the material quantity associated with each movement. This original variable was divided into three different ones – **‘Necessidade’**, when associated with ‘NecDep’ or ‘ResOrd’ movements; **‘Em.Trânsito’**, in case of ‘Div.Est’/’Div.Pr’ and ‘AviPed’; and **‘ControloQuali’** for ‘LoteQM’ entries.
- **‘Stock.Estimado’:** Originally named ‘Qtd.disponível’, it represents the inventory level after each movement.

While analysing the original datasets, variable ‘Qtd.disponível’ helped to flag an issue with the order in which the MRP movements were being stored. A quick look into this variable’s evolution and the ‘Entrada.Necess’ variable showed that the amount of material available in stock in nothing related to the sequence of movements presented. If that were the case, in the second entry of Table 3, the inventory level should be -229,04 square metres and not the same -222,712.

Table 3: Data Sample from the Original MRP Record

Data MRP	Momento MRP	Centro	Material	Tipo de material	Planejador MRP	Depósito	Unid.medida básica	Mais/menos	Data	Data rem./fim base	Dta.reprogramação	Cód.element .MRP	Elemento MRP	Dados p/elemento MRP	Chave	Mensagem de exceção	Entrada/Necess.	Qtd.disponível
09/01/2022	04:24:58	1102	101I0000001443	Z010	151	1200	M2	-	21/01/2022	21/01/2022		SB	NecDep	20705N5H00I0IAB			-4,320	-222,712
09/01/2022	04:24:58	1102	101I0000001443	Z010	151	1200	M2	-	18/02/2022	18/02/2022		SB	NecDep	20705K5B01I0HAB			-6,328	-222,712
09/01/2022	04:24:58	1102	101I0000001443	Z010	151	1200	M2	-	06/05/2022	06/05/2022		SB	NecDep	20705G5B01I4CAC			-117,368	1 603,590
09/01/2022	04:24:58	1102	101I0000001443	Z010	151	1200	M2	-	17/06/2022	17/06/2022		SB	NecDep	20705K5C01I4CAB			-18,984	3 092,354
09/01/2022	04:24:58	1102	101I0000001443	Z010	151	1200	M2	-	29/07/2022	29/07/2022		SB	NecDep	20705G5H06I4CAA			-46,800	1 776,218
09/01/2022	04:24:58	1102	101I0000001443	Z010	151	1200	M2	-	16/09/2022	16/09/2022		SB	NecDep	20705G5H04I0IAB			-92,280	3 092,354
09/01/2022	04:24:58	1102	101I0000001443	Z010	151	1200	M2	-	14/10/2022	14/10/2022		SB	NecDep	20705N5H04I0IAB			-50,754	1 603,590
09/01/2022	04:24:58	1102	101I0000001443	Z010	151	1200	M2	-	19/05/2022	19/05/2022		SB	NecDep	20705N5B02I0IAE			-8,520	2 572,828
09/01/2022	04:24:58	1102	101I0000001443	Z010	151	1200	M2	-	20/05/2022	20/05/2022		SB	NecDep	20705P5G03I4CAB			-145,024	2 547,798
09/01/2022	04:24:58	1102	101I0000001443	Z010	151	1200	M2	-	26/05/2022	26/05/2022		SB	NecDep	20705N5B02I0IAE			-8,520	2 539,278
09/01/2022	04:24:58	1102	101I0000001443	Z010	151	1200	M2	-	27/05/2022	27/05/2022		SB	NecDep	20705P5G03I4CAB			-140,492	2 553,640
09/01/2022	04:24:58	1102	101I0000001443	Z010	151	1200	M2	-	27/05/2022	27/05/2022		SB	NecDep	20705P5H00I0HAA			-3,008	2 550,632
09/01/2022	04:24:58	1102	101I0000001443	Z010	151	1200	M2	-	02/06/2022	02/06/2022		SB	NecDep	20705N5B02I0IAE			-8,520	2 542,112
09/01/2022	04:24:58	1102	101I0000001443	Z010	151	1200	M2	-	03/06/2022	03/06/2022		SB	NecDep	20705N5H02I0IAB			-15,120	2 661,474

This seemed to be happening because the MRP was being stored considering the ascending order of the 'Data.MRP' variable, followed by the alphabetical order of the 'Elemento.MRP' variable. Since, the inventory level is crucial to the desired analysis, rectifying this situation was of the utmost importance.

Consequently, each material's entry was ordered based on their 'Data.MRP' value, followed by 'Data.Disponível' (the same as 'Data' in Table 3) and, lastly, by 'Data.Movimento' ('Data rem./fim base' in Table 3). However, this new order was still not in line with the original records, but it was still decided to recalculate the inventory level based on this new entry sequence.

In addition to this, it was essential to downsize the amount of data entries. As a matter of fact, each time the MRP runs, it recalculates the inventory level until the last movement that it can find in the system, meaning that if there is, for example, EDI information until the end of 2024, the system will estimate stock levels until that specific moment. Thus, for each MRP date, only the entries with 'Data.Disponível' prior or equal to the following MRP reading were kept, therefore capturing each week's dynamics and accessing what was expected to happen during that production week at that moment in time.

The algorithm that allows for these transformations is available on Appendix II.

After this initial treatment, four different tables were created - the **Stock Out**, the **Summary**, the **Real** and the **ResOrd Tables** -, in order to organise the available data and turn it into useful information. A detailed description about the way these data tables were built and the information they keep can be found on Appendix III.

4.4.2 Raw Materials' Performance Assessment

Based on the created data tables, a Power BI Report was built to get some results out of the collected data and, consequently, to better understand the reality behind the current raw materials inventory management policies.

This report has 10 different pages that deliver information about several indicators, not just those related to raw materials' needs, so, in this section, it will only be highlighted the ones directly associated with the raw materials' performance assessment. The rest of the work will be properly discussed in chapter 5, along with the study of new inventory management policies.

Notwithstanding, before presenting the obtained results, there are two performance indicators that should be explained in greater detail. The first one relates to the variable 'NecDep_i1' and the unfulfilled demand. As stated in Appendix III, 'NecDep_i1' corresponds to the amount of material that was not able to be converted into real production orders, since the system was unable to ensure the availability of the specified quantities. Considering the service level as the fraction of production demand that was met during a period of time, the fraction of unmet demand is complementary to the service level and can be calculated based on 'NecDep_i1' variable. Hence, the fraction of unmet demand is given by Equation (1):

$$Unmet\ Demand\ Ratio = \frac{NecDep_{i1}}{ResOrd_{i}+ResOrd_{i1}+NecDep_{i1}} \tag{1}$$

where $ResOrd_i$ stands for the production orders to week i+1 confirmed by the costumer until the end of week i, and $ResOrd_{i1}$ stands for the production orders to week i+1, whose records only appeared on that week's MRP reading.

These production orders plus the amount of material in $NecDep_{i1}$ give an approximation of production's raw material demand during each week. However, this value will always be an approximation of the production total needs because other production orders might have been created, released and closed in between readings. Nevertheless, the majority of the cases are accounted for with the sum of these three variables and, as a result, this method is expected to give a good approximation of production demand.

The second indicator concerns the variation rate of materials' needs. As previously described, every week, the company faces short term variations in end-item demand. This, of course, has direct impact not only on raw materials' needs themselves, but also on the amount of production orders created and released to fulfil these new requests. Estimating the impact of such variations can be achieved by comparing the production volume that only appears on MRP records belonging to the end of week i+1 ($ResOrd_{i1}$ and $NecDep_{i1}$) with the production volume originally expected at the start of that very same week (in MRP records from week i, $ResOrd_i$), as shown in Equation (2).

$$Variation\ Rate\ of\ Materials'Needs = \frac{ResOrd_{i1}+ NecDep_{i1}}{ResOrd_{i}} \tag{2}$$

Figure 10 details the average result obtained for both of these variables, by group of materials, for the time period in question (January 2020 to March 2023).

Description	ResOrd_i (AVG)	Total Needs (AVG)	Unit of Measurement	Variation_Rate Materials' Needs	Unmet Demand Ratio
Cutting Mat. - Foam kits	644,66	672,23	UN	112,29%	6,09%
Cutting Mat. - Foam/Plush materials	365,29	394,65	M	50,34%	8,57%
Cutting Mat. - Textile	221,82	277,04	M	340,75%	16,72%
Cutting Mat. - Vinyl	321,62	421,24	M	264,50%	11,56%
Leather	535,57	611,86	M2	252,44%	15,23%
Leather Kit	343,35	390,50	UN	68,41%	10,74%
Small Mat. - Airbag material	30,35	31,13	M	15,09%	5,51%
Small Mat. - Velcro	12.808,25	13.990,84	M	12,33%	5,73%

Figure 10: Unmet Demand Ratio and Variation Rate of Materials' Needs – Results by Group of Materials

A preliminary analysis of these results allowed to identify four groups of materials with an unmet demand ratio superior to 10% - Textile, Leather, Vinyl and Leather Kits -, implying that their service levels were inferior to 90%. Furthermore, the top three groups with higher average of unmet production demand were also the ones presenting the top values for the variation rate of materials' needs.

This trend is only intensified if one decides to narrow these results to the year 2022 and the first months of 2023. In fact, during this period, Leather materials had their average of unmet demand raised to 21,52%, followed by Textile with 18,59% and Vinyl with 14,48%; while the average variation rates of materials' needs were 461,08%, 562,24% and 221%, respectively (Figure 11).

Description	ResOrd_i (AVG)	Total Needs (AVG)	Unit of Measurement	Variation_Rate Materials' Needs	Unmet Demand Ratio
Cutting Mat. - Foam kits	546,68	575,24	UN	197,18%	7,37%
Cutting Mat. - Foam/Plush materials	185,90	220,17	M	54,66%	9,98%
Cutting Mat. - Textile	281,76	355,40	M	562,24%	18,59%
Cutting Mat. - Vinyl	296,45	451,05	M	221,00%	14,48%
Leather	376,95	470,13	M2	461,08%	21,52%
Leather Kit	343,35	390,50	UN	68,41%	10,74%
Small Mat. - Airbag material	34,18	35,07	M	17,00%	6,21%
Small Mat. - Velcro	12.808,25	13.990,84	M	12,33%	5,73%

Figure 11: Unmet Demand Ratio and Variation Rate of Materials' Needs (2022-2023 Results)

The evolution of these indicators over time was also subject to evaluation. Figure 12 details the results obtained when considering all groups of materials, while Figure 13 focuses on the evolution for the three most critical categories (Leather, Textile and Vinyl).

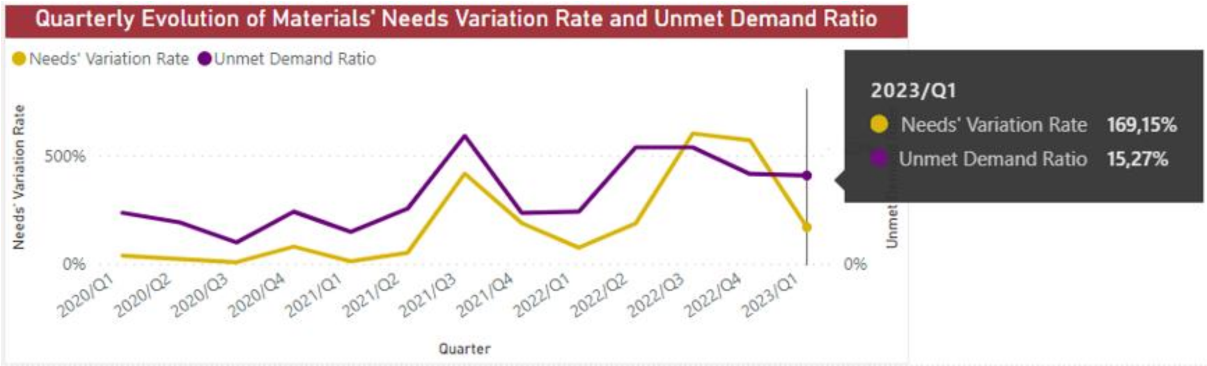


Figure 12: Performance Indicators' Evolution Over Time

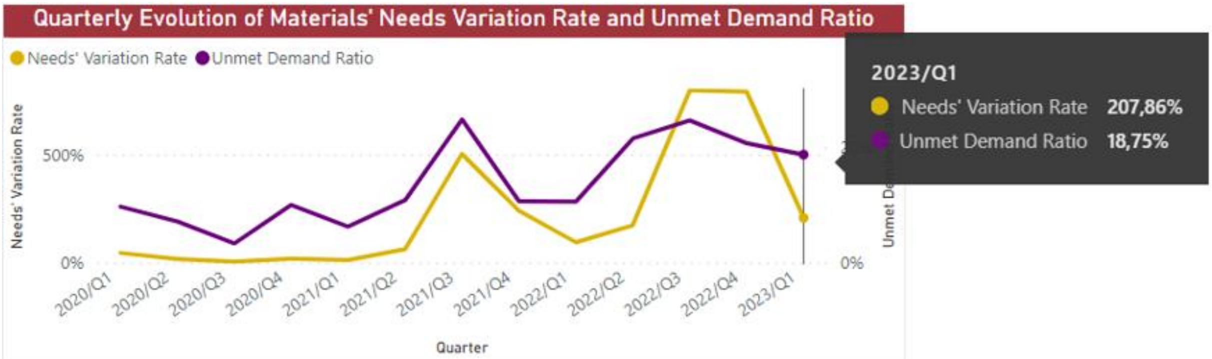


Figure 13: Performance Indicators' Evolution Over Time (Leather, Textile and Vinyl)

These results show that, over time, both indicators have followed similar patterns and that the combined average of the three most critical groups of materials seems to be around the same value as the combined average of all groups. Nonetheless, following a trend that appears to have started during 2022, the average found for the unmet demand ratio and for the variation rate of materials' needs for Leather, Textile and Vinyl are consistently superior to the total average of all materials, which implies that these groups are contributing to push the overall average up.

Additionally, the impact of $NecDep_{i1}$ on the total new needs presented by the end of week i+1 ($NecDep_{i1} + ResOrd_{i1}$) was also subject to analysis. In fact, as shown in Figure 14, when there were new needs at the end of week i+1 that had not been accounted for by the end of week i, most of the times, these fall under the category 'NecDep'. This means that the majority of new orders confirmed during that week does not have enough material available in stock to fulfil them, which comes as no surprise, since current inventory management policies rely heavily on the expected weekly demand.

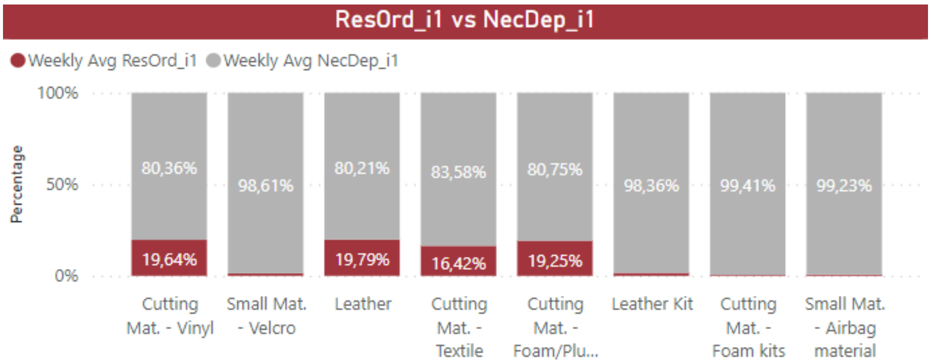


Figure 14: Impact of 'NecDep_i1' on the Total New Needs of Week i+1

Moreover, comparing the average probability of stock outs, considering both the MRP estimates and the most likely inventory level, with the unmet demand ratio, similarly allowed for interesting results (Figure 15). Contrary to the company's original belief, the average probability of stock outs given by the MRP system is much closer to their real ratio of unmet demand than the one derived from their "most likely inventory level". This only highlights the major demand fluctuations that the company faces during each week and how important it is to implement inventory management policies that take these uncertainties into account.

Description	Avg. Prob. Stock Outs MRP system	Avg.Prob. Stock Outs Most Likely Inventory Level	Unmet Demand Ratio
Cutting Mat. - Foam kits	19,27%	1,66%	6,09%
Cutting Mat. - Foam/Plush materials	2,94%	0,00%	8,57%
Cutting Mat. - Textile	22,26%	33,11%	16,72%
Cutting Mat. - Vinyl	12,44%	0,69%	11,56%
Leather	14,57%	5,44%	15,23%
Leather Kit	17,36%	0,08%	10,74%
Small Mat. - Airbag material	5,80%	0,09%	5,51%
Small Mat. - Velcro	8,25%	2,30%	5,73%
Total	**15,66%**	**7,55%**	**12,93%**

Figure 15: Comparison Between Stock Out Probabilities

Lastly, the evolution of the average stock kept on hand should also be mentioned. Comparing stock levels across groups of materials measured in different units can be done, provided their amounts are translated to a common unit, in this case, their monetary value in euros. However, relating average value kept in stock between groups of materials can still be a misleading analysis, since the unitary value of each material varies considerably. For instance, any Leather material is significantly more expensive than any Textile, which means that its average value kept in stock is much greater than the one of any fabric, without that implying that its stock volume is proportionately higher.

As a result, this type of analysis becomes more meaningful if, instead of looking at the values themselves, one looks to their evolution over time. In Figure 16, the evolution of the average value kept in stock for all materials is directly compared to the average value kept in stock for the two materials with the highest average stock value (unsurprisingly, two Leather items).

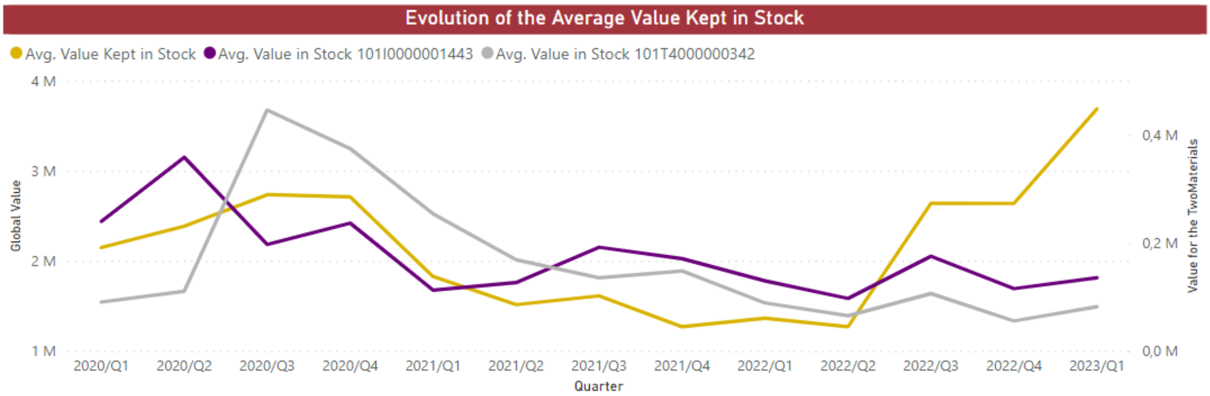


Figure 16: Evolution of the Average Value Kept in Stock

After a preliminary analysis, it was possible to ascertain that, although both products follow the general tendency of increasing their stock levels, this variation seems to be more significant for the combined stock value of all materials. A deeper look into this behaviour linked it to the sharper increase of inventory values in other less "valuable" groups of materials, especially in the case of Textiles and Vinyl. This conclusion was, in fact, much aligned with a shift in the company's production, since, during the past year, the production volume assigned to projects that require fabric and vinyl materials, instead of leather, has increased considerably.

All these results supported the conclusion that the Leather, Textile and Vinyl groups of materials are the ones that could better benefit from revised inventory management policies, thus improving the company's resilience towards market uncertainty.

On that note, and before moving on to the assessment of each materials' supply performance, it is paramount to narrow the scope of this study to a list of key items. As it will be properly detailed in section 4.5, assessing supply quality, using the information held in SAP, is not the most straightforward task, so, to draw valid and pertinent conclusions from it in the course of this dissertation, a group of ten different materials was considered as test subjects. This group includes three Leather, three Textile and four Vinyl materials. These were chosen based not only on their unmet demand ratio and their needs' variation rate, but also on the order volume they represent. This means that there could be other materials, within each group, that had worse performance than these, but, because they were also materials with less demand, they were not selected to the next stage of the analysis.

4.5 Raw Materials' Supply Performance

When defining safety buffers to help companies deal with uncertainty, it is fundamental to have a clear picture of the actual uncertainties they face on both sides of demand and supply. So far, it was possible to ascertain the performance of the current raw materials inventory management policies, as well as to estimate the evolution of each material's weekly demand variation. As a result, it is now time to turn one's attention to raw materials' supply quality, evaluating and comparing possible replenishment delays and non-compliance with requested quantities.

To this extent, collecting each material's replenishment history is of the utmost importance, since it allows to simultaneously identify and quantify supply problems and, consequently, signal suppliers with a poorer performance and materials more vulnerable to this kind of uncertainties. Nevertheless, gathering data to shed some light on these questions proved to be a challenging task, because of traceability issues.

Information regarding scheduled deliveries and receiving reports is split into two SAP transactions – ME3L and MB51, respectively. However, traceability between them is not ensured, due to the fact that the orders issued to the suppliers are not assigned to unique ID numbers. As shown in Tables 4 and 5, there is an ID number responsible for linking these transactions. In the case of the ME3L transaction, this number is under the name **'Doc.Compra'**, while in the MB51 transaction it appears in column **'Pedido'**. Nonetheless, this same number can be reused countless times to schedule new deliveries, meaning that, when looking back in time, it becomes rather difficult to make a particular delivery correspond to its receiving report(s). This turns out to be an even more intricate task when considering that a material's delivery may not occur on the day originally scheduled or that this delivery may be spread across a series of days or weeks.

For instance, in Table 4, 12.000 units of a certain material were requested to the supplier, with a scheduled delivery on October 16th, 2020 (**'Data.de.remessa'**). Comparing this information to the one found in MB51 transaction (Table 5), it is clear there were no receiving reports on that day, only on October 13th and October 27th (**'Data de lançamento'**). By analysing the movements registered in the MB51 transaction (dates and received quantities), it is possible to estimate that the corresponding receiving date is, in fact, October 27th, 2020, meaning that this delivery was carried out with over a week's delay. However, this conclusion is, quite noticeably, far from straightforward.

Table 4: ME3L Transaction – Example of Lack of Traceability

Doc Comp	Data.do.docume	Material	Grupo.	Preço.l	Moeda	Unidad	Data.de.reme	Cód fornece	Qtd.divi	UM.ped	Quantidade.ante	Qtd.entr
5500035424	2020-09-04	170C0000000074	102	10,41	EUR	100	2020-09-25	70234	12000	UN	12000	12000
5500035424	2020-09-04	170C0000000074	102	10,41	EUR	100	2020-10-16	70234	12000	UN	12000	12000
5500035424	2020-09-04	170C0000000074	102	10,41	EUR	100	2020-10-30	70234	12000	UN	12000	12000
5500035424	2020-09-04	170C0000000074	102	10,41	EUR	100	2020-11-13	70234	12000	UN	12000	12000
5500035424	2020-09-04	170C0000000074	102	10,41	EUR	100	2020-11-25	70234	12000	UN	12000	12000
5500035424	2020-09-29	170C0000000074	102	10,41	EUR	100	2020-12-17	70234	12000	UN	12000	12000
5500035424	2020-10-27	170C0000000074	102	10,41	EUR	100	2021-01-15	70234	12000	UN	12000	12000
5500035424	2020-11-16	170C0000000074	102	10,41	EUR	100	2021-01-29	70234	12000	UN	12000	12000
5500035424	2020-12-07	170C0000000074	102	10,41	EUR	100	2021-02-12	70234	12000	UN	12000	12000
5500035424	2021-01-11	170C0000000074	102	10,41	EUR	100	2021-02-25	70234	12000	UN	12000	12000
5500035424	2021-02-02	170C0000000074	102	10,41	EUR	100	2021-03-11	70234	6000	UN	6000	6000
5500035424	2021-02-02	170C0000000074	102	10,41	EUR	100	2021-04-08	70234	12000	UN	12000	12000
5500035424	2021-02-10	170C0000000074	102	10,41	EUR	100	2021-03-18	70234	6000	UN	6000	6000
5500035424	2021-03-10	170C0000000074	102	10,41	EUR	100	2021-04-15	70234	12000	UN	12000	12000
5500035424	2021-03-25	170C0000000074	102	10,41	EUR	100	2021-05-20	70234	6000	UN	6000	6000

Table 5: MB51 Transaction – Example of Lack of Traceability

Fornecedor	Data do documento	Material	Doc.material	Data de lançamento	Hora do registro	Qtd. UM registro	UM registro	Montante em MI	Lote	Referência	Unid.medida básica	Moeda	Pedido	UM pedido	Unid.prç.p dido
70234	02/10/2020	170C000000074	5001595569	06/10/2020	09:19:34	2.000	UN	195,57	B00Q5QK006	3000521604	UN	EUR	550003542	UN	UN
70234	02/10/2020	170C000000074	5001595569	06/10/2020	09:19:34	2.000	UN	195,57	B00Q5QK005	3000521604	UN	EUR	5500035424	UN	UN
70234	02/10/2020	170C000000074	5001595569	06/10/2020	09:19:34	2.000	UN	195,57	B00Q5QK004	3000521604	UN	EUR	5500035424	UN	UN
70234	02/10/2020	170C000000074	5001595569	06/10/2020	09:19:34	2.000	UN	195,57	B00Q5QK003	3000521604	UN	EUR	5500035424	UN	UN
70234	02/10/2020	170C000000074	5001595569	06/10/2020	09:19:34	2.000	UN	195,57	B00Q5QK002	3000521604	UN	EUR	5500035424	UN	UN
70234	02/10/2020	170C000000074	5001595569	06/10/2020	09:19:34	2.000	UN	195,57	B00Q5QK001	3000521604	UN	EUR	5500035424	UN	UN
70234	09/10/2020	170C000000074	5001648125	13/10/2020	14:12:11	2.000	UN	195,57	B00Q9BT006	3000523643	UN	EUR	5500035424	UN	UN
70234	09/10/2020	170C000000074	5001648125	13/10/2020	14:12:11	2.000	UN	195,57	B00Q9BT005	3000523643	UN	EUR	5500035424	UN	UN
70234	09/10/2020	170C000000074	5001648125	13/10/2020	14:12:11	2.000	UN	195,57	B00Q9BT004	3000523643	UN	EUR	5500035424	UN	UN
70234	09/10/2020	170C000000074	5001648125	13/10/2020	14:12:11	2.000	UN	195,57	B00Q9BT003	3000523643	UN	EUR	5500035424	UN	UN
70234	09/10/2020	170C000000074	5001648125	13/10/2020	14:12:11	2.000	UN	195,57	B00Q9BT002	3000523643	UN	EUR	5500035424	UN	UN
70234	09/10/2020	170C000000074	5001648125	13/10/2020	14:12:11	2.000	UN	195,57	B00Q9BT001	3000523643	UN	EUR	5500035424	UN	UN
70234	23/10/2020	170C000000074	5001743087	27/10/2020	08:52:58	2.000	UN	195,57	B00QFT5006	3000527294	UN	EUR	5500035424	UN	UN
70234	23/10/2020	170C000000074	5001743087	27/10/2020	08:52:58	2.000	UN	195,57	B00QFT5005	3000527294	UN	EUR	5500035424	UN	UN
70234	23/10/2020	170C000000074	5001743087	27/10/2020	08:52:58	2.000	UN	195,57	B00QFT5004	3000527294	UN	EUR	5500035424	UN	UN
70234	23/10/2020	170C000000074	5001743087	27/10/2020	08:52:58	2.000	UN	195,57	B00QFT5003	3000527294	UN	EUR	5500035424	UN	UN
70234	23/10/2020	170C000000074	5001743087	27/10/2020	08:52:58	2.000	UN	195,57	B00QFT5002	3000527294	UN	EUR	5500035424	UN	UN
70234	23/10/2020	170C000000074	5001743087	27/10/2020	08:52:58	2.000	UN	195,57	B00QFT5001	3000527294	UN	EUR	5500035424	UN	UN

Thus, there was the need to build an algorithm capable of crossing the information from both transactions and creating a new data table that fully coalesced the historical records of each requested delivery to its receiving reports. Although it was possible to achieve this goal, it is noteworthy that the solution reached is not viable for all possible situations. As it will be further discussed in section 4.5.3, a foundational algorithm, adapted to each material's unique supply dynamics, was first developed before others were created.

Lastly, similarly to what is described in section 4.4, before running any of these algorithms, the data files retrieved from SAP required proper treatment, all of which is detailed in sections 4.5.1 and 4.5.2, regarding the ME3L and MB51 transactions, respectively.

4.5.1 ME3L Data Treatment

ME3L SAP transaction was used to extract a historical list of each material's requested deliveries. In Table 6, one can find a small sample of the data collected from the system. Although it does not hold the full extent of this transaction's output, it shows that some key information – supplier and delivery ID numbers – was not presented in the best format for posterior processing, thus requiring some treatment.

Table 6: Sample of the File Obtained from ME3L Transaction

Divisão da remessa	Data do documento	Material	Início per.validade	Fim da validade	Grupo de mercadorias	Centro	Depósito	Qtd.do pedido	UM pedido	Preço líquido	Moeda	Unidade de preço	Qtd.divisão
Fornecedor/centro fornecedor 70077 Fornecedor 1													
Documento de compras 5500039331													
Item 10													
1	08/09/2020	101I0000001565	01/08/2020	31/12/2024	100	1102		109 159,070	M2	39,75	EUR	1	1 200
2	08/09/2020	101I0000001565	01/08/2020	31/12/2024	100	1102		109 159,070	M2	39,75	EUR	1	900
3	08/09/2020	101I0000001565	01/08/2020	31/12/2024	100	1102		109 159,070	M2	39,75	EUR	1	809,120
4	08/09/2020	101I0000001565	01/08/2020	31/12/2024	100	1102		109 159,070	M2	39,75	EUR	1	704,910
5	08/09/2020	101I0000001565	01/08/2020	31/12/2024	100	1102		109 159,070	M2	39,75	EUR	1	803,010
6	08/09/2020	101I0000001565	01/08/2020	31/12/2024	100	1102		109 159,070	M2	39,75	EUR	1	900
7	08/09/2020	101I0000001565	01/08/2020	31/12/2024	100	1102		109 159,070	M2	39,75	EUR	1	1 661,330
8	08/09/2020	101I0000001565	01/08/2020	31/12/2024	100	1102		109 159,070	M2	39,75	EUR	1	1 046,480
9	08/09/2020	101I0000001565	01/08/2020	31/12/2024	100	1102		109 159,070	M2	39,75	EUR	1	500
10	08/09/2020	101I0000001565	01/08/2020	31/12/2024	100	1102		109 159,070	M2	39,75	EUR	1	507,540
11	08/09/2020	101I0000001565	01/08/2020	31/12/2024	100	1102		109 159,070	M2	39,75	EUR	1	500,690
12	11/09/2020	101I0000001565	01/08/2020	31/12/2024	100	1102		109 159,070	M2	39,75	EUR	1	804,240

Consequently, it was necessary to select the most relevant columns for the intended analysis, as well as to create two new variables to accommodate supplier and delivery information. The two-step treatment detailed in Appendix IV allowed for these changes and resulted in a new dataset with the following variables:

- **'Doc Compras':** The reusable delivery ID number;
- **'Data.do.documento':** The last time any change was performed to a delivery request;
- **'Material':** The company's reference code for each material;
- **'Group of Materials':** The group of materials to which the requested material belongs to;
- **'Price in Contract':** The price negotiated with the supplier for each material;
- **'Currency':** The currency of the price in the contract;
- **'Price Unit':** The amount of material the price in contract refers to;
- **'Data.de.remessa':** The moment for which the delivery was scheduled to;
- **'Cód fornecedor':** Supplier ID number;
- **'Descr.Fornecedor':** Supplier's name;
- **'Qtd.divisão':** The amount of material requested;
- **'UM.pedido':** The requested material's units of measurement;
- **'Quantidade.anterior':** The original amount of material requested in each specific entry;
- **'Qtd.entrada':** The amount of material delivered to the company's facilities. At first glance, when performing a historical data assessment it may prove of little value, since, with the course of time, it will equal **'Qtd.divisão'** (eventually, in principle all requested material will be delivered). However, when a delivery has not been completely fulfilled, this variable holds the quantity that has actually been delivered to the company to that date. For instance, by the time the data was retrieved from the system (June 9th, 2023), the highlighted delivery in Table 7 had not been completely fulfilled yet, because only 1.326,19 square metres out of the requested 3.674 had arrived. Still, as soon as all the requested amount arrives, there will be no more record of this delay or non-compliance, since this variable will then equal the requested amount.

Table 7: Example of How Variable 'Qtd.entrada' Works

Doc Compr	Data.do.document	Material	Grupo.de.mercadori	Preço.líqui	Moeda	Unidad	Data.de.remes	Cód for	Descr. Fornecedor	Qtd.divis	UM.ped	Quantidade.anteri	Qtd.entra
5500039413	2023-02-08	101I0000001443	100	39,53	EUR	1	2023-05-25	70363	Fornecedor 2	4500	M2	4500	4500
5500039413	2023-02-08	101I0000001443	100	39,53	EUR	1	2023-06-01	70363	Fornecedor 2	4000	M2	4000	4000
5500039413	2023-02-17	101I0000001443	100	39,53	EUR	1	2023-06-08	70363	Fornecedor 2	3674	M2	3674	1326,19
5500039413	2023-03-03	101I0000001443	100	39,53	EUR	1	2023-06-15	70363	Fornecedor 2	4500	M2	4500	0
5500039413	2023-03-17	101I0000001443	100	39,53	EUR	1	2023-06-22	70363	Fornecedor 2	3500	M2	3500	0

Afterwards, an exploratory data analysis (EDA) was conducted to the treated data. Firstly, some variables had their data types changed and the presence of missing values was accounted for ('NA' values), although this search returned no positive results.

Furthermore, the use of the R *summary* function did not reveal any abnormalities with the sampled data, which would have been the case if, for example, the 'Qtd.divisão' or the 'Price in Contract' variable ever equalled zero – cases of cancelled replenishment orders and outdated contracts, respectively.

In order to better understand the status of the orders returned by the system, the variable **'Estado'** (named 'Status' in Figure 17) was created. This variable can assume four main values – 'Fulfilled', if **'Qtd.entrada'** and **'Qtd.divisão'** equal the same number, different from zero; 'Delayed', if orders with **'Data.de.remessa'** prior to the moment data was collected (**'Data.Recolha.Dados'**) do not have equalling values in **'Qtd.entrada'** and '**Qtd.divisão**'; 'Cancelled', if **'Qtd.entrada'** and '**Qtd.divisão'** equal zero; and 'Scheduled', in case **'Data.de.remessa'** is over or equal to **'Data.Recolha.Dados'**, but the total ordered quantity has not been delivered yet. The piece of code responsible for this value assignment task to variable **'Estado'** is detailed in Appendix V, together with the rest of the EDA algorithm, while the resulting split dataset is shown in Figure 17.

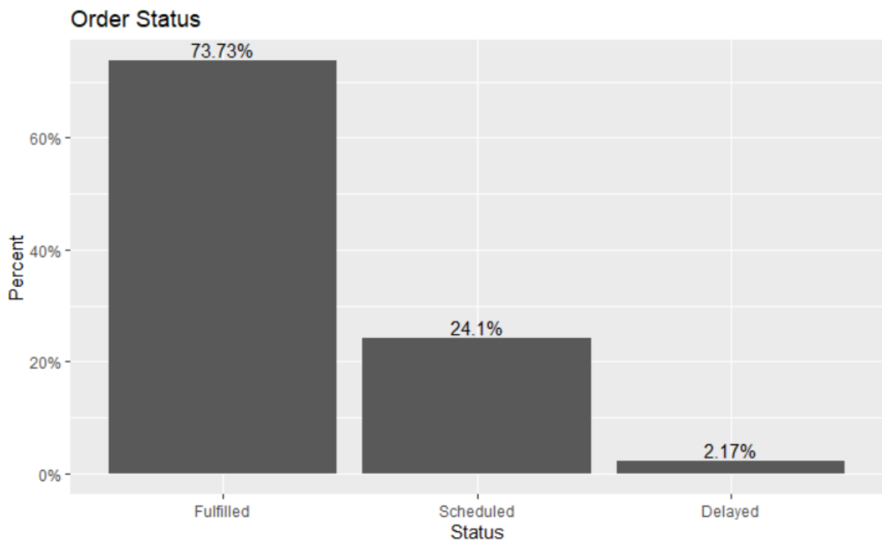


Figure 17: Split Dataset by the 'Estado' Variable

As expected, most orders fell into the 'Fulfilled' status, while plenty of others were scheduled to arrive soon. Nonetheless, 2,17% of the total number of orders was 'Delayed', an interesting statistic whose record will cease to exist the moment this material is received in the warehouse.

Lastly, the week number was assigned to each entry in 'Data.de.remessa' column, since the company only considers orders to be delayed or ahead of time when their delivery happens in a different week than the one of the scheduled date.

All this treatment resulted in a dataset structured as presented in Table 8.

Table 8: ME3L Final Layout After Treatment

Data.do.docu	Material	Grupo.de.mer	Preço.líquido	Moeda	Unidade.de.p	Data.de.remessa	Ano.Semana.Entrega	Cód.forneced	Qtd.divisão	UM.pedido	Quantidade.a	Qtd.entrada	Data.Recolha.Dados	Estado
04/09/2020	104I0000000003	118	53,12	EUR	1	17/09/2020	202038	70238	160	M	160	160	09/06/2023	Concluído
09/09/2020	101I0000001509	100	41,28	EUR	1	17/09/2020	202038	70428	994,1	M2	994,1	994,1	09/06/2023	Concluído
08/09/2020	101I0000001565	100	39,75	EUR	1	18/09/2020	202038	70077	1200	M2	1200	1200	09/06/2023	Concluído
09/09/2020	101I0000001443	100	39,53	EUR	1	18/09/2020	202038	70363	1750	M2	1750	1750	09/06/2023	Concluído
04/09/2020	104I0000000003	118	53,12	EUR	1	24/09/2020	202039	70238	103	M	103	103	09/06/2023	Concluído
09/09/2020	101I0000001509	100	41,28	EUR	1	24/09/2020	202039	70428	1000	M2	1000	1000	09/06/2023	Concluído
08/09/2020	101I0000001565	100	39,75	EUR	1	25/09/2020	202039	70077	900	M2	900	900	09/06/2023	Concluído
09/09/2020	101I0000001443	100	39,53	EUR	1	25/09/2020	202039	70363	3050	M2	3050	3050	09/06/2023	Concluído
04/09/2020	104I0000000003	118	53,12	EUR	1	01/10/2020	202040	70238	120	M	120	120	09/06/2023	Concluído
09/09/2020	101I0000001509	100	41,28	EUR	1	01/10/2020	202040	70428	1500	M2	1500	1500	09/06/2023	Concluído

4.5.2 MB51 Data Treatment

Similarly to what happened to the data collected from the ME3L transaction, the MB51 dataset needed some treatment before being ready to associate its receiving reports with ME3L's delivery requests. A preliminary analysis also involved the elimination of some variables, rearranging column order and checking for missing values and data abnormalities. At this stage, the main variables included in the dataset were:

- **'Pedido':** The same as **'Doc Compras'** in ME3L transaction (reusable delivery ID number);
- **'Data.do.documento':** The moment when the warehouse staff created the receiving report. It can happen several days before the material is delivered;
- **'Data.de.lançamento':** The moment when the material was truly received;
- **'Material':** The company's reference code for each material;
- **'Referência':** A reference number associated to the batch number;
- **'Lote':** Batch number;
- **'Fornecedor':** Supplier ID number;
- **'Qtd...UM.registro':** The amount of material added to inventory with each entry;
- **'Unid.medida.básica':** The requested material's units of measurement;
- **'UM.registro':** Units of measurement associated with the delivery (for these materials, always equals **'Unid.medida.básica'**);

- **‘Montante.em.MI’:** The monetary value of the amount of material added to inventory. It includes the material’s price and inbound costs;
- **‘Moeda’:** The currency linked to **‘Montante.em.MI’**;
- **‘Unid.prç.pedido’:** The units of measurement to which the **‘Montante.em.MI’** refers to (for these materials, it always equals **‘Unid.medida.básica’**).

Unlike what happened with the ME3L data sample, in this case, the *summary* function allowed to identity some confusing values in the ‘Montante.em.MI’ variable. They had to do with materials received in reasonable quantities, but with a corresponding monetary value so low that their cost by unit of measurement had to be close to zero, in order for that result to make sense. A deeper analysis revealed that these situations concerned old, outdated contracts, no longer in use, so the decision was made to create a new variable **‘Montante.em.MI.Total.Atual’** to link the material’s delivered quantities with their current monetary value, available in SAP transaction MM60.

After completing this initial data analysis and understanding phases, another problem concerning its structure needed to be addressed. As hinted by the previous variables’ descriptions, and more clearly illustrated in Table 9, the same delivery is split into multiple data entries, because of reference and batch numbers. That is to say one delivery entry in ME3L transaction is associated with multiple entries in MB51 transaction, in fact as many as the number of batches the total requested quantity was divided into. The example highlighted in Table 9 shows one delivery that has been split into five data entries, because of reference and batch numbers. However, because the next set of receiving records is also linked to the same material and delivery date as the first, differing only on reference and batch numbers, it is unclear, without analysing the ME3L transaction, if these two sets refer to one or two delivery requests.

Table 9: Implications of Reference and Batch Numbers in MB51’s Structure

Data do documento	Material	Data de lançamento	Qtd. UM registro	UM registro	Montante em MI	Lote	Referência	Unid.medida básica	Moeda	Pedido	UM pedido	Unid.prç.pedido
07/01/2021	101I0000001565	07/01/2021	459,220	M2	17 856,77	00R4P9A	3000541985	M2	EUR	5500039331	M2	M2
07/01/2021	101I0000001565	07/01/2021	186,720	M2	7 260,61	00R4P8A	3000541985	M2	EUR	5500039331	M2	M2
07/01/2021	101I0000001565	07/01/2021	67,100	M2	2 609,18	00R4P7A	3000541985	M2	EUR	5500039331	M2	M2
07/01/2021	101I0000001565	07/01/2021	108,070	M2	4 202,30	00R4P6A	3000541985	M2	EUR	5500039331	M2	M2
07/01/2021	101I0000001565	07/01/2021	179,520	M2	6 980,64	00R4P5A	3000541985	M2	EUR	5500039331	M2	M2
07/01/2020	101I0000001565	07/01/2020	340,300	M2	13 232,57	00NQBFB	3000454960	M2	EUR	5500022979	M2	M2
07/01/2020	101I0000001565	07/01/2020	454,400	M2	17 669,34	00NQBFA	3000454960	M2	EUR	5500022979	M2	M2
07/01/2020	101I0000001565	07/01/2020	121,770	M2	4 735,03	00NQBEA	3000454960	M2	EUR	5500022979	M2	M2
07/01/2020	101I0000001565	07/01/2020	38,650	M2	1 502,91	00NQBDA	3000454960	M2	EUR	5500022979	M2	M2
07/01/2020	101I0000001565	07/01/2020	47,400	M2	1 843,15	00NQBCA	3000454960	M2	EUR	5500022979	M2	M2
14/01/2019	101I0000001565	14/01/2019	300,540	M2	12 947,62	00K5CPA	3000362015	M2	EUR	5500022979	M2	M2
14/01/2019	101I0000001565	14/01/2019	532,280	M2	22 931,26	00K5COA	3000362015	M2	EUR	5500022979	M2	M2
07/01/2022	101I0000001565	10/01/2022	476,160	M2	17 457,45	00UUPSA	3000612971	M2	EUR	5500039331	M2	M2
07/01/2022	101I0000001565	10/01/2022	225,120	M2	8 253,57	00UUPRA	3000612971	M2	EUR	5500039331	M2	M2

Consequently, in an effort to decrease the number of entries that one ME3L entry matches on the MB51 transaction, entries with the same reference and batch numbers were grouped together, meaning that these two variables were not included in the final dataset. Another consequence of this decision was the replacement of the original ‘Qtd...UM.registro’ and ‘Montante.em.MI’ variables by new ones that constitute the sum of the aggregated entries – respectively, **‘Qtd_Total_Registada’** and **‘Montante.MI.Total’**, the latter later originating **‘Montante.em.MI.Total.Atual’**.

The final step of this treatment was, once again, assigning the week number corresponding to each ‘Data.de.lançamento’ and reordering the dataset according to it.

All these transformations were carried out by implementing the algorithm in Appendix VI and resulted in the structure presented in Table 10.

Table 10: MB51 Final Layout After Treatment

Pedido	Data.do.documento	Data.de.lançamento	Ano.Semana.Entrega	Material	Fornecedor	Qtd_Total_Registada	Unid.medida.	UM.registro	Montante.MI.Total	Montante.MI.Total.Atual	Moeda	Unid.prç.pedido
5500022222	07/01/2019	07/01/2019	201902	101I0000001509	70428	2099,36	M2	M2	91811,3	87762,18288	EUR	M2
5500022577	08/01/2019	08/01/2019	201902	101I0000001443	70363	1958,15	M2	M2	83064,73	78543,53284	EUR	M2
5500022222	11/01/2019	11/01/2019	201902	101I0000001509	70428	531,16	M2	M2	23229,22	22204,74862	EUR	M2
5500022979	14/01/2019	14/01/2019	201903	101I0000001565	70077	1833,09	M2	M2	78971,71	72555,7186	EUR	M2
5500026594	11/01/2019	14/01/2019	201903	104I0000000003	70006	102	M	M	4731,71	5541,234048	EUR	M
5500026594	14/01/2019	14/01/2019	201903	104I0000000003	70006	160,6	M	M	7450,12	8724,727334	EUR	M
5500022577	15/01/2019	15/01/2019	201903	101I0000001443	70363	1957,59	M2	M2	83040,96	78521,07063	EUR	M2
5500022577	21/01/2019	21/01/2019	201904	101I0000001443	70363	1950,58	M2	M2	82743,61	78239,89188	EUR	M2
5500022979	21/01/2019	21/01/2019	201904	101I0000001565	70077	509,32	M2	M2	21942,11	20159,44585	EUR	M2
5500022979	22/01/2019	22/01/2019	201904	101I0000001565	70077	499,62	M2	M2	21524,22	19775,50918	EUR	M2
5500026594	22/01/2019	22/01/2019	201904	104I0000000003	70006	154	M	M	7143,95	8366,176896	EUR	M
5500022222	23/01/2019	23/01/2019	201904	101I0000001509	70428	1151	M2	M2	50336,68	48116,69866	EUR	M2
5500022222	28/01/2019	28/01/2019	201905	101I0000001509	70428	1434,28	M2	M2	62725,37	59959,0083	EUR	M2
5500022577	28/01/2019	28/01/2019	201905	101I0000001443	70363	833,73	M2	M2	35366,82	33441,8199	EUR	M2
5500022979	30/01/2019	30/01/2019	201905	101I0000001565	70077	1296,5	M2	M2	55854,75	51316,89615	EUR	M2
5500022222	05/02/2019	05/02/2019	201906	101I0000001509	70428	1542,18	M2	M2	67444,16	64469,68752	EUR	M2

4.5.3 Crossing ME3L and MB51 Transactions

After the described data treatment, it was time to integrate the delivery requests found in the ME3L transaction with the receiving reports collected from the MB51 transaction, a quite delicate task, considering the underlying traceability issues between them.

On that account, before taking this analysis any further, one fundamental question had to be answered: how can a receiving report from a specific delivery request be properly identified if the orders issued to the suppliers are not assigned to unique ID numbers?

At this stage, it should be made clear that there was no simple answer to this question, since order fulfilment can occur under many different scenarios, namely:

- Materials can arrive several days before or after the scheduled delivery day, meaning that comparing ‘Data.de.remessa’ and ‘Data.de.lançamento’ dates can be misleading;
- The amount of ordered material may not be the same as the actual amount of material received (superior or inferior amounts to the original request can be delivered);
- One delivery request may be linked to more than one receiving report if its fulfilment was ensured by multiple deliveries;
- Not all delivery requests have their own receiving reports, since suppliers might prefer to send extra amounts of material while fulfilling other orders, until they complete the requested quantity in a supressed delivery;

- Deliveries with extra amount of material can also be linked to the fulfilment of past orders, in case the requested amount of material had not yet been delivered.

Thus, combining certain variables, in a similar fashion to the one described in Appendix III, to ensure a match between the two transactions was not feasible, since matching entries would, most likely, have different values.

Under these circumstances, all these scenarios uncovered the need to include a variable, in the new combined dataset– **'Balanço'** -, that balanced out the delivered quantities with the amount of requested material and quantified possible excess or deficit of supplies, as shown in Equation (3):

$$Balanço_{[k]} = Balanço_{[k-1]} + Qtd_{Excedente[k]} - Qtd_{Pendente[k]} - Qtd_{Compensada[k]} \quad (3)$$

where $Balanço_{[k-1]}$ is the balance for the previously matched entries; $Qtd_{Excedente[k]}$ is the extra amount of delivered material, when comparing the delivery request and the corresponding receiving report(s) (variable 'Qtd_Excedente'); $Qtd_{Pendente[k]}$ is the amount of missing material (variable 'Qtd_Pendente'); and $Qtd_{Compensada[k]}$ is an auxiliary variable important in situations where 'Qtd_Excedente' and 'Qtd_Pendente' do not balance each other out (variable 'Qtd_Compensada'). Appendix VII helps to shed some light on the use and meaning of this last variable, as well as variable 'Balanço' itself.

To sum up the main conclusions presented so far, it has been ascertained that an algorithm capable of crossing ME3L and MB51 transactions must account for a multitude of scenarios, and that a variable such as 'Balanço' plays a key role in distinguishing most of them.

However, even when considering a wide range of possible scenarios, there are always others, particular to each material's dynamics, which are harder to include in a general, closed-form algorithm. Hence, a foundational algorithm encompassing all the described scenarios for material '101I0000001565' was developed, followed by its adaptation to the other nine. This adaptation process involved changing the values of some parameters and including situations more specific to each material's supply.

Because the rationale behind all algorithms is based on the one developed for material '101I0000001565', this was the one chosen to be further explained and to have its code detailed in Appendix VIII. In simple terms, the algorithm assesses each line of both transactions in parallel, comparing a requested delivery in line i of ME3L transaction with the potential receiving report in line j of MB51 transaction. This activity can be divided into four main possible moments – comparing past values of variable **'Balanço'**; if this is proven fruitless, verifying if **'Qtd_Total_Registada'** in line j is equal to

‘**Qtd.divisão’** in line i; if, instead, **‘Qtd_Total_Registada’** in line j is inferior or superior to ‘**Qtd.divisão’** in line i, then it evaluates their respective possibilities.

While assigning ME3L and MB51 entries, the algorithm also verifies if the materials were delivered on time, with some delay, or a few days in advance. The amount of weeks delayed or ahead of time is also calculated and assigned to variables **‘Atraso_semanas’** and **‘Avanço_semanas’** when the respective binary variables **‘Atraso’** or **‘Avanço’** equal one. Should one delivery request of ME3L transaction match more than one MB51 receiving report, the assessment is made based on the date of the last MB51 entry. Moreover, under these circumstances, the material is only considered to be missing if the final delivery week number is superior to the scheduled week number in the corresponding ME3L entry.

An example of the new databases obtained after this treatment is shown in Appendix IX.

One final note concerns the importance of variable ‘Balanço’ in understanding if the combinations suggested by the algorithms make sense, considering the records found in ME3L transaction for each material. In fact, as previously illustrated in Table 7, when the data was collected from SAP, it was possible to identify which deliveries were delayed or anticipated and which materials had lower inventory levels than expected, due to the connection between variables **‘Qtd.entrada’** and **‘Qtd.divisão’**. At that time, the highlighted delivery in Table 7 had not been completely fulfilled, because only 1.326,19 square metres out of the requested 3.674 had arrived, meaning that 2.347,81 were missing. If one compares this number with the result of variable ‘Balanço’ in Table 11, it is clear that the algorithm assigned the entries of both transactions in a valid way, since the final inventory level also equalled - 2.347,81 square metres of material.

Table 11: Importance of the ‘Balanço’ Variable in Validating the Combined Dataset

Pedido_Compra	Material	Data_Remess	Semana_Pedi	Cód_Fornecedor	Qtd_Divisão	Unid_Medida_Pedido	Qtd_Entrada_Total	Data_Lançamento	Semana_Real	Qtd_Registad	Qtd_Pendent	Qtd_Exceden	Balanço
5500039413	101I0000001	05/18/2023	202320	70363	1467,02	M2	1467,02	05/18/2023	202320	966,22	0	0	0
5500039413	101I0000001	05/25/2023	202321	70363	4500	M2	4500	05/22/2023	202321	1371,32	0	0	0
5500039413	101I0000001	05/25/2023	202321	70363	4500	M2	4500	05/24/2023	202321	2145,28	983,4	0	-983,4
5500039413	101I0000001	06/01/2023	202322	70363	4000	M2	4000	05/30/2023	202322	2514,15	0	0	-983,4
5500039413	101I0000001	06/01/2023	202322	70363	4000	M2	4000	06/01/2023	202322	877,94	607,91	0	-1591,31
5500039413	101I0000001	06/08/2023	202323	70363	3674	M2	1326,19	06/05/2023	202323	2917,5	756,5	0	-2347,81

4.5.4 Auxiliary Dataset for Supply Stock Outs

After building a historical record of what happened to each delivery request, it was paramount to ensure that the way data was presented allowed to quantify the impact of materials’ stock outs over time, as well as to determine how long it took a supplier to restock the amount of material missing – in other words, how long it took to variable ‘Balanço’ go from a negative value to, at least, zero. A closer look into the combined dataset makes one realise that, although the information needed to answer these questions is available on the data table, it is not presented in the best format to clearly reach any conclusions on the subject.

As a result, a smaller dataset was created, summarising key information related to these topics. The algorithm developed for this purpose starts by selecting entries with negative values in variable 'Balanço', first giving a list of possible materials' stock outs and then returning the list of real stock outs for the period under study. Appendix X details the logic behind this selection.

Having reached the final list of stock outs, it was possible to identify the amount of material truly missing in each entry (variable **'QuebraReal'**). Considering a list of deliveries that share the same **'Data_ReposiçãoBalanço'**, the amount of missing material in the first entry is given by variable **'Balanço'** itself, while, for the rest of the lines, it is directly given by **'Qtd_Pendente'** (because variable **'Balanço'** adds **'Qtd_Pendente'** to its previous value, accumulating the amount of missing material between entries), as exemplified in Table 12.

Table 12: List of Stock Outs – Example of Final Output

Material	Data_Remessa	Cód_Fornecedor	Data_Lançamento	Qtd_Pendente	Balanço	Data_ReposiçãoBalanço	eliminado	QuebraReal	index
101I0000001509	2021-05-27	70428	2021-05-24	200.70	-200.67	2021-06-01	0	200.67	103
101I0000001509	2021-07-22	70428	2021-07-20	517.29	-517.29	2021-07-27	0	517.29	104
101I0000001509	2021-10-28	70428	2021-10-28	61.25	-61.25	2021-11-05	0	61.25	105
101I0000001509	2021-11-11	70428	2021-11-09	1.00	-1.00	2021-11-11	0	1.00	106
101I0000001509	2021-11-18	70428	2021-11-15	524.59	-100.98	2021-11-19	0	100.98	107
101I0000001509	2021-12-16	70428	2021-12-15	570.87	-570.83	2022-01-18	0	570.83	108
101I0000001509	2022-01-10	70428	2022-01-07	212.46	-377.58	2022-01-18	0	212.46	109
101I0000001509	2022-01-13	70428	2022-01-14	533.67	-911.25	2022-01-18	0	533.67	110
101I0000001509	2022-02-03	70428	2022-02-07	3462.90	-1985.81	2022-04-12	0	1985.81	111
101I0000001509	2022-02-17	70428	2022-02-21	409.42	-1093.45	2022-04-12	0	409.42	112
101I0000001509	2022-03-10	70428	2022-03-10	385.89	-953.36	2022-04-12	0	385.89	113
101I0000001509	2022-03-17	70428	2022-03-15	1462.62	-2415.98	2022-04-12	0	1462.62	114
101I0000001509	2022-04-07	70428	2022-04-04	3150.99	-4585.87	2022-04-12	0	3150.99	115
101I0000001509	2022-08-18	70428	2022-08-19	549.81	-549.81	2022-08-22	0	549.81	116
101I0000001509	2022-11-10	70428	2022-11-15	481.20	-481.20	2022-11-18	0	481.20	117
101I0000001509	2023-01-19	70428	2023-01-20	38.83	-38.83	2023-01-23	0	38.83	118
101I0000001509	2023-02-02	70428	2023-01-31	135.37	-135.37	2023-02-10	0	135.37	119
101I0000001509	2023-03-23	70428	2023-03-22	515.10	-515.10	2023-03-28	0	515.10	120
101I0000001509	2023-04-20	70428	2023-04-18	819.85	-132.78	2023-04-26	0	132.78	121

The code that allowed to create this auxiliary dataset is presented in Appendix XI.

4.5.5 Raw Materials' Supply Assessment

With both datasets created – the combined ME3L and MB51 table and the list of supply stock outs -, new pages were added to the Power BI Report, so that conclusions regarding supply uncertainties and their consequences could be drawn. Similarly to what happened in section 4.4.2, this chapter will only include the main results of this analysis. Other features of this part of the report will be properly mentioned in section 5.4.

While assessing supply performance, it is fundamental to have indicators that measure the impact of replenishment delays and situations of non-compliance with the ordered quantity - in this case, variables **'%Atrasos.NoTotal.Entradas'** and **'%Qtd_Real_Quebra'**, respectively.

On the one hand, non-compliance with the ordered quantity can be defined as the amount of material missing, considering the total amount of ordered material. Following this logic, it is clear that the amount of missing material can be estimated based on variable **'QuebraReal'** from the supply stock out table. Nonetheless, determining the total amount of requested material proved not to be such a straightforward exercise.

Considering the combination of ME3L and MB51 transactions, some delivery requests were repeated over several entries, because they did not relate to a unique delivery report on MB51 transaction. Consequently, adding the total amount of requested material (**'Qtd.Divisão'**) over a certain period of time is bound to lead to an overestimate of real raw material demand.

Because of this, a binary variable, named **'contabilizar'**, was added to the combined dataset. If two consecutive entries request the same material and have the same **'Data.de.remessa'** and **'Qtd.Divisão'**, then they both refer to the same delivery and **'contabilizar'** equals zero for the latter. Should consecutive entries relate to different delivery requests, it will be assigned value 1 to variable **'contabilizar'**. This method allowed to quantify the total amount of ordered material, since, for each line, the real amount (**'Qtd_OG_Encomendada'**) is given by Equation (4):

$$Qtd_{OG_{Encomendada}} = Qtd.Divisão \times contabilizar \quad (4)$$

This guaranteed that repeated entries of the ME3L transaction did not have their 'Qtd.Divisão' included when adding the values of variable **'Qtd_OG_Encomendada'**, since the requested amount on them had already been considered once, in the first entry with the same values for variables 'Material', 'Data.de.remessa' and 'Qtd.Divisão'.

As a result, **'%Qtd_Real_Quebra'** can now be defined as shown in Equation (5):

$$\%Qtd\_Real\_Quebra_{[Material]} = \frac{\sum_{t=1}^{t=T} QuebraReal_{[t]}}{\sum_{t=1}^{t=T} Qtd\_OG\_Encomendada_{[t]}} \quad (5)$$

with T representing the last entry found, on the combined dataset, for each material.

The results obtained for **'%Qtd_Real_Quebra'** by group of materials are shown in Figure 18, while Figure 19 allows the comparison between this variable and **'NecDep_i1'** by material.

Group of Materials	AVG. Value of 'Balanço'	AVG. 'QuebraReal'	Unit of Measurement	%Qtd_Real_Quebra	AVG. Number of Days to Level 'Balanço'	AVG. Number of Weeks to Level 'Balanço'
Cutting Mat. - Textile	**-28,73**	**697,29**	**M**	**9,41%**	**11,23**	**1,60**
104I0000000003	10,46	20,10	M	1,11%	11,33	1,62
105I0000000403	-72,49	895,72	M	11,97%	11,80	1,69
105I0000000405	-96,50	1.335,10	M	9,78%	10,75	1,54
Cutting Mat. - Vinyl	**-742,98**	**1.300,00**	**M**	**17,22%**	**17,18**	**2,45**
102B0000000001	-26,48	380,60	M	6,36%	9,50	1,36
102B0000000002	-48,85	166,99	M	2,73%	4,00	0,57
102I0000000083	-1.431,87	1.724,21	M	20,59%	22,04	3,15
102I0000000124	-0,39	311,38	M	6,12%	4,80	0,69
Leather	**-45,49**	**656,40**	**M2**	**7,53%**	**11,24**	**1,61**
101I0000001443	-146,55	916,60	M2	8,18%	8,42	1,20
101I0000001509	-107,01	513,51	M2	10,70%	15,26	2,18
101I0000001565	146,92	171,82	M2	1,10%	5,33	0,76
Total	**-190,64**	**854,50**	**M**	**10,52%**	**12,99**	**1,86**

Figure 18: Results for Non-compliance with the Ordered Quantity and other Key Variables

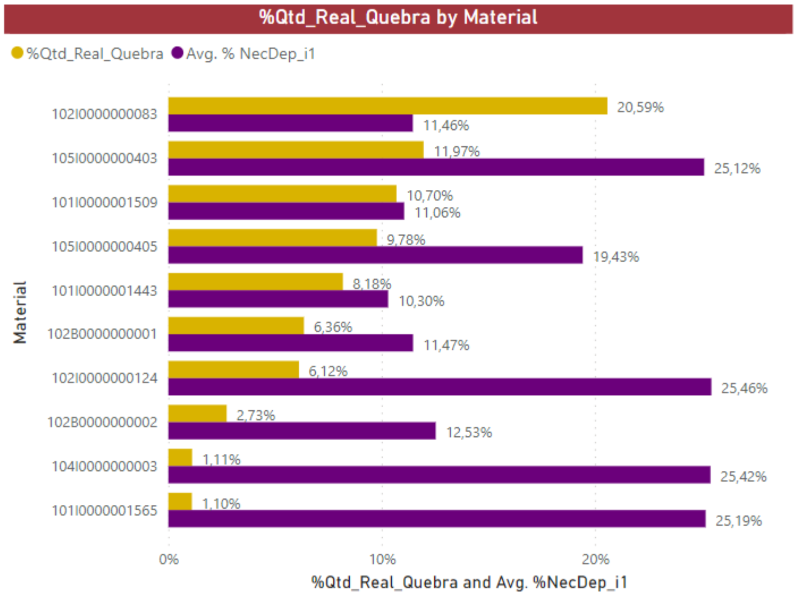


Figure 19:Non-compliance with the Ordered Quantity and 'NecDep_i1' by Material

After analysing Figure 18, it becomes apparent that vinyl materials tend to have greater amounts of missing material, in comparison with the total amount of ordered material, since 17,22% of their total requested quantity was accounted for in variable 'QuebraReal'. The performance of material '102I0000000083' contributes significantly to this result, because, on its own, '%Qtd_Real_Quebra' equals 20,59%.

These supply struggles might be related to the previously mentioned shift in the company's production. In fact, as also illustrated in Figure 20, before 2021 the company did not produce any vinyl seat covers. Since then, however, it has not only added that kind of projects to their portfolio, but also increased their production volume, which could have led to fluctuations in the ordered quantities that made the suppliers struggle to keep up with.

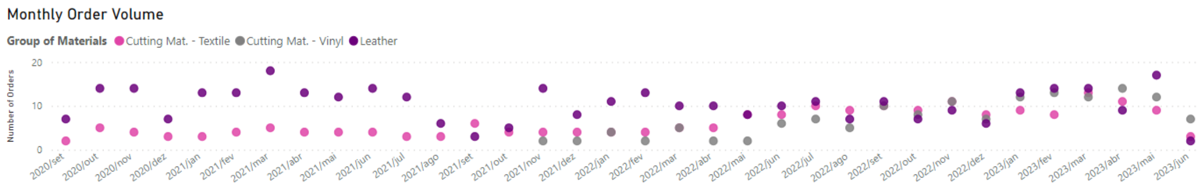


Figure 20: Monthly Order Volume by Group of Materials

On the other hand, it also seems to be quite clear that raw materials with worse service levels do not suffer from severe problems of non-compliance with the ordered quantity. For example, Figure 19 shows that materials '104I0000000003' and '101I0000001565' have service levels below 75% ('NecDep_i1' equals 25,42% and 25,19%, respectively), but the amount of missing material during replenishments only represents 1,11% and 1,10% of their total requested amount. This suggests that the low service level performance of some of these raw materials may be more related to the inventory management policies themselves and their shortcomings in accounting for demand uncertainty than to supply inefficiencies of this kind, though a more definitive conclusion can only be drawn after completing this analysis with an assessment of replenishment delays.

Additionally, Figure 18 shows that the average value of variable 'Balanço' is negative for all groups of materials. Once again, vinyl has, on average, the highest amount of material missing from stock (-742,98 metres), while materials '104I0000000003' and '101I0000001565' are the only ones with positive average balances – 10,46 metres and 146,92 square metres, respectively.

Lastly, the average number of days that it takes to variable 'Balanço' be equal or superior to zero is, unsurprisingly, greater for vinyl materials, reaching 2,45 weeks. Similarly to what happens with variable 'QuebraReal', material '102I0000000083' takes the longest to balance out requested and delivered quantities of material, surpassing the three week mark.

Turning one's attention to variable **'%Atrasos.NoTotal.Entradas'**, it represents each material's percentage of delayed deliveries on its total amount of entries (Equation 6), which ultimately translates into the probability of a delivery arriving later than scheduled.

$$\%Atrasos.NoTotal.Entradas_{[material]} = \frac{Sum\ 'Atraso'\ equal\ to\ 1}{Count\ 'Qtd.divisão'} \quad (6)$$

The main results regarding this performance indicator are summarised in Figures 21 and 22.

Group of Materials	AVG. Value of 'Balanço'	Unit of Measurement	%Qtd_Real_Quebra	%Atrasos.NoTotal.Entradas	AVG. Delay (In Weeks)	AVG. Delay (In Days)
Cutting Mat. - Textile	**-28,73**	**M**	**9,41%**	**14,35%**	**0,99**	**6,94**
104I0000000003	10,46	M	1,11%	0,75%	0,57	4,00
105I0000000403	-72,49	M	11,97%	40,54%	1,13	7,93
105I0000000405	-96,50	M	9,78%	30,19%	0,88	6,19
Cutting Mat. - Vinyl	**-742,98**	**M**	**17,22%**	**35,23%**	**0,74**	**5,16**
102B0000000001	-26,48	M	6,36%	44,00%	0,78	5,45
102B0000000002	-48,85	M	2,73%	44,00%	0,78	5,45
102I0000000083	-1.431,87	M	20,59%	32,22%	0,72	5,07
102I0000000124	-0,39	M	6,12%	30,56%	0,69	4,82
Leather	**-45,49**	**M2**	**7,53%**	**12,11%**	**0,91**	**6,39**
101I0000001443	-146,55	M2	8,18%	4,79%	0,75	5,25
101I0000001509	-107,01	M2	10,70%	15,08%	0,88	6,16
101I0000001565	146,92	M2	1,10%	18,75%	0,99	6,96
Total	**-190,64**	**M**	**10,52%**	**17,68%**	**0,86**	**5,99**

Figure 21: Results for Delays in Material Delivery

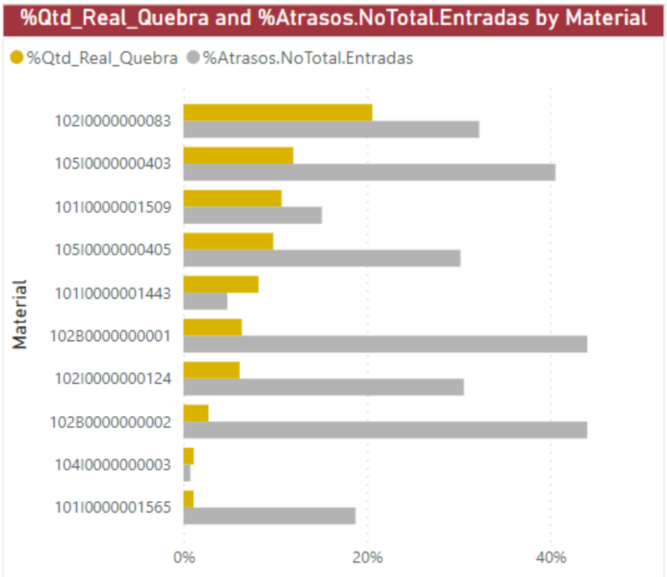


Figure 22: Comparison Between Delays and Non-compliance with Ordered Quantity (in Percentage)

Although these results highlight that, once again, vinyl materials are particularly prone to supply delays (the group average is 35,23%), it is also noticeable that some materials with lower **'%Qtd_Real_Quebra'** have relatively high **'%Atrasos.NoTotal.Entradas'**, as it is the case of materials '101I0000001565' and '102B0000000002', for example.

Bearing this in mind and adding the fact that material '101I0000001565' has, on average, a positive inventory balance, one can conclude that even though, sometimes, its deliveries may arrive later than expected, its tendency to have a certain surplus of material in stock may be the supplier's attempt to compensate expected future delays. Connecting this to the material's low service level, one can conclude both replenishment delays and demand uncertainty may be influencing its performance.

On the contrary, considering material '104I0000000003' presents low values for '%Qtd_Real_Quebra' and '%Atrasos.NoTotal.Entradas', the earlier conclusion that its inventory management policies and their shortcomings in accounting for demand uncertainty are the biggest contributors to its poor service level performance seems to be validated.

Finally, beforehand delivery and exceeding amounts of material per delivery were also subject to analysis. While the deliveries ahead of time (**'%Avanços.NoTotal'**) were measured in a similar fashion to the one shown in Equation 6, only replacing variable 'Atraso' by 'Avanço', the impact of extra amount of material delivered in the total amount of material ordered was assessed following Equation (7):

$$\%Qtd.Excedente = \frac{'Qtd\_Excedente'}{'Qtd.divisão'} \quad (7)$$

Figures 23 and 24 show, respectively, how these indicators performed by material and evolved over time. Note that in Figure 23 the analysis is made using the median value of **'%Qtd.Excedente'**, while Figure 24 illustrates its average over time, transformed by the logarithmic function, since this indicator's average value proved to be severely affected by a few outliers, mainly related to material '101I0000001443'.

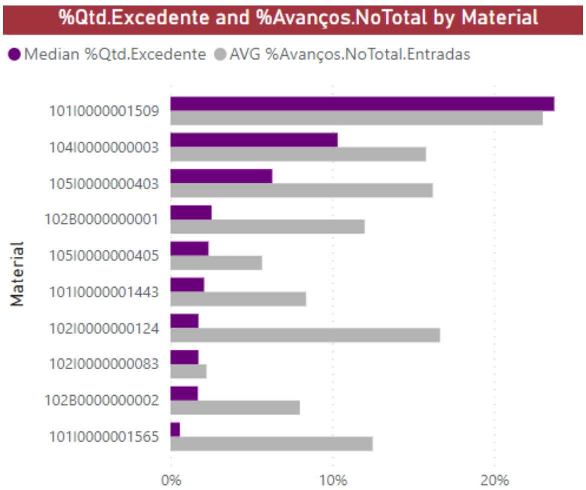


Figure 23: Median Value of '%Qtd.Excedente' by Material

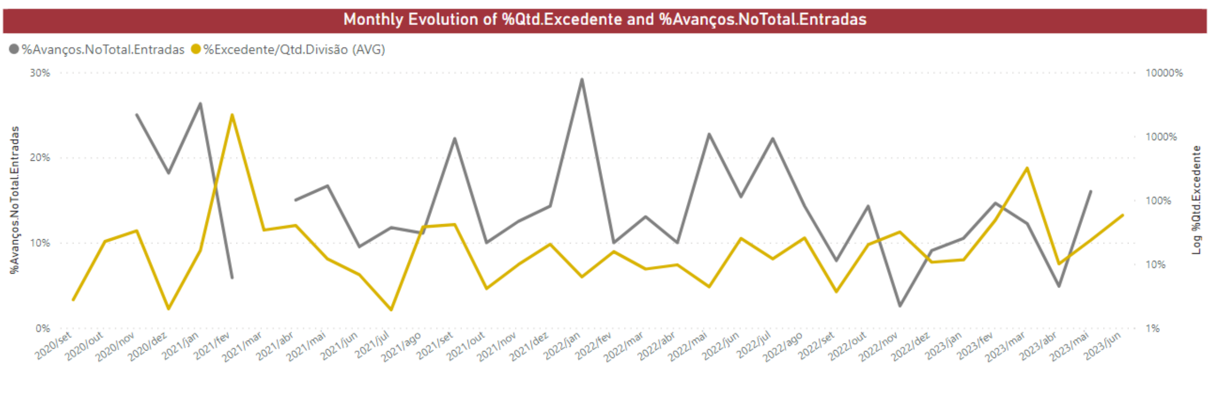


Figure 24: Monthly Evolution of '%Qtd.Excedente' and '%Avanços.NoTotal'

This analysis revealed that deliveries scheduled for early in the year (especially during January) and, sometimes, before or after summer months tend to happen ahead of time. This has everything to do with Christmas and summer holidays, during which COINDU, its suppliers and customers stop production for a few days. During these periods, end-item demand still needs to be accounted for and all players must prepare to meet their demand during the time their production is on hold. This, aligned with the fact that not all parties stop production at the same time, leads to an anticipation of needs and of scheduled deliveries, so that COINDU has enough material to carry on production during their suppliers' break and to prepare production in advance and fulfil end-item demand during the time they also stop manufacturing.

In conclusion, it is important to underline that situations where extra amount of material is delivered may relate to two completely different scenarios – order anticipation or delivery of missing material. This helps to explain why, in Figure 24, an increase of '%Avanços.NoTotal' is not always met with an increase of '%Qtd.Excedente'.

4.6 Main Findings

At this stage, it is relevant to summarise the main findings uncovered during the system diagnosis stage and described in great detail throughout this chapter. Therefore, one must start by addressing the unstructured way data is currently stored in the company's information systems. In fact, the lack of file format standardisation, coherence, connection and traceability between systems and, oftentimes, within the same system required intensive data gathering and treatment, before the performance of current inventory management policies and supply quality could be assessed.

After collecting, understanding and summarising the data referring to historical MRP records, as well as establishing new KPIs to measure A-type raw materials' performance, three groups of materials stood out as particularly vulnerable to demand unfulfilment and short term variation of materials' needs - Textile, Leather and Vinyl. For these materials, during the past year alone, the unmet demand ratio equalled 21,52% for Leather materials, 18,56% for Textile and 14,48% for Vinyl, which translates into service levels of, respectively, 78,48%, 81,44% and 85,52%, whereas the average variation rates of materials' needs were 461,08%, 562,24% and 221%.

In regard to supply performance, it was clear that Vinyl materials tend to have greater amounts of missing material, in comparison with the total amount of ordered material, as well as a higher risk of supply delay.

These supply struggles might be related to the shift in the company's production towards an increase of vinyl and textile seat covers as opposed to the traditional leather ones.

Additionally, raw materials with worse service levels did not seem to suffer from severe problems of non-compliance with the ordered quantity, though some materials with low '%Qtd_Real_Quebra' presented high '%Atrasos.NoTotal.Entradas'.

All these results supported the conclusion that Leather, Textile and Vinyl groups of materials could better benefit from revised inventory management policies, thus improving the company's resilience towards market uncertainty.

5. IMPROVEMENT PROPOSALS

This chapter details the improvement proposal presented to the company – a Decision Support System (DSS) that keeps track of KPIs concerning demand and supply uncertainty and that, based on information collected from COINDU's information systems, as well as user input, is capable of simulating the performance of new inventory management policies and comparing its results to the policies currently in place.

This DSS is thoroughly described in section 5.1, while sections 5.2 and 5.3 test its application to a small group of raw materials. Lastly, an overview of the other KPIs that can be found on the Power BI report developed during the diagnosis stage is presented in section 5.4, as well as its potentialities for a future adoption by the company, independent of the DSS itself.

5.1 Decision Support System

In order to improve raw materials' service levels, while taking into account demand and supply uncertainty, the creation of a DSS that analyses the trade-offs between inventory-related costs and achieved service levels, considering the separate and joint use of safety stocks and safety time buffers was proposed to the company and tested for the ten materials under study in section 4.5.

As detailed in Figure 25, this DSS starts by treating supply and MRP-related data collected from the company's information systems and turning it into useful information regarding the evolution of demand and supply KPIs, as well as other indicators related to the manufacturing process itself. This process is, in fact, designed to be quite similar to the one presented in sections 4.4.1 and 4.5.1 to 4.5.3, although the strategy of combining ME3L and MB51 transactions must be revised by the company before being put into practice.

The reports resulting from this process correspond to the ones already shown in sections 4.4.2 and 4.5.5, as well as new ones that will be presented in section 5.4, displaying information about, for example, (i) the unmet demand ratio, (ii) the average variation rates of materials' needs, (iii) the amount of missing material, in comparison with the total amount of ordered material, (iv) the risk of supply delay and (v) the average number of extra days it takes to close 'ResOrd'.

The second stage of the DSS encompasses the determination of parameters that are crucial to the simulation of new inventory management policies, including the estimate of safety stock and safety time buffers. During this phase, the system can base its calculations on each material's historical demand and supply behaviour (available due to the data treatment and cleansing stage) or it can use inputs provided by the user themselves.

Afterwards, the DSS is meant to study a series of new approaches to raw materials inventory management and compare their performance to inventory-related costs and service levels achieved by the policies currently in place (Simulation stage). Nevertheless, before definitively choosing new inventory management policies, these preliminary results must be subject to a sensitivity analysis to assess their consistency. Consequently, it makes sense for the user to have the power to adjust parameters that directly influence the performance of the inventory management policies under study, since, this way, they can evaluate the impact of small variations to the original test conditions on the preferable policies.

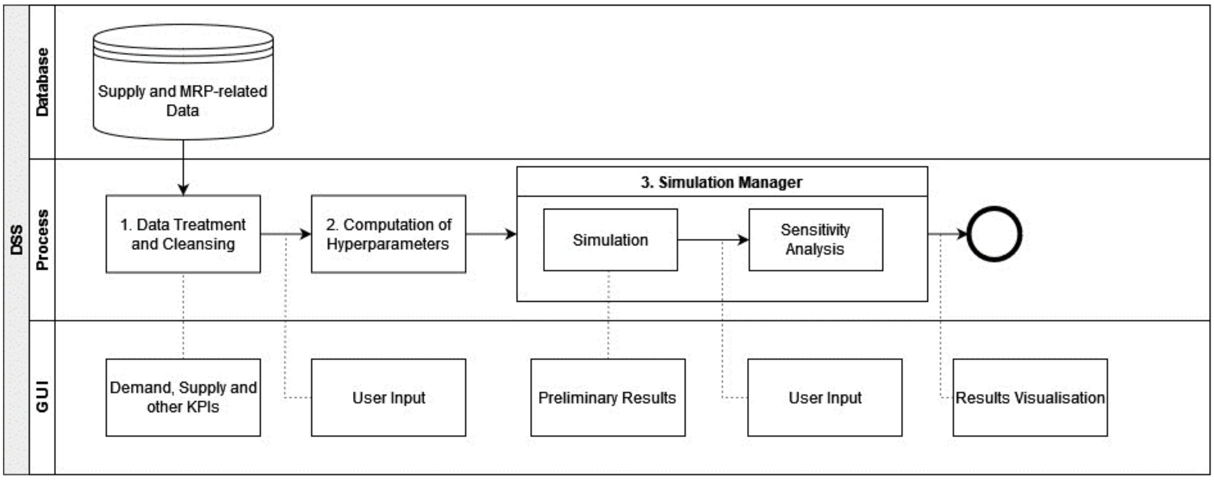


Figure 25: Proposed DSS

To assess how such a DSS would work, a test version was developed, in this dissertation, considering historical demand and supply uncertainty data for the computation of hyperparameters stage and for comparing the performance of the current status and new approaches scenarios shown in Figure 26. Current status scenarios include one version that considers the probability of each supplier not complying with the ordered quantity. This scenario was created to allow a direct comparison between inventory management policies' performance when considering compliance or not.

When it comes to the new approaches scenarios, these determine the expected weekly average demand and its deviation for each material based on two different methods – the use of theoretical normal distributions that best fitted each material's total demand, and the estimate of a seasonal variation rate that affected the expected demand values. These two main approaches were assessed in parallel, meaning all scenarios evaluated under one method were also assessed using the other, and the performance of all inventory management policies derived from them were compared to the performance of the policies currently in place.

The calculation of safety time buffers relied on each supplier's historical delay risk and the average number of extra days they needed to deliver the material, so that a probability function returning the most adequate safety time value to a certain and customisable significance level was built.

Since all the materials subject to this analysis were categorised as A-type items in the company's ABC analysis and periodic-review systems (R, s, S) are known to more efficiently reduce replenishment and shortage costs, while ensuring material availability, the undertaken simulations considered all new approaches scenarios to follow this inventory management policy. This means that for every R units of time, the inventory position is checked and, if it is below the reorder point s, material is ordered up to level S.

R, s and S parameters were estimated based on inventory management costs C1, C2 and C3 – holding, stock out and ordering costs, respectively –, as well as on the expected average demand per period and its deviation. However, the theoretical expressions used in these calculations rely on the assumption that demand is normality distributed over time, which required that, first and foremost, normality had to be ensured.

In both theoretical normal distribution and seasonal variation rate approaches, the hypothesis of keeping the company's current review period of one week was assessed in contrast to the adoption of a new review period R, all the while considering the possibility of suppliers not complying with the ordered quantity.

Additionally, all these scenarios were tested for the separate and joint adoptions of safety stock and safety time buffers, considering target service levels of 95% and 99%. This translated into the simulation and assessment of 28 different scenarios, 26 of which regarding new inventory management policies.

Nonetheless, testing different scenarios and comparing their results is only possible if they relate to the same data. Consequently, all possibilities were tested for the same period of time – from the first week of November 2022 (week 44 of 2022), until mid-March 2023 (the last week included in the dataset, week 11 of 2023). This means that, for each material, its simulations reproduced the system's performance over the course of 20 weeks, a reasonable timeframe, considering that it allowed for all of them to virtually place and receive orders to and from their suppliers multiple times.

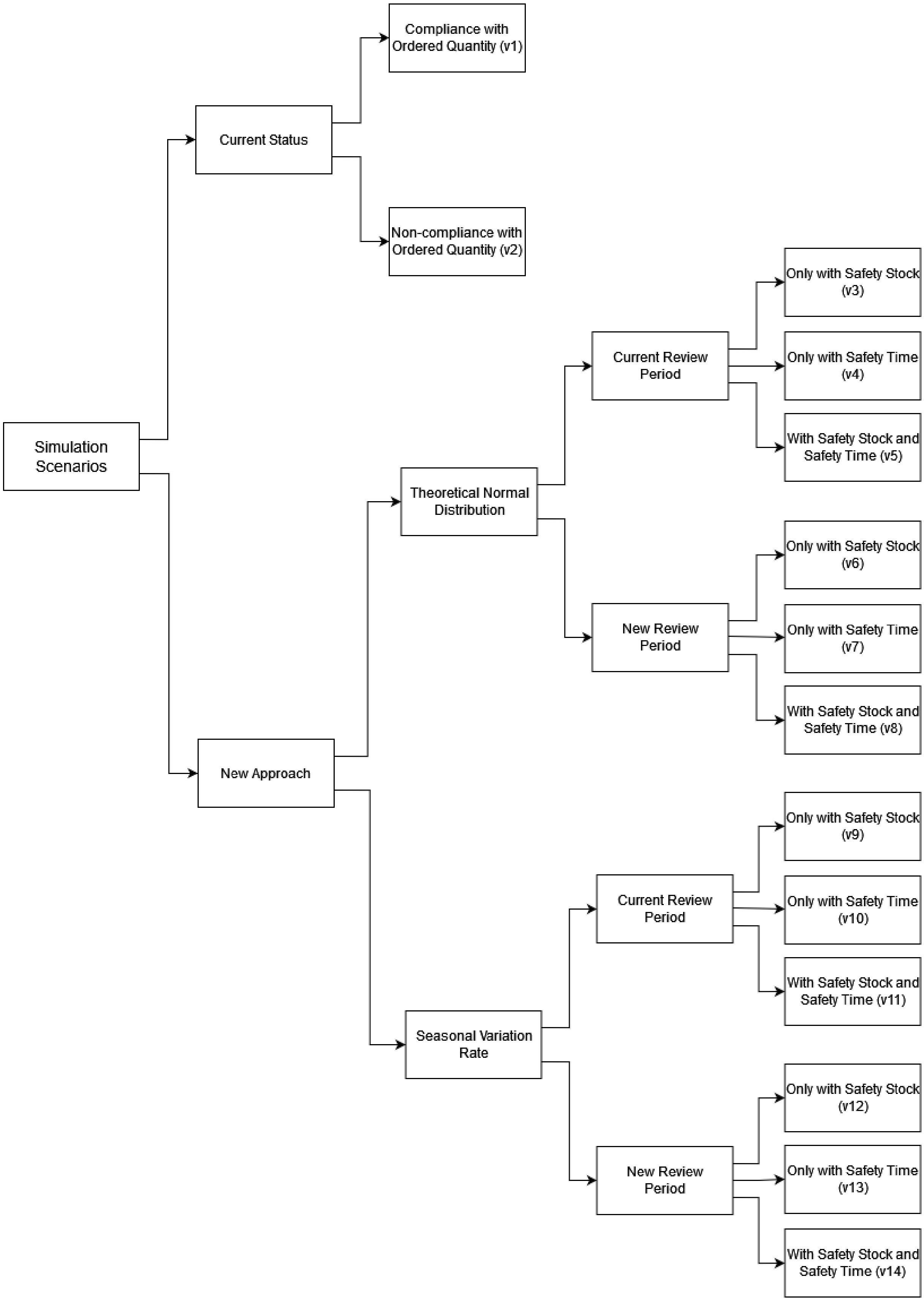


Figure 26: Simulation Scenarios

5.2 Computation of Hyperparameters

5.2.1 Raw Materials' Estimated Weekly and Monthly Demand

By adding **Real Table**'s variables 'ResOrd_i', 'ResOrd_i1' and 'NecDep_i1', it is possible to obtain an estimate of production's raw material demand during each week. However, this is bound to be an overestimate of the real demand, since production orders are not immediately closed after their completion and the company's production capacity does not always meet total customer demand.

As a result, in order to obtain a more adequate approximation of raw materials' real weekly demand, the production orders that remain in the system from one week to the other must be disregarded. Because the amount of material associated with these orders is held on **Real Table**'s variable **'ResOrd.Transitadas'**, each raw material's historical weekly demand (**'ProcuraSemanalReal'**) was calculated based on Equation (8):

$$ProcuraSemanalReal_{[j]} = ResOrd_{i_{[j]}} + ResOrd_{i1_{[j]}} + NecDep_{i1_{[j]}} - ResOrd.Transitadas_{[j-1]} \quad (8)$$

This transformation led to the creation of a new dataset, comprising these five variables, as well as each material's reference code and the year's week number corresponding to each entry, as shown in Table 13. Appendix XII details the R code used to achieve the final weekly demand dataset. Note that, for each material's first recorded week, the value of $ResOrd.Transitadas_{[j-1]}$ is unknown and, consequently, 'ProcuraSemanalReal' could not be determined, which implied that those weeks could not be included in the analysis.

Table 13: Sample of the Raw Materials' Weekly Demand Dataset

Material	Semana	ResOrd.Ser	ResOrd.Tra	ResOrd.No	NecDep.Se	ProcuraSemanalRe
101I0000001443	202002	951,252	4,26	0	0	0
101I0000001443	202003	2634,771	149,149	0,512	0	2631,023
101I0000001443	202004	1689,719	54,278	0	0	1540,57
101I0000001443	202005	2102,802	51,29	0	107,28	2155,804
101I0000001443	202006	2243,015	34,755	0	11,948	2203,673
101I0000001443	202007	1103,553	0	0	31,106	1099,904
101I0000001443	202008	2986,043	134,975	0	3,62	2989,663
101I0000001443	202009	1294,222	100,528	0	0	1159,247
101I0000001443	202010	1867,965	221,834	0	0	1767,437
101I0000001443	202011	2405,474	310,514	0	0	2183,64
101I0000001443	202012	3221,252	312,934	0	0	2910,738
101I0000001443	202013	4060,458	1998,542	0	5596,955	9344,479
101I0000001443	202014	2009,986	2009,986	0	2420,632	2432,076
101I0000001443	202015	2009,986	2009,986	0	4,539	4,539
101I0000001443	202016	2009,986	2009,986	0	0,905	0,905
101I0000001443	202017	2009,986	2009,986	0	2,115	2,115

Nevertheless, because seasonality analysis and normality tests were to be conducted on raw materials' demand records, this weekly demand was grouped by month. To this purpose, an auxiliary dataset, matching the year's week numbers and the calendar months, was used. This table had been created during the diagnosis stage in order to allow time evolution analysis in the Power BI report, and it assigns a month to a week number, based on each Thursday's date. Thursday was chosen as reference point, since it represents 4/7 of the week. This logic allowed to correspond each year's week number to only one calendar month and, consequently, to transform the raw materials' weekly demand dataset into a monthly demand dataset, as illustrated in Table 14.

Table 14: Sample of the Raw Materials' Monthly Demand Dataset

Material	Mês	Ano	ProcuraRealMens
101I0000001443	jan	2020	6327,397
101I0000001443	fev	2020	7452,487
101I0000001443	mar	2020	16206,294
101I0000001443	abr	2020	2439,635
101I0000001443	mai	2020	3708,231
101I0000001443	jun	2020	6581,254
101I0000001443	jul	2020	10318,709
101I0000001443	ago	2020	9172,997
101I0000001443	set	2020	12252,051
101I0000001443	out	2020	12584,054
101I0000001443	nov	2020	12460,138
101I0000001443	dez	2020	5366,82
101I0000001443	jan	2021	11851,338
101I0000001443	fev	2021	7179,282
101I0000001443	mar	2021	5770,345
101I0000001443	abr	2021	10410,198
101I0000001443	mai	2021	6048,017
101I0000001443	jun	2021	10516,426
101I0000001443	jul	2021	8324,068

The codes used to create both the auxiliary week-month dataset and the raw materials' monthly demand dataset are presented in Appendixes XIII and XIV, respectively.

5.2.2 Time Series Plots and Demand Seasonality Analysis

After creating the raw materials' monthly demand dataset, it was possible to obtain the time series plots shown in Figure 27.

A quick look into these results revealed that some of these materials (all belonging to Textile and Vinyl groups) have very few observations, which is explained by the fact that they are associated to new projects, whose production only started last year. Moreover, these raw materials were the only ones clearly showing a positive trend over time, which is consistent with the increase of production volume assigned to projects that require textile and vinyl materials.

Furthermore, this preliminary analysis did not allow to identify any seasonal patterns in the demand of materials with a larger number of observations. Consequently, as presented in Figure 28, polar seasonal and seasonal subseries plots were generated for raw materials with, at least, two full years of observations

– materials '101I0000001443', '101I0000001509', '101I0000001565', '104I0000000003', hereafter named materials A, B, C and D, respectively – in an attempt to complete this analysis and, if that were the case, to confirm these early findings.

Indeed, although in this second analysis each material revealed its own monthly demand fluctuations, seasonal patterns were not unmistakably identified, which led to the conclusion that raw materials belonging to projects in production for several years do not have any particular trend or seasonal patterns. The R code that allowed for this analysis is detailed in Appendix XV.

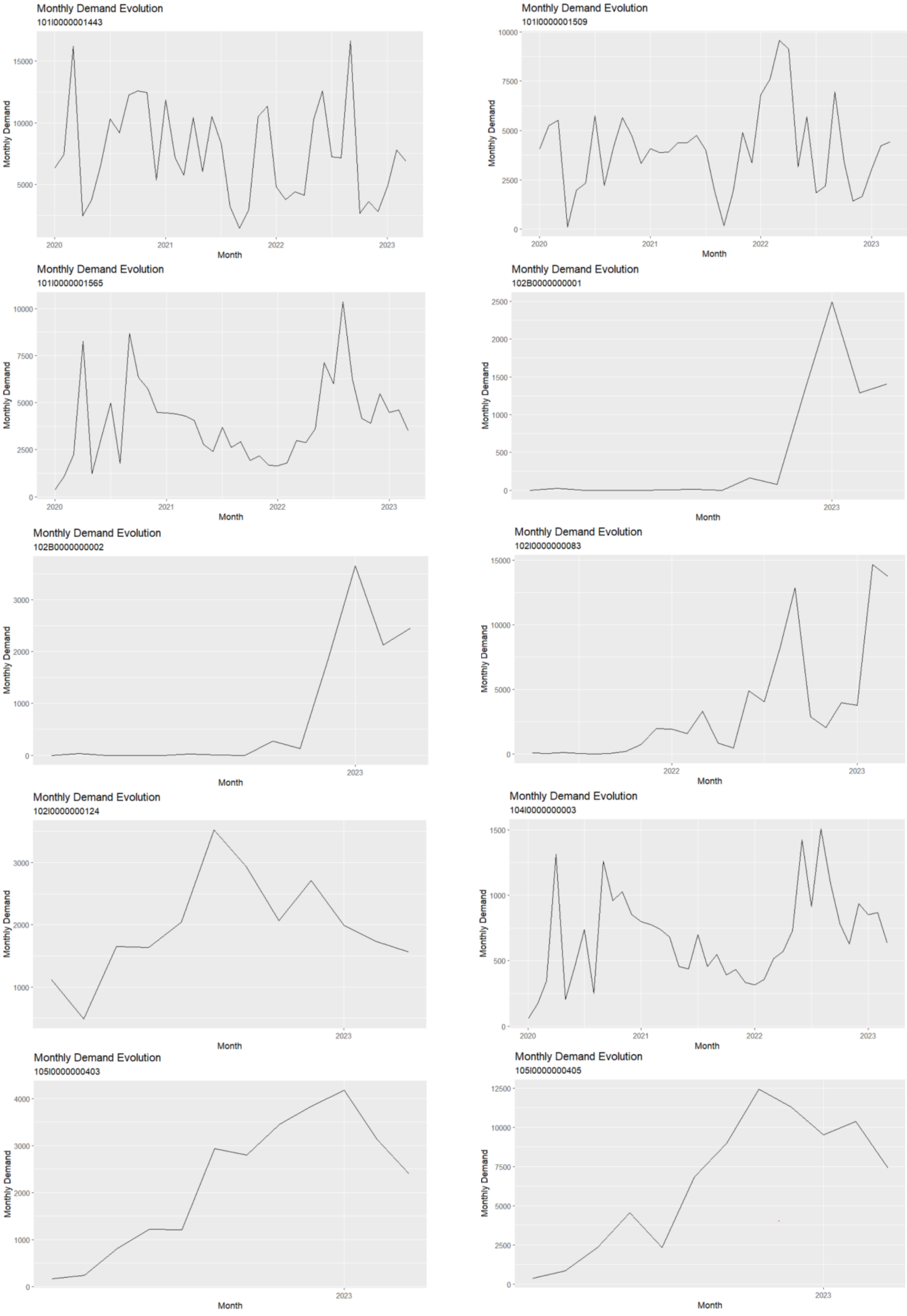


Figure 27: Raw Materials' Demand - Time Series Plots

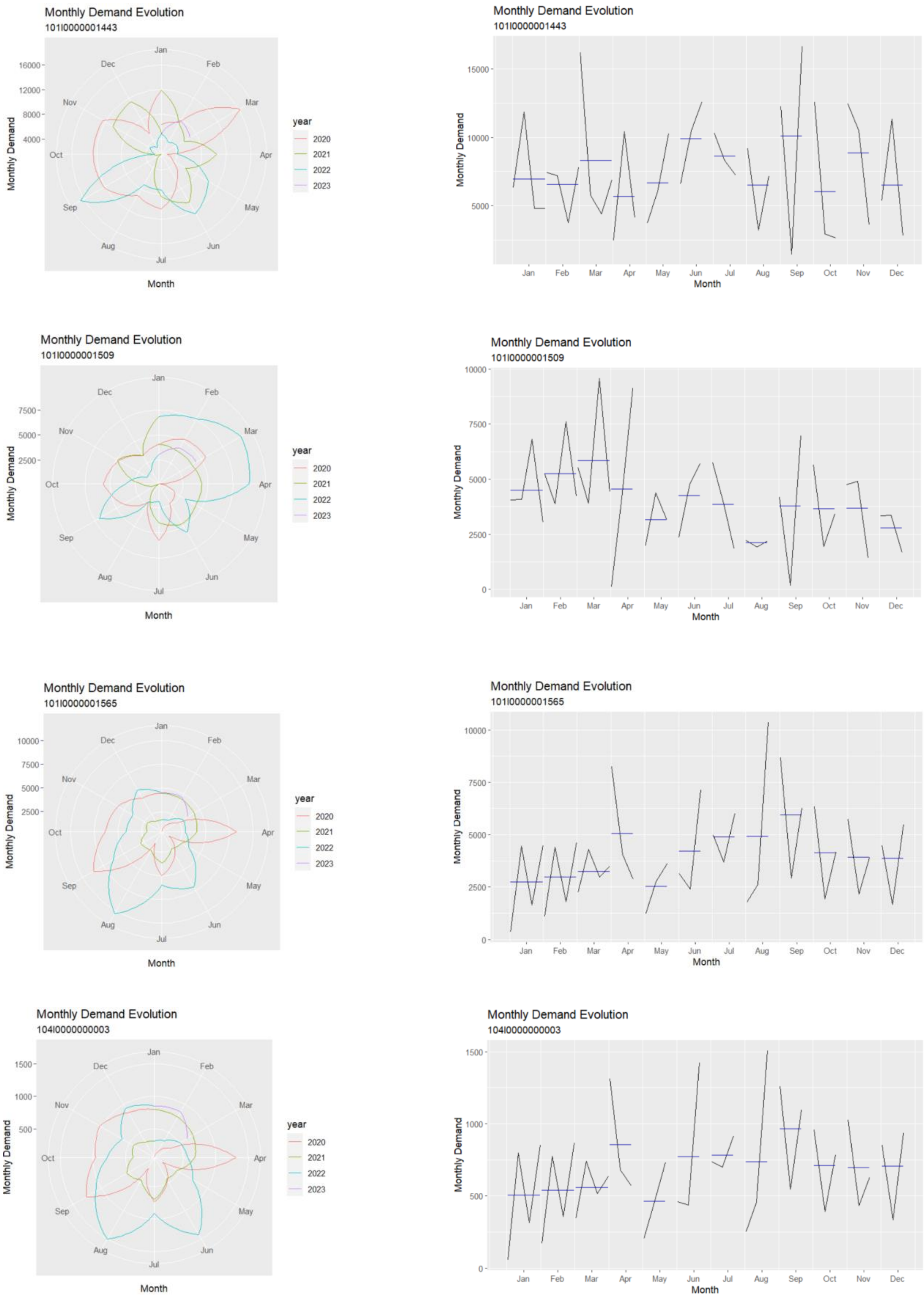


Figure 28: Raw Materials' Demand - Polar Seasonal (Left) and Seasonal Subseries (Right) Plots

5.2.3 Theoretical Normal Distributions

In order to evaluate if demand is normally distributed for any of the ten raw materials under study, statistical and graphical tests were conducted, as shown in Appendix XVI. Their results narrowed the scope of the inventory management simulations to four out of the ten original raw materials – A, B, C and D (three leather items and one textile material) – the ones for which demand could be considered as normally distributed.

Bearing this in mind, it was time to reflect on strategies that allowed a demand estimate during planning period (the period of time encompassing the supplier lead time and the inventory revision period). In periodic-review systems (R, s, S), this estimate is crucial, since the determination of parameters R, s and S also relies on the expected demand values during that time.

Consequently, and as previously mentioned in the beginning of chapter 5, two strategies were put in place to calculate the expected weekly average demand and its deviation for each material – the use of theoretical normal distributions that best fitted each material's demand data, and the estimate of a seasonal variation rate that affected the expected demand values. For the remainder of this section, the former method will be the sole focus of discussion.

At this stage, one could argue that the theoretical distributions reached while assessing demand normality could very well be used to this purpose. Notwithstanding, this constitutes an oversimplification of the problem, since information about the simulation period, which, in reality under normal circumstances, would not have been available to decision-makers, would then be used to define safety buffers during that same period of time.

In a real world scenario, if one intended to establish inventory management policies that would be put in place from November 2022 onwards, then one could only take into account the demand data available at the beginning of that month. Thus, if one now intends to simulate what would have happened to inventory levels during that period, then one should disregard all demand information known after November 2022, otherwise it would lead to better approximations than the ones that would have been obtained in reality and, therefore, the achieved simulations' results would be biased.

Hence, *fitdist* function was again used, in a similar fashion to the one detailed in Appendix XVI, to find the theoretical normal distribution that best fitted demand data, this time excluding the last five months of observations (November 2022 to March 2023). Figures 29 to 32 show the graphical comparison between the empirical and the obtained theoretical values, while Table 15 summarises the average and standard deviation values of each normal distribution proposed by the *fitdist* function.

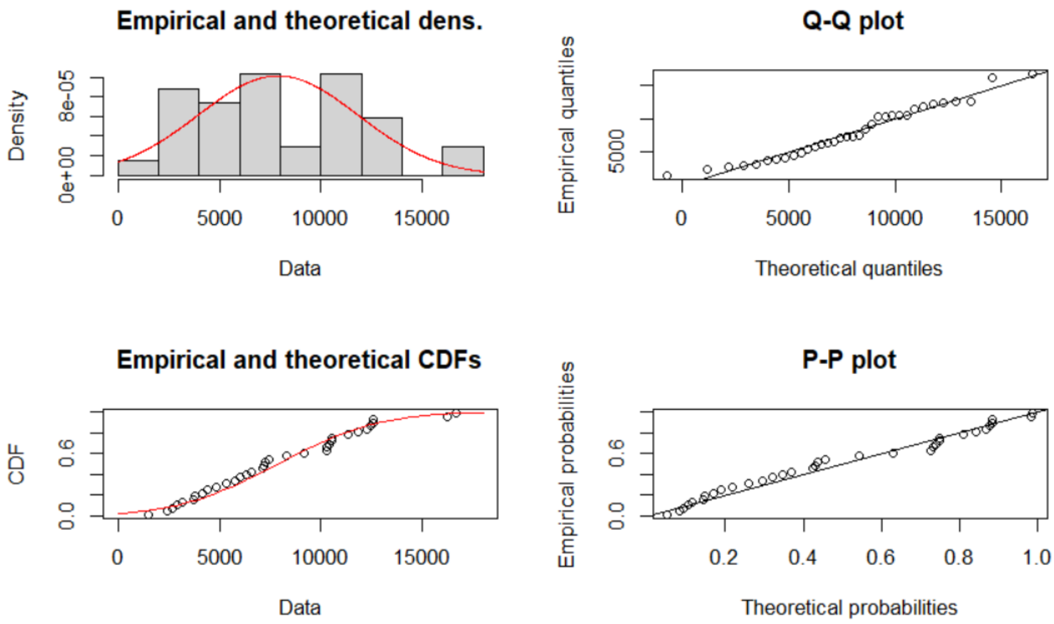


Figure 29: Theoretical Normal Distribution Results for Simulation – Material '101I0000001443' (material A)

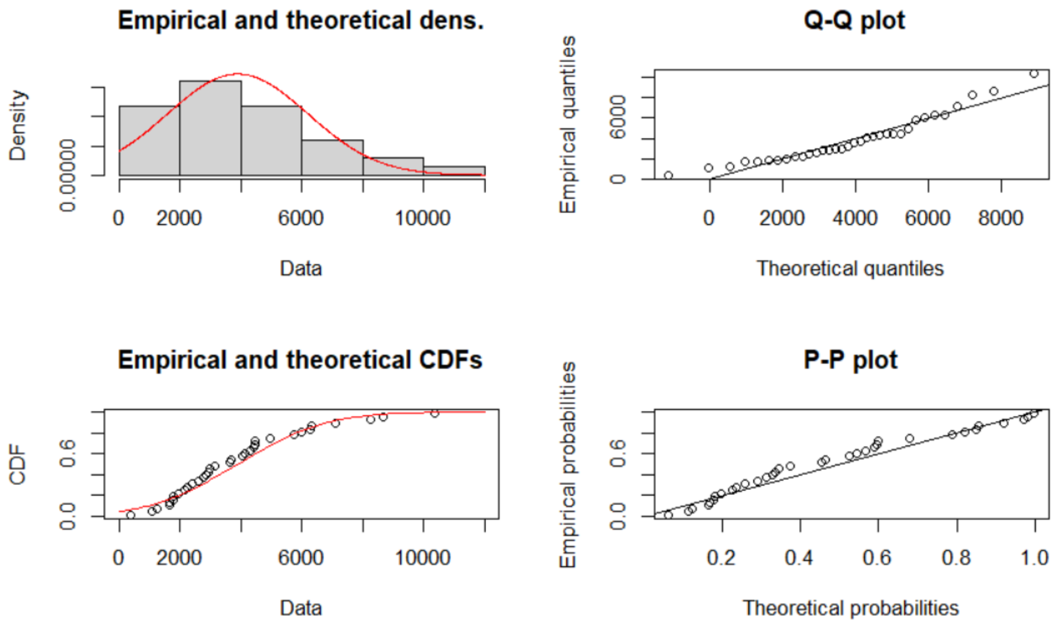


Figure 30: Theoretical Normal Distribution Results for Simulation – Material '101I0000001565' (material C)

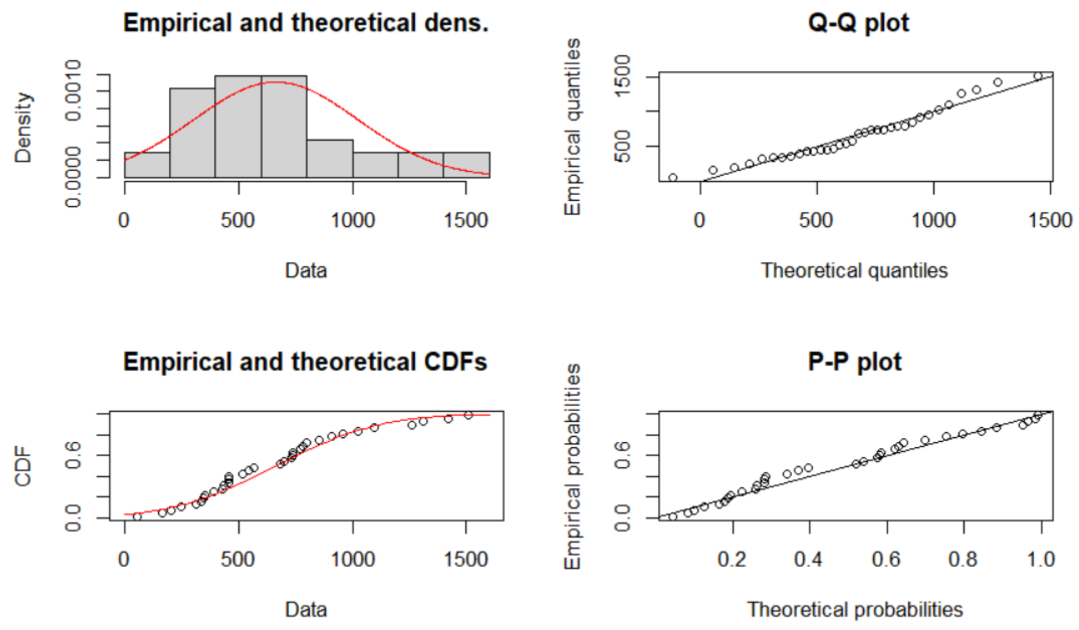


Figure 31: Theoretical Normal Distribution Results for Simulation – Material '104I0000000003' (material D)

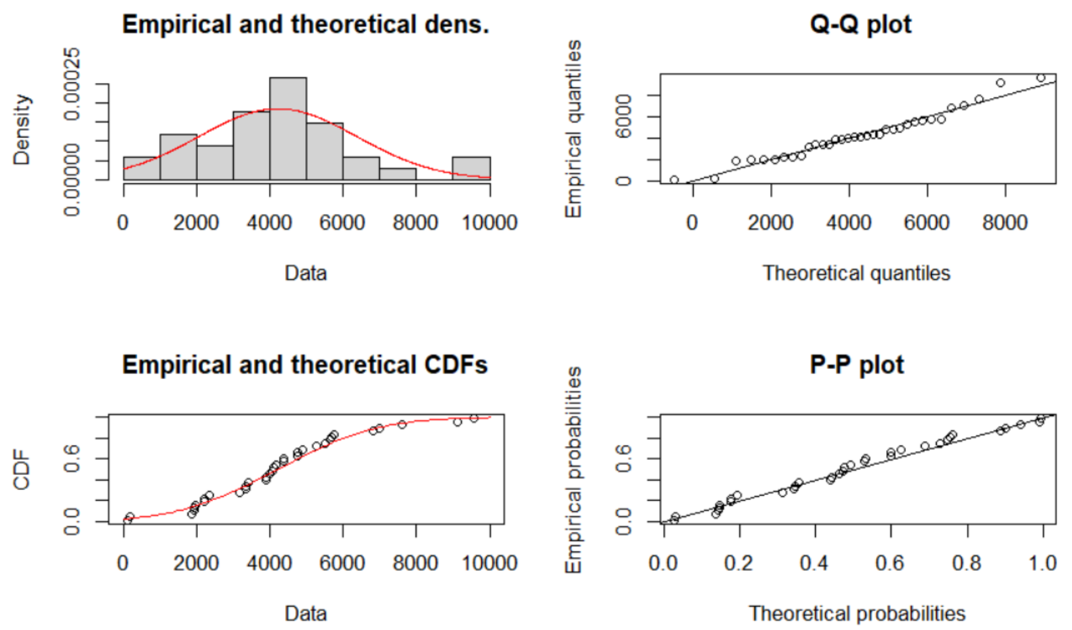


Figure 32: Theoretical Normal Distribution Results for Simulation – Material '101I0000001509' (material B)

Table 15: Theoretical Normal Distributions – Average and Standard Deviation (Monthly Values)

Material	Distribution	MonthlyAverage	Std.Deviation	Unit of Measurement
101I0000001443	Normal	7886,31	3934,33	M2
101I0000001565	Normal	3897,07	2302,16	M2
104I0000000003	Normal	664,21	359,58	M
101I0000001509	Normal	4213,80	2158,49	M2

However, the attained theoretical normal distributions are approximations of each material's monthly demand values. In order to obtain the corresponding weekly demand estimates, the average and standard deviation values presented in Figure 44 were transformed following Equations (9) and (10):

$$Weekly\ Average\ Demand = \frac{Monthly\ Average\ Demand}{n} \tag{9}$$

$$Weekly\ Standard\ Deviation = \frac{Monthly\ Standard\ Deviation}{\sqrt{n}} \tag{10}$$

In this analysis, each month was considered to have four weeks ($n = 4$), so the weekly average demand and standard deviation of each raw material under study equalled the values shown in Table 16. These results were the ones used to determine demand and standard deviation during the planning period, as explained in greater detail in section 5.2.6.

Table 16: Theoretical Normal Distributions – Average and Standard Deviation (Weekly Values)

Material	Distribution	WeeklyAverage	Weekly.Std.Deviation	Unit of Measurement
101I0000001443	Normal	1971,58	1967,17	M2
101I0000001565	Normal	974,27	1151,08	M2
104I0000000003	Normal	166,05	179,79	M
101I0000001509	Normal	1053,45	1079,25	M2

5.2.4 Real Variation Rate of Materials' Needs – Seasonality Analysis

In section 4.4.2, the variation rate of materials' needs allowed for the comparison between the production volume recorded by the MRP only at the end of week i+1 and the production volume expected at the start of that very same week. However, although this performance indicator is extremely helpful in understanding short term variations in the production volume, it relates directly to production and not to material demand itself, which, in previous sections, has already been made clear not to be quite the same thing.

Thus, in order to understand if there are any particular times of the year in which materials' demand is more likely to suffer bigger short-term variations, Equation (2), regarding the variation rate of materials' needs, was properly adjusted to exclude the production orders that remain in the system from one week to the other ('ResOrd.Transitadas'), as shown in Equation (11):

$$Real\ Variation\ Rate\ of\ Materials'Needs_{[j]} = \frac{(ResOrd_{i1_{[j]}} + NecDep_{i1_{[j]}})}{(ResOrd_{i_{[j]}} - \mathrm{ResOrd.Transitadas}_{[j-1]})} \tag{11}$$

Note that this new indicator was calculated based on information retrieved from the **Real Table**, where data is displayed by week. To get an estimate of each material's real variation rate by month, the weekly variation rate was aggregated, using its average value and the date assumptions described in section 5.2.1.

Afterwards, a preliminary analysis, similar to the one conducted in section 5.2.2, was performed on the monthly variation dataset. As it is detailed in Appendix XVII, big outliers on the dataset influenced the proper visualisation of the time series, so the logarithmic function was used to reduce the scale of the data and provide a better understanding of this indicator's dynamics.

The new graphics obtained after this transformation allowed to characterise the real variation rate of materials' needs as rather irregular, since its values seemed to constantly increase and decrease over time. Nevertheless, for all materials under study, no particular tendency was found in this indicator's behaviour, as seasonal patterns were also quite hard to distinguish.

As a result, polar seasonal and seasonal subseries plots were, once again, generated, in order to get a clearer picture of possible seasonality trends. However, as it was the case with the regular time series plots, these graphics were also incredibly affected by the scale of the original data, so the logarithmic transformation was also applied in this analysis, which, then, allowed to obtain the results shown in Figure 33.

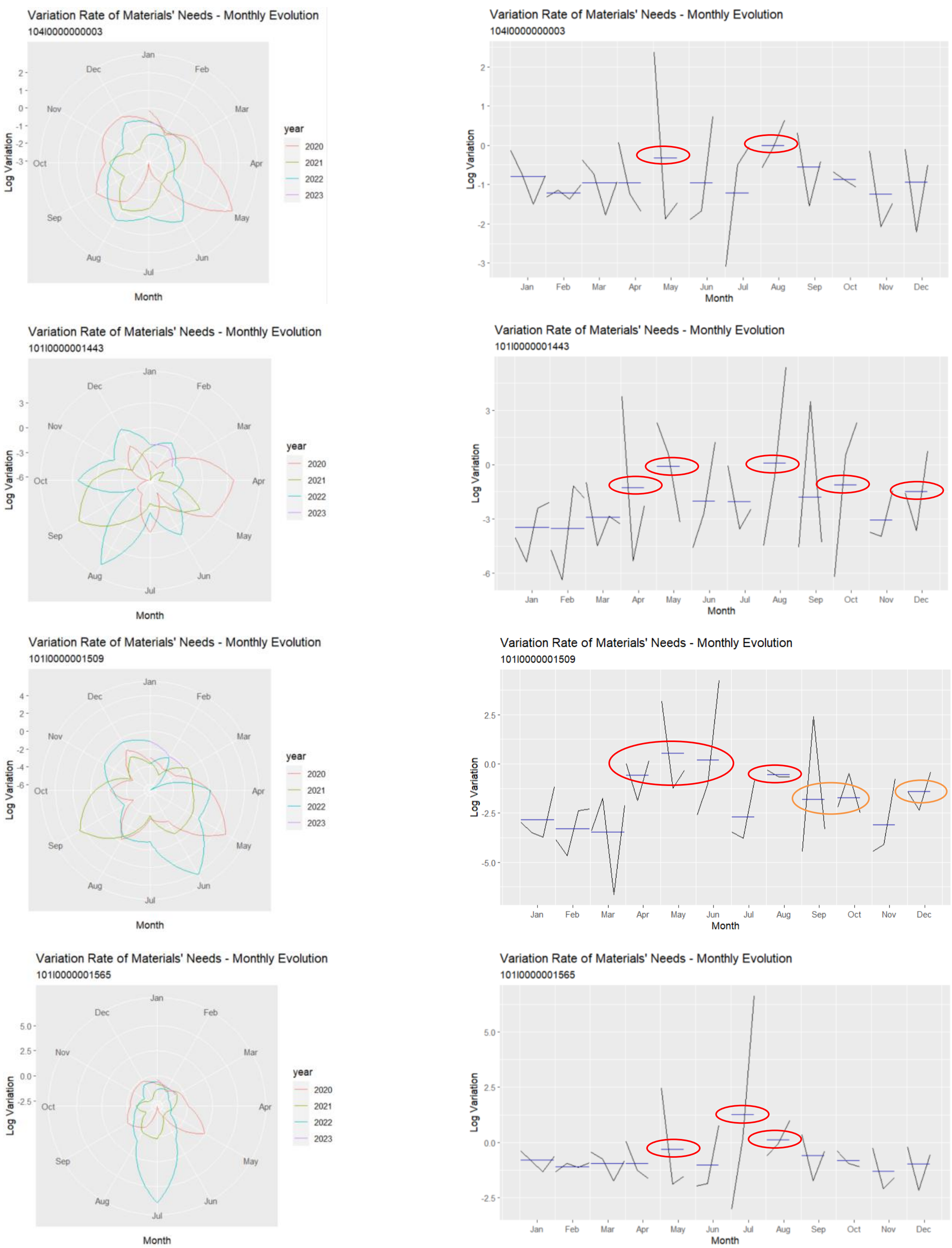


Figure 33: Real Variation Rate of Materials' Needs - Polar Seasonal (left) and Seasonal Subseries (right) Plots

If, on the one hand, reducing the scale of the real variation rate helped the visualisation of struggles caused by the impact of outliers, on the other, it also made it harder to identify possible seasonal patterns, now that the data got concentrated around the same values and that the months with outliers will always set themselves slightly apart from the rest. Nonetheless, keeping in mind that the ultimate goal of this analysis was to identify months with similar dynamics, so that more accurate monthly variation rates could be later estimated, the results obtained in the subseries plot were grouped as also illustrated in Figure 33. Note that these subgroups mainly relate to summer months and to the end of the year, which is aligned with the time periods that the company, its suppliers and customers may hold production, introducing, therefore, more uncertainty in the system.

The average value of the real variation rate of each material's needs was, then, calculated based on this group division and resulted in the rates presented in Table 17. It is noteworthy, though, that the "selection 1" value of material C and the "rest of the year selection" value of material A were calculated by excluding two major outliers – the values of July 2022 and September 2021, respectively. The average variation values in green correspond to the estimates that were used to determine the expected demand during the simulation period.

Table 17: Estimate of the Average Variation Rates for Each Material

Material	Average Variation Rate: Selection 1	Average Variation Rate: Selection 2	Average Variation Rate: Rest of the Year
104I0000000003	241,30%		52,93%
101I0000001443	2034,54%		28,78%
101I0000001509	829,64%	155,17%	6,74%
101I0000001565	219,72%		52,65%

As explained in section 5.2.3, weekly demand and standard deviation values during the simulation period needed to be determined, without including any information from November 2022 onwards. To that purpose, in that section, preceding demand values were employed to estimate a theoretical demand distribution, from which derived the needed average and standard deviation values.

In sharp contrast, the method that will be described in this chapter intended to estimate the EDI information at the start of the simulation period (an estimate of confirmed orders at the beginning of November 2022) by adjusting this demand value with the help of the corresponding average variation rate. Thus, weekly confirmed production orders at the beginning of the simulation period were considered to be approximately given by Equation (12):

$$Weekly\ Production\ Orders = ProcuraSemanalReal - (\ ResOrd_{i1} + NecDep_{i1}) \quad (12)$$

These needs were, then, multiplied by the variation rate corresponding to their year's week number, obtaining, as a result, the estimated demand for each material's 20-week simulation. After calculating these results, each material's weekly average demand for the entire simulation period was calculated and the respective average values were compared to the estimated weekly demand, so that the weekly standard deviation for that period could be determined. Table 18 illustrates these calculations for material B, while Table 19 encompasses average demand and standard deviation results for each raw material.

Table 18: Example of Weekly Demand and Standard Deviation Rate by Variation Rate Method

Material	Week	Month	Year	Estimated Weekly Production Orders	Estimated Monthly Variation Rate	Estimated Weekly Demand	Estimated Weekly Average Demand	Dif	Dif^2	Weekly Standard Deviation
101I0000001509	202244	nov	2022	299,85	6,74%	320,05		-444,18	197300,30	
101I0000001509	202245	nov	2022	339,41	6,74%	362,28		-401,95	161564,57	
101I0000001509	202246	nov	2022	19,66	6,74%	20,98		-743,25	552424,61	
101I0000001509	202247	nov	2022	337,46	6,74%	360,20		-404,03	163242,13	
101I0000001509	202248	dez	2022	612,01	155,17%	1561,64		797,41	635856,70	
101I0000001509	202249	dez	2022	135,28	155,17%	345,19		-419,05	175601,09	
101I0000001509	202250	dez	2022	507,30	155,17%	1294,46		530,22	281135,00	
101I0000001509	202251	dez	2022	0,00	155,17%	0,00		-764,23	584053,89	
101I0000001509	202252	dez	2022	0,00	155,17%	0,00		-764,23	584053,89	
101I0000001509	202301	jan	2023	491,43	6,74%	524,54	764,23	-239,69	57452,93	542,90
101I0000001509	202302	jan	2023	429,06	6,74%	457,97		-306,27	93798,74	
101I0000001509	202303	jan	2023	526,40	6,74%	561,87		-202,36	40951,18	
101I0000001509	202304	jan	2023	1032,04	6,74%	1101,58		337,34	113798,99	
101I0000001509	202305	fev	2023	622,04	6,74%	663,95		-100,29	10057,13	
101I0000001509	202306	fev	2023	1039,25	6,74%	1109,28		345,04	119054,12	
101I0000001509	202307	fev	2023	872,95	6,74%	931,77		167,54	28067,98	
101I0000001509	202308	fev	2023	1373,51	6,74%	1466,06		701,83	492558,65	
101I0000001509	202309	mar	2023	1248,19	6,74%	1332,29		568,06	322690,05	
101I0000001509	202310	mar	2023	1150,77	6,74%	1228,30		464,07	215360,83	
101I0000001509	202311	mar	2023	1538,61	6,74%	1642,28		878,05	770965,18	

Table 19: Seasonal Variation Rate - Average and Standard Deviation (Weekly Values)

Material	WeeklyAverage	Weekly.Std.Deviation	Unit of Measurement
104I0000000003	208,54	78,73	M
101I0000001443	3230,59	5302,44	M1
101I0000001509	764,23	542,90	M2
101I0000001565	1160,58	453,09	M2

Table 19 results were the ones used to determine demand and standard deviation during the planning period in seasonal variation rate scenarios, as detailed in section 5.2.6.

5.2.5 Holding (C1), Stock Out (C2) and Ordering (C3) Costs

Classic inventory management policies, such as the case of periodic-review systems (R, s, S), rely on inventory management costs to determine the key parameters of their policies. These costs typically fall under three categories, commonly referred to as C1, C2 and C3 costs - holding, stock out and ordering costs, respectively.

Inventory holding costs (C1 costs) are associated with the cost of keeping stock of raw materials over time. In theory, it is calculated based on each material's unitary value multiplied by an internal interest rate estimated by companies.

On the other hand, stock out costs (C2 costs) relate to the costs incurred in case there is not enough material in inventory to meet customer demand. C2 costs work as opportunity costs, since not having enough stock on hand of a certain material, prevents companies from producing and selling its dependent end-items to customers. If unmet orders can be fulfilled over time, then these costs are calculated until the moment demand is completely met, otherwise companies face a lost sales situation and, in that case, opportunity costs only occur at the time of the stock out.

The expenses companies have when ordering raw materials to suppliers are accounted for in the ordering costs (C3 costs), ranging from the overheads of inventory placement to document preparation and release tasks. It is noteworthy that C3 costs must be represented by order and not by each material's unit of measurement.

However, although, in theory, it seems quite simple to distinguish C1, C2 and C3 costs, as well as the operational expenses that can be included in each of these categories, in practice, distinguishing and quantifying such operational costs is everything but a straightforward task. Consequently, most companies, including COINDU, do not keep track of them, which implies that, in order to put in practice classic inventory management policies, C1, C2 and C3 costs had to be, primarily, estimated.

Regarding the projection of each materials' C1 costs by unit of measurement, COINDU did not have any estimate of the internal interest rate for keeping stock of raw materials. Nonetheless, a few years ago, the company tried to determine warehousing costs and, at that time, they used an allocation base to assign global overheads. Thus, this allocation base was now used as an approximation of the internal interest rate for holding material in stock and, consequently, to calculate C1 costs. This rate equalled 14,75% of each material's value per year, which is equivalent to 0,28% of their value per week, considering a year with 52 weeks. After reaching this number, the weekly interest rate was multiplied by the contract value of each material (the price established with the supplier), allowing for the determination of each material's weekly C1 costs by unit of measurement.

The contract value used in the holding costs estimate, was also considered to be the stock out cost by each material's unit of measurement over time, since, at COINDU, raw materials' stock outs lead to order backlog and not to lost sales situations.

Lastly, calculating the C3 costs associated with each material's orders proved to be quite a challenge as well. Although MM60 transaction holds each material's total value considering its price and inbound costs, deriving the latter from this transaction's values by comparing them to the price established with the supplier, only returned an inbound estimate per each material's unit of measurement and not by order. Because the theoretical expressions that relate C3 costs with the $\underline{R}$ and $\underline{S}$ parameters used in periodic-review systems ($\underline{R}$, $\underline{s}$, $\underline{S}$) consider this cost per order, an approximation to C3 values was reached by multiplying the calculated inbound costs with each material's MOQ, though, in reality, orders made to the supplier are very likely to be superior to this amount.

The final holding, stock out and ordering costs that resulted from these considerations are displayed in Table 20.

Table 20: Holding, Stock Out and Ordering Costs Estimates

Material	Internal Interest Rate	Contract Value (€/unit measurment)	MM60 Value (€/unit measurment)	Inbound (€/unit measurment)	MOQ	C1 (€/unit measurment)	C2 (€/unit measurment)	C3 (€/order)
101I0000001565	0,28%	39,75 €	40,34 €	0,59 €	500,00	0,11 €	39,75 €	296,14 €
104I0000000003	0,28%	53,12 €	54,33 €	1,21 €	60,00	0,15 €	53,12 €	72,35 €
101I0000001509	0,28%	41,28 €	41,80 €	0,52 €	1500,00	0,12 €	41,28 €	786,38 €
101I0000001443	0,28%	39,53 €	40,11 €	0,58 €	500,00	0,11 €	39,53 €	290,55 €

5.2.6 Periodic-review System (R, s, S) – Parameter Estimation

In order to determine R, s and S parameters, demand and standard deviation during planning period, C1, C2 and C3 costs, as well as the target service level must be taken into consideration. Although most of these input values differ depending on the scenario under simulation (with the exception of holding, stock out and ordering costs), the logic behind estimating the three parameters remains the same, regardless of the situation. Therefore, in this section, the calculation of R, s and S values will only be explained for one scenario in particular, knowing that, for all others, the same principles apply. The chosen scenario for this purpose is the one in which demand and standard deviation were estimated based on theoretical normal distributions, the target service level is 95% and the revision period R is to be determined.

Demand and standard deviation during planning period are the cornerstones of safety stock and reorder point estimates, hence the calculation of these two values was prioritised. As explained in section 5.2.3, demand and standard deviation can be transformed using Equations (9) and (10). Nevertheless, in this case, the n value is given by the sum of supplier lead time with the revision period to be adopted. As a result, before calculating each material's demand and standard deviation during the planning period, the revision period, R, was determined, following Equation (13), in which r represents each material's weekly demand:

$$Revision\ Period\ (R) = \sqrt{\frac{2*C3}{C1*r}} \tag{13}$$

For the scenarios in which the company's revision period of one week was adopted, this step did not apply, meaning that demand and standard deviation values were immediately calculated. The results obtained for the scenario under study are summarised in Table 21.

Table 21: Demand and Standard Deviation During Planning Period

Material	Unit of Measurement	Weekly Average Demand	Weekly Standard Deviation	Supplier Lead Time	New Revision Period, R (in weeks)	Expected Demand During Planning Period	Standard Deviation During Planning Period
101I0000001565	M2	974,27	1151,08	4	2	5706,43	2785,79
104I0000000003	M	166,05	179,79	8	2	1660,52	568,54
101I0000001509	M2	1053,45	1079,25	8	4	12641,40	3738,62
101I0000001443	M2	1971,58	1967,17	7	2	17744,19	5901,50

After reaching these values, safety stock was, finally, appraised. Since supply uncertainty was considered to be accounted for by the application of the safety times detailed in section 5.2.7, the simplified safety stock formula, only including demand uncertainty (Equation 14), was applied:

$$Safety\ Stock = Z * \sigma_{DDPP} \tag{14}$$

Where Z represents the z-value for the normal distribution and σ_{DDPP} stands for the standard deviation during planning period. Because the z-value depends on the target service level to be ensured by the buffer, z equals 1,645 for the target service level of 95%, whereas it increases to 2,327 when the target service level of 99% is expected.

Following the safety stock calculation, the reorder point, s, is given by its sum with the demand during planning period, as detailed in Equation (15):

$$Reorder\ Point = \mu_{DDPP} + Z * \sigma_{DDPP} \tag{15}$$

Where μ_{DDPP} is the demand during planning period.

Lastly, the order up to level point, S, was calculated based on Equation (16):

$$Order\ Up\ to\ Level\ Point = \sqrt{\frac{2*r*C3}{C1}} + s - \frac{r*R}{2} \tag{16}$$

All these calculations allowed to obtain the R, s, and S parameters, to apply in each scenario that considers the use of safety stock as, at least, one of the safety buffers. For the scenario exemplified in this section, its final results are illustrated in Table 22:

Table 22: Reorder and Order Up to Level Points

Material	Safety Stock	Reorder Point, s	Order Up to Level, S	Unit of Measurement
101I0000001565	4582,63	10290	11578	M2
104I0000000003	935,25	2596	2830	M
101I0000001509	6150,03	18792	20447	M2
101I0000001443	9707,96	27453	28678	M2

5.2.7 Supply Uncertainty

The adoption of safety time buffers instead of and in combination with safety stocks was also subject to analysis. To that purpose, information about supply delays was used to build a probability function that would return the most adequate safety time value to a certain significance level, customised by the decision-maker.

Bearing this in mind, the ME3L and MB51 combined dataset was used to get information about the average number of days it takes for materials to arrive after their scheduled date and the probability of that happening. These values were collected by month and together allowed to build a new record of the expected delay each month, in days, per material.

Nonetheless, this new dataset had a strong presence of null values, making it harder to fit a distribution to the original data. To solve this problem, two actions were taken. The first consisted in relaxing the principle that a delivery should only be considered to be late if it happened at least a week after the one it was initially scheduled to, which allowed for delays of, for instance, one or two days to also be included in the analysis. Secondly, instead of considering the expected delay itself as the target variable for the fitting model, each supplier's lead time in days was added to this value, giving way to the average lead time expected by month and, consequently, to a new dataset without the presence of null entries, as shown in Table 23.

Table 23: Sample of the New Dataset with the Expected Average Lead Time by Month

Material	Year	Month	Average Delay (days)	Probability of Late Delivery	Expected Monthly Delay (days)	Supplier Lead Time (days)	Expected Total Lead Time (days)
101I0000001565	2020	set	0,0	0,00	0,00	27	27,00
101I0000001565	2020	out	0,0	0,00	0,00	27	27,00
101I0000001565	2020	nov	0,0	0,00	0,00	27	27,00
101I0000001565	2020	dez	3,5	1,00	3,50	27	30,50
101I0000001565	2021	jan	0,0	0,00	0,00	27	27,00
101I0000001565	2021	fev	0,0	0,00	0,00	27	27,00
101I0000001565	2021	mar	0,0	0,00	0,00	27	27,00
101I0000001565	2021	abr	0,0	0,00	0,00	27	27,00
101I0000001565	2021	mai	0,0	0,00	0,00	27	27,00
101I0000001565	2021	jun	3,0	0,40	1,20	27	28,20
101I0000001565	2021	jul	1,0	0,20	0,20	27	27,20
101I0000001565	2021	ago	0,0	0,00	0,00	27	27,00
101I0000001565	2021	set	0,0	0,00	0,00	27	27,00
101I0000001565	2021	out	0,0	0,00	0,00	27	27,00
101I0000001565	2021	nov	1,0	0,25	0,25	27	27,25
101I0000001565	2021	dez	1,0	0,50	0,50	27	27,50
101I0000001565	2022	jan	0,0	0,00	0,00	27	27,00
101I0000001565	2022	fev	0,0	0,00	0,00	27	27,00
101I0000001565	2022	mar	4,0	0,25	1,00	27	28,00
101I0000001565	2022	abr	1,0	0,50	0,50	27	27,50
101I0000001565	2022	mai	4,0	0,40	1,60	27	28,60
101I0000001565	2022	jun	8,0	0,33	2,67	27	29,67
101I0000001565	2022	jul	0,0	0,00	0,00	27	27,00

Assuming that, for each material, the expected supplier lead time could be represented by a normal distribution, *fitdist* function was used to calculate which average and standard deviation values best fitted the data. These results combined with the decision-maker's desired significance level were used as inputs in R's *qnorm* function, in order to obtain the estimated supplier lead time that should be considered when ordering each raw material. For simulation purposes, the desired significance level was set to 95% or 99%, depending on the scenarios under study.

Appendix XVIII details the code used to implement this solution, while Tables 24 and 25 present the outputs obtained for each material under study. Note that the difference between the estimated supplier lead time and the lead time used today by the company equals the safety time value in days. However, since, for all simulations, time will be measured in weeks, this safety time value was properly converted to its corresponding number of weeks. In order to assess safety time as a means of protection against uncertainty, scenarios with safety time equal to and different from zero needed to be considered for all materials, so this conversion was always done by excess.

Table 24: Safety Time Values for each Material – Target Service Level of 95%

Material	Original.LT	SignificanceLevel	Estimated.LT.Days	Estimated.LT.Weeks	ST.Days	ST.Weeks
101I0000001565	27	0,95	32,58	5	5,58	1
101I0000001443	49	0,95	50,65	8	1,65	1
104I0000000003	56	0,95	69,90	10	13,90	2
101I0000001509	56	0,95	59,19	9	3,19	1

Table 25: Safety Time Values for each Material – Target Service Level of 99%

Material	Original.LT	SignificanceLevel	Estimated.LT.Days	Estimated.LT.Weeks	ST.Days	ST.Weeks
101I0000001565	27	0,99	34,25	5	7,25	2
101I0000001443	49	0,99	51,20	8	2,20	1
104I0000000003	56	0,99	76,26	11	20,26	3
101I0000001509	56	0,99	60,18	9	4,18	1

5.3 Simulation Manager

5.3.1 Simulation Stage

Simulating all scenarios presented in Figure 26 entailed the creation of three separate algorithms, referring to – (i) the current status of the system, without considering the probability of suppliers not complying with the requested amount of material; (ii) the current status, now considering that same supply uncertainty, and, lastly, (iii) the new simulation approaches.

To test each scenario, all algorithms required the use of two different datasets – one summarising key information about each material (**data**) and another specifying material demand and scheduled deliveries, during each of the twenty weeks of simulation (**data2**). The main variables included in the first dataset were:

- **'Material':** The company's reference code for each material;
- **'lead_time_semanas':** The supplier lead time, in weeks, currently used by the company;
- **'moq':** Each material's minimum order quantity;
- **'Inbound':** Each material's inbound costs;
- **'n':** Each material's revision period (R);
- **'initial_stock':** Each material's stock on hand at the start of the simulation period;

- **'initial_lotesQm':** The amount of material expected to be approved by quality inspection during the first week of simulation, hence becoming available for production in the course of that week;
- **'reorder_point':** Each material's reorder point (s). For scenarios that did not include the use of safety stock as a means of protection against supply uncertainty, it solely equalled demand during planning period;
- **'order_up_to_level':** Each material's order up to level point (S);
- **'order_multiple':** If the amount of material requested to the supplier must be a multiple of a certain quantity, then this variable would equal that value. If not, 'order_multiple' equalled -1;
- **'C1':** Each material's holding cost per week and per unit of measurement;
- **'C2':** Each material's stock out cost per week and per unit of measurement;
- **'C3':** Each material's ordering cost per order;
- **'Classe':** The result of the company's ABC analysis. In this case, equalled type A for all four materials;
- **'Percent.QtdQuebra_Fornec':** The probability of each material's suppliers not complying with the requested amount of material per order. It was calculated with the Power BI report used for the system's performance analysis;
- **'ST':** Each material's estimated safety time buffer.

Depending on the scenario under study, variables **'n'**, **'reorder_point'**, **'order_up_to_level'** and **'ST'** assumed different values.
On the other hand, **data2** included the variables:

- **'Material':** The company's reference code for each material;
- **'Semana':** Each entry's corresponding simulation week;
- **'ProcuraSemanalReal':** Each material's estimated weekly demand, as seen in section 5.1.1;
- **'Chegada.Material':** Each material's deliveries scheduled during simulation period. These correspond to the orders made by the raw materials planners, based on current inventory management policies.
- **ResOrd:** The confirmed customer orders at the start of each week. This value is considered to be known during the entire simulation period.

In this section, only two out of the three created algorithms will be described in greater detail, since both of the current status simulators are quite similar to each other. Notwithstanding, all algorithms follow a similar structure that can be divided into four main sections – (i) variable and table creation; (ii) determining initial and final stocks in week 202244 for each material; (iii) simulating stock evolution during the other nineteen weeks and (iv) calculating performance measurements.

Focusing on variable and table creation, this included the establishment of two fundamental tables – **tabelaPrint** that stores information about the simulation itself, as well as crucial variables to the calculation of performance measurements; and **dataCustos**, responsible for summarising the results obtained in each scenario.

In addition to holding the aforementioned **data2** variables, **tabelaPrint** also had information about:

- **'Chegada.Material.Real':** The amount of material expected to be delivered by the supplier, considering the probability of them not complying with the ordered quantity. This variable was not included in the V1 Current Status algorithm;
- **'StockInicial':** The amount of material in stock at the start of each week;
- **'StockFinal':** The estimated amount of material in stock at the end of each week;
- **'StockFinal_Antecipado':** The virtual amount of material in stock, considering future confirmed orders (**data2**'s **'ResOrd'**). It equals 'StockFinal' in case safety time is set as zero, otherwise it adds the needs during the safety time period to 'StockFinal' value. This variable is not included in either of the current status algorithms;
- **'QuantEnc':** The amount of material to be ordered at each inventory review point. Another variable not applicable in the current status algorithms;
- **'StockTransito':** The amount of material ordered from the supplier and with pending delivery;
- **'StockTotal':** The sum of variables **'StockFinal'** and **'StockTransito'**;
- **'Quebras':** In case of stock outs, it represents the amount of material missing from inventory. It accumulates stock outs from one week to another, if past shortages were not fulfilled;
- **'QuebrasReais':** In case of stock outs, it represents the amount of material missing from inventory each week. It does not consider old stock outs that have not yet been replenished;
- **'StockMedio':** The average amount of material in stock during each week, considering **'StockInicial'** and **'StockFinal'** values;
- **'C1semanal':** Holding costs per week and material;
- '**C2':** Stock out costs per week and material, considering variable **'Quebras'**;
- **'C3':** Ordering costs per week and material;
- **'CustoGestaoStocks':** Total inventory management costs per material after the twenty weeks of the simulation;
- **'NivelServico':** Achieved service level per material after the twenty weeks of the simulation.

On the other hand, all variables found in **dataCustos** compiled information about holding, stock out, ordering and total costs achieved in the course of the simulation's twenty weeks, as well as service level results and the average values of variables 'StockMedio', 'StockTransito', 'StockTotal', 'Quebras' and 'QuebrasReais' by material.

Figure 34 outlines the fundamental operations performed in each section of the V2 Current Status algorithm, the one that accounts for supplier non-compliance with ordered quantities.

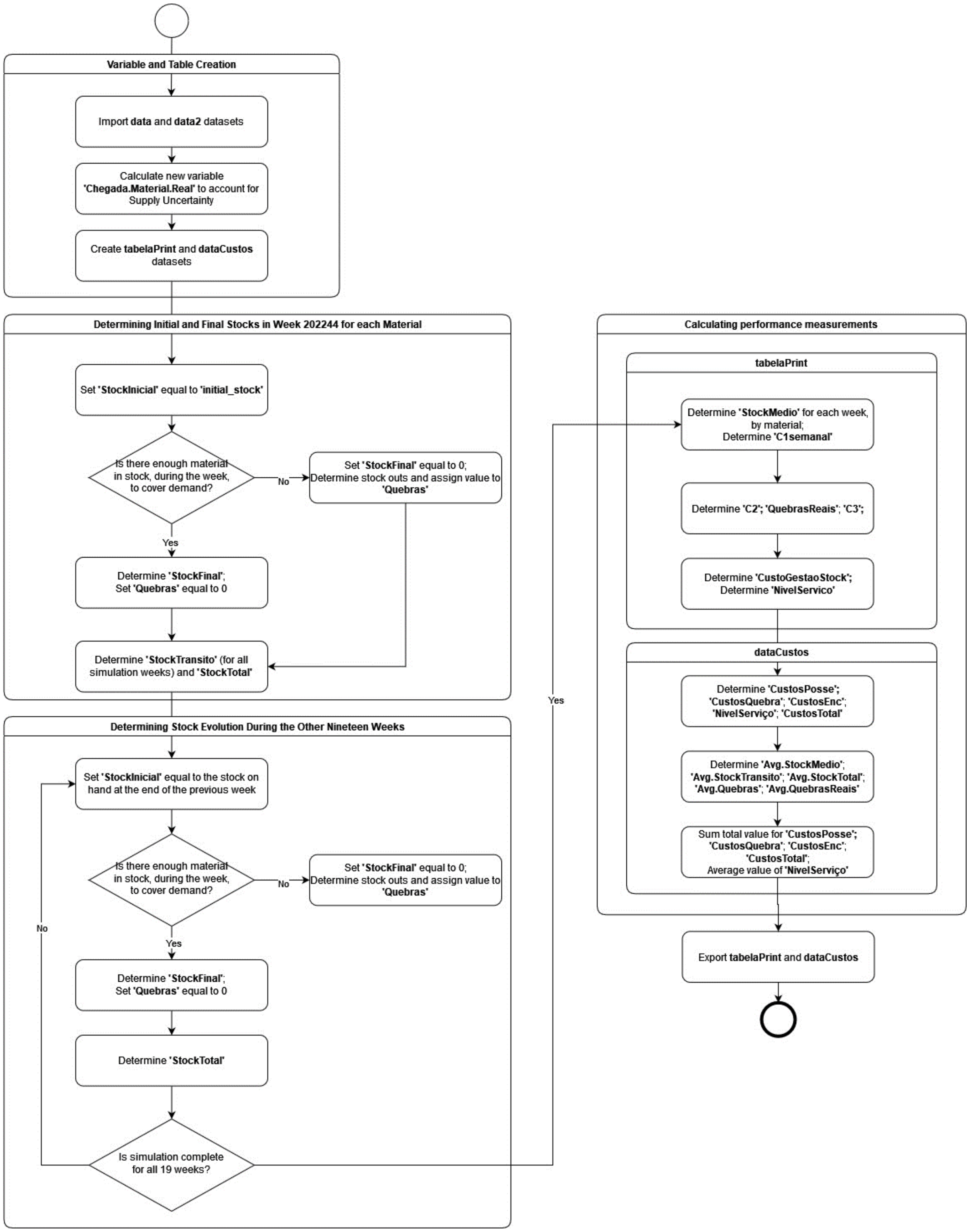


Figure 34: Current Status Algorithm

As shown in the diagram of Figure 34, while creating the **tabelaPrint** and **dataCustos** tables, variable **'Chegada.Material.Real'** is calculated based on Equation (17).

$$Chegada.Material.Real = Chegada.Material * (1 - Percent.QtdQuebra\_Fornec) \quad (17)$$

It is only after this stage that the simulation of what would have happened during week 202244 gets under way for all materials. Note that week 202244 is processed separately from the others, since, for the first week of simulation, determining initial and final stocks, as well as stock outs does not rely in past values obtained during the simulation itself. Instead, **'StockInicial'** has its value held in **data**'s **'initial_stock'**, while **'StockFinal'** is obtained using Equation (18), which includes the amount of material in inventory at the start of the first week of simulation, all the material expected to arrive and each material's real needs during that week.

$$StockFinal = StockInicial + Chegada.Material.Real + lotesQm - ProcuraSemanalReal \quad (18)$$

However, if **'ProcuraSemanalReal'** is superior to the amount of material available, **'StockFinal'** equals zero and Equation (18) returns the amount of material missing in inventory to fulfil demand (its absolute value is presented in variable **'Quebras'**).

During the other nineteen weeks of simulation, **'StockInicial'** equals **'StockFinal'** value in the previous entry (a week ends and the other starts with the same amount of material in inventory), while, in the absence of stock outs, **'StockFinal'** is given by Equation (19), this time also considering possible material stock outs:

$$StockFinal_{[j]} = StockFinal_{[j]} + StockInicial_{[j]} + Chegada.Material.Real_{[j]} - \\ - ProcuraSemanalReal_{[j]} - Quebras_{[j-1]} \quad (19)$$

Similarly, variable **'Quebras'** is calculated resorting to Equation (20):

$$Quebras_{[j]} = abs(StockInicial_{[j]} + Chegada.Material.Real_{[j]} - \\ - ProcuraSemanalReal_{[j]}) + Quebras_{[j-1]} \quad (20)$$

The performance measurements used to compare all scenarios rely on **tabelaPrint**'s variables, as well as holding, stock out and inbound costs kept on table **data**. As a result, **'C1semanal'** was obtained by multiplying **'C1'** cost by the average stock on hand during each week (**'StockMedio'**); '**C2'** cost was calculated by multiplying stock out cost by each week's **'Quebras'**; while **'C3'** was determined by multiplying each material's **'Inbound'** costs by the estimated amount of delivered material (**'Chegada.Material.Real'**).

In regard to service level (**'NivelServico'**) determination, it relates to the new amount of material missing from stock each week (**'QuebrasReais'**) and each material's total demand during the simulation period, as shown in Equation (21):

$$NivelServico = \frac{(1 - \sum_{j=1}^{20} QuebrasReais_j)}{\sum_{j=1}^{20} ProcuraSemanalReal_j)} \quad (21)$$

It is noteworthy, though, that should the amount of material in inventory not be enough to cover its needs during week 202244, variable **'QuebrasReais'** will equal the value of variable **'Quebras'**, otherwise, if, during the other nineteen weeks of simulation, the amount of material missing from stock increases between consecutive weeks, the value of **'QuebrasReais'** is given by that variation.

Appendix XIX details the V2 Current Status algorithm created in R. Although V1 Current Status algorithm is not shown, the only difference that would be found in comparison to the V2 version would relate to the use of variable **'Chegada.Material'**, instead of **'Chegada.Material.Real'**, when calculating the stock evolution over the simulation period.

Having understood the way current status algorithms operate, it is quite clear that the logic behind them was rather simple, since the algorithms themselves did not have to make any supply decisions – those had already been made by the raw materials planners. The role of these simulators was, therefore, to calculate the values of each variable, based on the recorded data, in order to obtain the performance results achieved by the inventory management policies currently in place.

On the contrary, the algorithm that simulated the new periodic-review (R, s, S) policies, was much more complex, since it had to calculate stock evolution and performance measurements, as well as to make decisions about when and how much material should be requested to the supplier, as illustrated in Figure 35.

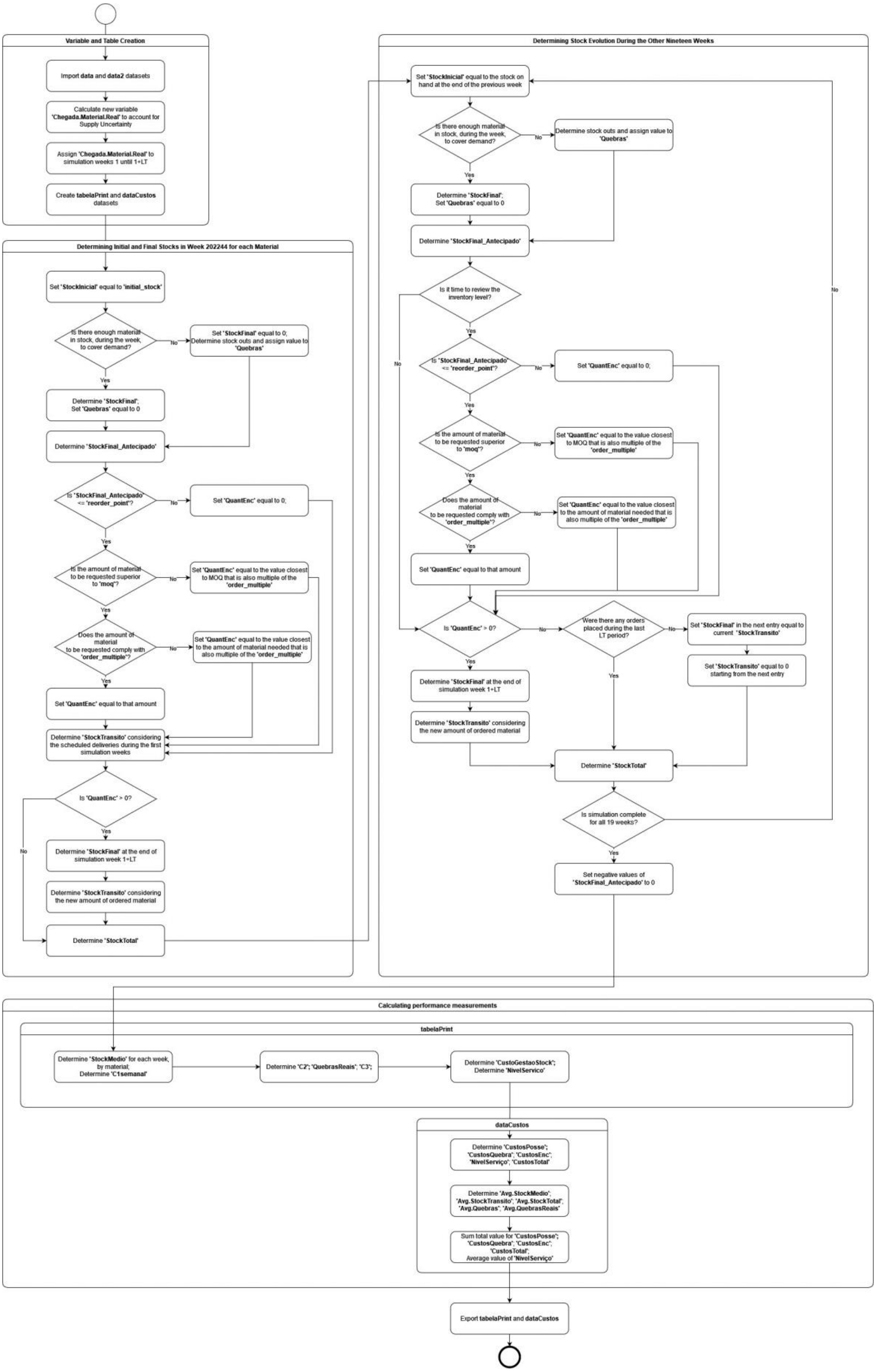


Figure 35: Algorithm used in all New Approaches

Focusing on the variable and table creation stage, it is noticeable that the real values of **'Chegada.Material.Real'** are assigned to each material's first weeks of simulation, while, for the rest of the time, this variable is set to zero. This has everything to do with the way the transition between old and new inventory management policies was approached by the simulation algorithm.

Regardless of the scenario, all materials have their inventory levels reviewed in the first week of simulation (week 202244). In case a material has its inventory level below its reorder point, then a certain amount is ordered (**'QuantEnc'**), considering its availability in stock, possible stock outs and its order up to level point. Nonetheless, an order placed in the first week of simulation will only be added to stock (**'StockFinal'**) at the end of week 1+LT and, consequently, is only considered to be available for production (**'StockInicial'**) at the start of week 1+LT+1. This means it is solely after this point that the new inventory management policies truly start to impact the system's performance.

As a result, it was assumed that between each material's week 1 and week 1+LT of the simulation, its scheduled deliveries, requested following current inventory management policies, would still apply. From that moment on, however, **'Chegada.Material.Real'** is set to zero, so that these historical deliveries do not mix with the estimated amounts of delivered material, following the new inventory management approaches.

On the other hand, during the second stage of the algorithm, the main difference found in contrast with the current status simulator lies in the fact that the new approaches simulator must decide whether or not to order material from the supplier and validate a series of conditions in order to do so.

Although **'StockInicial'** and **'StockFinal'** are calculated similarly to what was previously described for the current status algorithm, the decision to order more material from the supplier is made using variable **'StockFinal_Antecipado'**, which considers each week's estimated **'StockFinal'** and the confirmed customer orders ('**ResOrd'**) included in the safety time window. In other words, if a material being reviewed in week 202244 has a safety time of two weeks, then **'StockFinal_Antecipado'** at the end of week one of simulation will be equal to the difference between the corresponding **'StockFinal'** value and the amount of material already known to be ordered by the customer for the second and third weeks of simulation. Should the scenario under assessment not include the use of safety time as a means of protection against uncertainty, then **'StockFinal_Antecipado'** will naturally assume the same value as **'StockFinal**'.

After determining variable **'StockFinal_Antecipado'**, its value is compared to the reorder point and, if it is below this level, material must be ordered from the supplier (**'QuantEnc'**), considering the order up to level point and the impact of possible stock outs (**'Quebras'**). Moreover, strategies were put in place to ensure that **'QuantEnc'** complied with both MOQ and order multiples, before settling it as the amount of material ordered from the supplier.

In case an order is placed, the value of **'StockFinal'** for week 1+LT gets automatically updated, since it is already known that, by the end of that week, the amount of requested material, considering **'Percent.QtdQuebra_Fornec'** will be delivered and added to stock. Nevertheless, while it is not delivered, **'QuantEnc'** will remain as **'StockTransito'** between weeks 2 and 1+LT-1, the latter being the moment after which the amount delivered in week 1+LT will no longer be included in this category.

Moving on to the determination of stock evolution during the other nineteen weeks, it starts by setting **'StockInicial'** equal to the **'StockFinal'** value of the previous entry and estimating all variables following the logic presented for the first week of simulation. Nonetheless, inventory levels will only be reviewed considering each material's predetermined revision period **'n'**, meaning that if a material has, for instance, a revision period of two weeks, the first inventory review after week 202244 will only happen in the third week of simulation, regardless of the inventory levels presented in week number two.

Additionally, it is also important to highlight that, during this simulation stage, if no new orders are placed following a consecutive number of weeks equal to each material's lead time, then, after the last scheduled delivery is fulfilled, **'StockTransito'** holds the amount of material that has not been supplied yet, because of the uncertainty introduced by variable **'Percent.QtdQuebra_Fornec'**. In these circumstances, this amount of material is included in the **'StockFinal'** value of the subsequent week, while being disregarded from **'StockTransito'**.

Finally, the last simulation stage of this second algorithm does not present any changes from what can be found in the current status simulators, hence implying that all performance measures were calculated based on the logic previously described for the simpler V1 and V2 scenarios. Appendix XX details the R code used to create the algorithm that allows for the simulation of all new approaches' scenarios.

5.3.2 Preliminary Results

Tables 26 to 29 show the simulation results obtained for each material under study. A preliminary analysis to this data allows to verify that for all materials, with the exception of material '101I0000001443', the service levels achieved by any of the new approaches scenarios were considerably superior to the theoretical ones estimated by current status algorithms V1 and V2.

Taking a closer look to these results individually, for material '101I0000001509', all new scenarios were capable of ensuring a service level of 100%, which translated into going from an average stock out of 339,98 square metres per week, in the current status V2 scenario, to fulfilling total material demand every week, during the simulation period. This, of course, happened at the expense of an increase in the amount of material kept in stock and, consequently, in the amount of material ordered from the supplier. As it can be seen in Table 26 the new approaches scenarios with less average stock of material on hand ensured an average inventory level of 7.257,91 square metres per week, almost ten times more than the values obtained in the current policies scenarios.

Regarding the calculated total costs, it is noteworthy that, no matter the material under study, these only allowed for an overall assessment of the average amount of material kept on hand, its possible stock outs and orders placed to the supplier, since, by nature, they combine its holding, stock out and ordering costs. Consequently, under no circumstances, do each material's total costs represent the real costs associated with the implementation of any of the simulated policies, working only as a means of comparison across scenarios.

Bearing this in mind, in the case of material '101I0000001509', two scenarios can be considered to have achieved top performance, since they managed to guarantee the maximum service level, while incurring the least theoretical inventory management costs – V13 and V25.

Both V13 and V25 scenarios correspond to the seasonal variation rate approach, using a new inventory review period and safety time as the safety buffer of choice, differing only in their target service levels (95% and 99%, respectively). This equal performance between scenarios relates to the fact that, for both target service levels under study, the safety time values returned by its estimate algorithm were identical (Tables 24 and 25), which translated into V13 and V25 scenarios representing the same inventory management policy.

If one decides to analyse the top five scenarios with the best service level and total costs performance, it is also clear that the best results were achieved by always considering the new inventory level review period of four weeks, instead of the current weekly review in place. This is explained by the fact that reviewing the inventory levels every week, following a (R, s, S) policy, would only lead to an increase of orders placed to the supplier and, consequently, an increase in the amount of material held in stock, without that translating into any service level gains.

Additionally, most of these top scenarios referred to seasonal variation rate approaches - the only two scenarios with top performance associated with the use of theoretical normal distributions relate to the use of safety time for both 95% and 99% service levels (scenarios V7 and V19, also equivalent to each other).

Lastly, scenario V12, which included the use of safety stock as opposed to the safety time buffer, proved to be the second best scenario under assessment, though it represented a considerable increase in the average amounts of material handled, in comparison to what can be found in equivalent scenarios V13 and V25.

Table 26: Simulation Results – Material '101I0000001509'

Scenario	Service_Level	Holding_Costs	StockOut_Costs	Ordering_Costs	Total_Costs	Avg.QuebrasReais	Avg.StockMedio	Avg.StockTotal	Avg.StockTransito	Units of Measurement
V13	100,00%	16 996,91 €	0,00 €	10 592,98 €	27 589,89 €	0,00	7257,91	15085,76	7655,99	M2
V25	100,00%	16 996,91 €	0,00 €	10 592,98 €	27 589,89 €	0,00	7257,91	15085,76	7655,99	M2
V12	100,00%	23 065,89 €	0,00 €	13 581,16 €	36 647,05 €	0,00	9849,44	19914,26	9750,46	M2
V14	100,00%	23 688,04 €	0,00 €	13 918,67 €	37 606,71 €	0,00	10115,11	20431,16	9985,59	M2
V7	100,00%	24 457,96 €	0,00 €	14 301,32 €	38 759,28 €	0,00	10443,87	21046,20	10253,63	M2
V19	100,00%	24 457,96 €	0,00 €	14 301,32 €	38 759,28 €	0,00	10443,87	21046,20	10253,63	M2
V24	100,00%	25 840,52 €	0,00 €	14 960,23 €	40 800,75 €	0,00	11034,25	22130,85	10716,47	M2
V26	100,00%	26 462,66 €	0,00 €	15 297,74 €	41 760,40 €	0,00	11299,92	22647,75	10951,61	M2
V6	100,00%	37 135,87 €	0,00 €	20 574,35 €	57 710,22 €	0,00	15857,51	31154,45	14649,09	M2
V8	100,00%	37 758,01 €	0,00 €	20 911,85 €	58 669,86 €	0,00	16123,18	31671,35	14884,23	M2
V18	100,00%	42 650,51 €	0,00 €	23 315,29 €	65 965,80 €	0,00	18212,35	35559,99	16569,10	M2
V20	100,00%	43 272,70 €	0,00 €	23 652,79 €	66 925,49 €	0,00	18478,02	36076,89	16804,22	M2
V10	100,00%	56 669,82 €	0,00 €	35 684,83 €	92 354,65 €	0,00	24198,78	49822,46	24292,77	M2
V22	100,00%	56 669,82 €	0,00 €	35 684,83 €	92 354,65 €	0,00	24198,78	49822,46	24292,77	M2
V9	100,00%	74 266,24 €	0,00 €	45 897,81 €	120 164,05 €	0,00	31712,69	64859,10	31328,48	M2
V11	100,00%	76 177,97 €	0,00 €	46 920,70 €	123 098,67 €	0,00	32529,02	66432,26	32036,52	M2
V4	100,00%	78 631,96 €	0,00 €	48 334,08 €	126 966,04 €	0,00	33576,91	68521,66	33010,63	M2
V16	100,00%	78 631,96 €	0,00 €	48 334,08 €	126 966,04 €	0,00	33576,91	68521,66	33010,63	M2
V21	100,00%	82 356,42 €	0,00 €	50 557,37 €	132 913,79 €	0,00	35167,30	71747,30	34539,86	M2
V23	100,00%	84 268,12 €	0,00 €	51 580,27 €	135 848,39 €	0,00	35983,63	73320,46	35247,91	M2
V3	100,00%	115 503,51 €	0,00 €	69 648,72 €	185 152,23 €	0,00	49321,56	99969,70	47697,60	M2
V5	100,00%	117 415,23 €	0,00 €	70 671,60 €	188 086,83 €	0,00	50137,89	101542,86	48405,65	M2
V15	100,00%	131 581,90 €	0,00 €	78 909,14 €	210 491,04 €	0,00	56187,25	113659,30	54079,92	M2
V17	100,00%	133 493,61 €	0,00 €	79 932,05 €	213 425,66 €	0,00	57003,58	115232,46	54787,96	M2
V1	55,81%	1 849,91 €	1 413 710,72 €	3 497,99 €	1 419 058,62 €	327,68	789,94	5308,21	4579,67	M2
V2	54,15%	1 785,14 €	1 477 774,37 €	3 322,02 €	1 482 881,53 €	339,98	762,28	5385,81	4684,93	M2

In the case of materials '101I0000001565', '104I0000000003' and '101I0000001443', the maximum service levels achieved were not of 100%, since these materials' stock outs occurred within the transition period between the old and the new inventory management policies, during which the effects of the latter would still not be visible.

As a result, when it comes to material '101I0000001565' (Table 27), all new approaches guaranteed a service level of 91,33% for the twenty weeks of the simulation, although scenario V7 – theoretical normal distribution, using the new inventory review period of two weeks and the safety time buffer for a target service level equal to 95% – was the one that ensured this while requiring less amount of material in stock.

Notwithstanding, V7's performance was closely matched by scenarios V13 and V19, both resulting from small derivations of the first – the only difference between V7 and V13 is that the latter used the seasonal variation rate, whereas V19 differs from V7 in its target service level (99%, as previously mentioned, which, in this case, resulted in a change of safety time value from one to two weeks).

In comparison with V1 and V2 scenarios, all new approaches scenarios increased the simulation period's service level in over 50%, which meant that instead of missing, on average, 730,95 square metres of material per week from inventory, this number dropped to 95,33 square metres. This service level improvement meant, once again, that more material was required to be kept in stock in comparison with current status scenarios, which translated into going from an average of 88,89 square metres of material in inventory, for scenarios V1 and V2, to 4.535,49 square metres in the best V7 scenario.

Table 27: Simulation Results – Material '101I0000001565'

Scenario	Service_Level	Holding_Costs	StockOut_Costs	Ordering_Costs	Total_Costs	Avg.QuebrasReais	Avg.StockMedio	Avg.StockTotal	Avg.StockTransito	Units of Measurement
V7	91,33%	10 227,77 €	124 716,34 €	17 142,91 €	152 087,02 €	95,33	4535,49	9085,39	4466,89	M2
V13	91,33%	13 236,87 €	124 716,34 €	18 206,00 €	156 159,21 €	95,33	5869,89	10509,53	4556,61	M2
V19	91,33%	15 203,44 €	124 716,34 €	16 975,26 €	156 895,04 €	95,33	6741,96	10899,72	4131,04	M2
V12	91,33%	15 682,12 €	124 716,34 €	19 715,10 €	160 113,56 €	95,33	6954,23	11674,44	4661,43	M2
V25	91,33%	18 608,13 €	124 716,34 €	16 975,11 €	160 299,58 €	95,33	8251,77	12405,32	4105,44	M2
V14	91,33%	18 071,09 €	124 716,34 €	19 345,51 €	162 132,94 €	95,33	8013,62	12746,40	4652,77	M2
V24	91,33%	18 001,43 €	124 716,34 €	19 715,05 €	162 432,82 €	95,33	7982,73	12721,63	4661,43	M2
V6	91,33%	20 850,92 €	124 716,34 €	19 715,00 €	165 282,26 €	95,33	9246,34	14008,23	4661,44	M2
V8	91,33%	23 097,53 €	124 716,34 €	19 345,35 €	167 159,22 €	95,33	10242,59	14911,82	4568,58	M2
V26	91,33%	26 952,82 €	124 716,34 €	16 587,97 €	168 257,13 €	95,33	11952,21	16454,53	4326,59	M2
V18	91,33%	26 806,87 €	124 716,34 €	19 714,90 €	171 238,11 €	95,33	11887,50	16746,99	4701,53	M2
V4	91,33%	29 904,76 €	124 716,34 €	18 513,64 €	173 134,74 €	95,33	13261,25	18157,44	4664,18	M2
V16	91,33%	35 284,89 €	124 716,34 €	20 555,10 €	180 556,33 €	95,33	15647,06	21146,49	5181,24	M2
V20	91,33%	36 167,27 €	124 716,34 €	19 926,20 €	180 809,81 €	95,33	16038,36	21527,14	5172,15	M2
V10	91,33%	36 332,44 €	124 716,34 €	20 925,39 €	181 974,17 €	95,33	16111,60	21720,44	5275,03	M2
V9	91,33%	41 591,66 €	124 716,34 €	22 910,78 €	189 218,78 €	95,33	18443,80	24639,30	5777,89	M2
V22	91,33%	41 712,55 €	124 716,34 €	22 966,86 €	189 395,75 €	95,33	18497,41	24709,49	5792,10	M2
V21	91,33%	45 891,50 €	124 716,34 €	24 524,13 €	195 131,97 €	95,33	20350,56	27022,80	6186,52	M2
V11	91,33%	46 700,06 €	124 716,34 €	24 815,44 €	196 231,84 €	95,33	20709,11	27467,44	6260,31	M2
V3	91,33%	51 144,76 €	124 716,34 €	26 495,22 €	202 356,32 €	95,33	22680,12	29934,80	6685,77	M2
V5	91,33%	56 253,17 €	124 716,34 €	28 399,88 €	209 369,39 €	95,33	24945,44	32762,94	7168,19	M2
V23	91,33%	56 380,03 €	124 716,34 €	28 470,27 €	209 566,64 €	95,33	25001,69	32839,99	7186,01	M2
V15	91,33%	62 068,04 €	124 716,34 €	30 593,77 €	217 378,15 €	95,33	27524,03	35989,80	7723,85	M2
V17	91,33%	72 556,56 €	124 716,34 €	34 539,90 €	231 812,80 €	95,33	32175,17	41806,99	8723,34	M2
V1	33,48%	200,46 €	5 867 488,25 €	3 951,82 €	5 871 640,53 €	730,95	88,89	4622,84	4579,67	M2
V2	33,48%	200,46 €	5 867 653,60 €	3 951,42 €	5 871 805,48 €	730,96	88,89	4623,05	4579,88	M2

On the other hand, the results achieved for material '104I0000000003' (Table 28) were quite similar to the ones found for material '101I0000001565', since the top five scenarios not only included the same approaches, as the V7 scenario was, again, the one reaching the best trade-off between service level and investment in raw material. This approach implies the review of inventory levels every two weeks and that a safety time of another two weeks is also put in place.

Furthermore, all new approaches allowed to improve the service level from around 13% to 64%, while scenario V7 ensured this transition by increasing the average inventory level from 3,79 to 2.981,13 metres.

In sharp contrast to all results described so far, in the case of material '101I0000001443', current status scenarios performed at the same level as the new approaches, ensuring an equal service level of 99% (Table 29). However, because they achieved this with a fifth of the average inventory level attained by the highest ranking new approach scenario (scenario V7), current inventory management policies guaranteed the best service level/raw material investment trade-off, at least during this simulation period.

Table 28: Simulation Results – Material '104I0000000003'

Scenario	Service_Level	Holding_Costs	StockOut_Costs	Ordering_Costs	Total_Costs	Avg.QuebrasReais	Avg.StockMedio	Avg.StockTotal	Avg.StockTransito	Units of Measurement
V7	63,93%	8 983,75 €	338 709,96 €	12 887,49 €	360 581,20 €	70,63	2981,13	6908,78	3758,36	M
V19	63,93%	9 511,98 €	338 709,96 €	13 386,76 €	361 608,70 €	70,63	3156,41	7240,07	3904,01	M
V13	63,93%	11 177,44 €	338 709,96 €	14 961,51 €	364 848,91 €	70,63	3709,07	8284,78	4363,42	M
V25	63,93%	11 705,63 €	338 709,96 €	15 460,78 €	365 876,37 €	70,63	3884,35	8616,07	4509,08	M
V12	63,93%	12 009,21 €	338 709,96 €	15 854,77 €	366 573,94 €	70,63	3985,08	8839,57	4623,68	M
V6	63,93%	12 498,96 €	338 709,96 €	16 317,81 €	367 526,73 €	70,63	4147,60	9146,77	4758,76	M
V24	63,93%	12 876,46 €	338 709,96 €	16 674,73 €	368 261,15 €	70,63	4272,87	9383,57	4862,89	M
V14	63,93%	13 263,97 €	338 709,96 €	16 934,23 €	368 908,16 €	70,63	4401,46	9593,58	4938,93	M
V8	63,93%	13 753,72 €	338 709,96 €	17 397,27 €	369 860,95 €	70,63	4563,98	9900,78	5074,02	M
V18	63,93%	14 478,34 €	338 709,96 €	18 189,25 €	371 377,55 €	70,63	4804,44	10388,37	5304,73	M
V26	63,93%	14 659,47 €	338 709,96 €	18 253,47 €	371 622,90 €	70,63	4864,53	10468,87	5323,80	M
V20	63,93%	16 261,36 €	338 709,96 €	19 767,99 €	374 739,31 €	70,63	5396,10	11473,67	5765,63	M
V4	63,93%	20 330,71 €	338 709,96 €	25 613,31 €	384 653,98 €	70,63	6746,46	14653,74	7474,15	M
V16	63,93%	21 432,26 €	338 709,96 €	26 701,33 €	386 843,55 €	70,63	7111,99	15359,51	7791,82	M
V10	63,93%	24 255,08 €	338 709,96 €	29 558,76 €	392 523,80 €	70,63	8048,71	17189,54	8625,91	M
V22	63,93%	25 356,65 €	338 709,96 €	30 646,77 €	394 713,38 €	70,63	8414,24	17895,31	8943,57	M
V9	63,93%	25 678,49 €	338 709,96 €	31 162,91 €	395 551,36 €	70,63	8521,05	18162,91	9093,67	M
V3	63,93%	26 532,48 €	338 709,96 €	32 021,46 €	397 263,90 €	70,63	8804,42	18714,71	9344,30	M
V21	63,93%	27 223,32 €	338 709,96 €	32 716,02 €	398 649,30 €	70,63	9033,67	19161,11	9547,05	M
V11	63,93%	27 987,57 €	338 709,96 €	33 311,27 €	400 008,80 €	70,63	9287,27	19601,34	9721,34	M
V5	63,93%	28 841,52 €	338 709,96 €	34 169,83 €	401 721,31 €	70,63	9570,65	20153,14	9971,96	M
V15	63,93%	30 063,45 €	338 709,96 €	35 571,39 €	404 344,80 €	70,63	9976,13	20996,31	10380,59	M
V23	63,93%	30 633,90 €	338 709,96 €	35 952,40 €	405 296,26 €	70,63	10165,43	21305,31	10492,39	M
V17	63,93%	33 474,06 €	338 709,96 €	38 807,80 €	410 991,82 €	70,63	11107,89	23140,51	11325,93	M
V1	12,72%	11,42 €	1 878 851,43 €	430,60 €	1 879 293,45 €	170,90	3,79	318,59	318,59	M
V2	12,68%	11,42 €	1 879 215,83 €	426,76 €	1 879 654,01 €	170,97	3,79	318,93	318,93	M

Table 29: Simulation Results – Material '101I0000001443'

Scenario	Service_Level	Holding_Costs	StockOut_Costs	Ordering_Costs	Total_Costs	Avg.QuebrasReais	Avg.StockMedio	Avg.StockTotal	Avg.StockTransito	Units of Measurement
V2	99,45%	12 861,09 €	10 183,36 €	21 667,83 €	44 712,28 €	7,17	5734,99	32539,61	26519,06	M2
V1	99,56%	16 821,78 €	8 233,35 €	24 326,72 €	49 381,85 €	5,71	7501,12	32537,15	24636,06	M2
V7	99,45%	69 116,18 €	10 183,36 €	44 138,32 €	123 437,86 €	7,17	30820,12	56825,14	24676,48	M2
V19	99,45%	69 116,18 €	10 183,36 €	44 138,32 €	123 437,86 €	7,17	30820,12	56825,14	24676,48	M2
V6	99,45%	107 428,31 €	10 183,36 €	66 082,00 €	183 693,67 €	7,17	47904,16	87004,21	36827,43	M2
V8	99,45%	108 577,14 €	10 183,36 €	66 703,25 €	185 463,75 €	7,17	48416,45	87890,74	37174,94	M2
V4	99,45%	117 880,63 €	10 183,36 €	73 453,94 €	201 517,93 €	7,17	52565,04	95043,79	39965,22	M2
V16	99,45%	117 880,63 €	10 183,36 €	73 453,94 €	201 517,93 €	7,17	52565,04	95043,79	39965,22	M2
V18	99,45%	123 785,01 €	10 183,36 €	75 435,24 €	209 403,61 €	7,17	55197,90	99881,01	42008,09	M2
V20	99,45%	124 933,84 €	10 183,36 €	76 056,49 €	211 173,69 €	7,17	55710,19	100767,54	42355,61	M2
V3	99,45%	178 793,16 €	10 183,36 €	108 400,64 €	297 377,16 €	7,17	79727,00	143054,82	59310,79	M2
V5	99,45%	182 989,37 €	10 183,36 €	110 685,02 €	303 857,75 €	7,17	81598,17	146300,59	60587,11	M2
V10	99,45%	191 418,74 €	10 183,36 €	115 505,16 €	317 107,26 €	7,17	85356,97	152936,59	63256,94	M2
V13	99,45%	191 418,74 €	10 183,36 €	115 505,16 €	317 107,26 €	7,17	85356,97	152936,59	63256,94	M2
V22	99,45%	191 418,74 €	10 183,36 €	115 505,16 €	317 107,26 €	7,17	85356,97	152936,59	63256,94	M2
V25	99,45%	191 418,74 €	10 183,36 €	115 505,16 €	317 107,26 €	7,17	85356,97	152936,59	63256,94	M2
V15	99,45%	205 788,44 €	10 183,36 €	123 837,32 €	339 809,12 €	7,17	91764,66	164306,82	67861,00	M2
V17	99,45%	209 984,65 €	10 183,36 €	126 121,70 €	346 289,71 €	7,17	93635,83	167552,59	69137,32	M2
V9	99,45%	362 716,67 €	10 183,36 €	213 573,45 €	586 473,48 €	7,17	161741,71	287848,42	117564,88	M2
V12	99,45%	362 716,67 €	10 183,36 €	213 573,45 €	586 473,48 €	7,17	161741,71	287848,42	117564,88	M2
V11	99,45%	366 912,92 €	10 183,36 €	215 857,85 €	592 954,13 €	7,17	163612,89	291094,19	118841,19	M2
V14	99,45%	366 912,92 €	10 183,36 €	215 857,85 €	592 954,13 €	7,17	163612,89	291094,19	118841,19	M2
V21	99,45%	435 479,44 €	10 183,36 €	255 181,31 €	700 844,11 €	7,17	194187,90	345130,82	140611,02	M2
V24	99,45%	435 479,44 €	10 183,36 €	255 181,31 €	700 844,11 €	7,17	194187,90	345130,82	140611,02	M2
V23	99,45%	439 675,68 €	10 183,36 €	257 465,71 €	707 324,75 €	7,17	196059,07	348376,59	141887,33	M2
V26	99,45%	439 675,68 €	10 183,36 €	257 465,71 €	707 324,75 €	7,17	196059,07	348376,59	141887,33	M2

All in all, no matter the material under assessment, the choice of a policy that relies on the use of safety time as a means of protection against uncertainty and that reviews inventory levels based on new revision periods was the one that ensured better service level performance at a lower cost. Even in the case of material '101I0000001443', although current status algorithms are the preferable choice, the best new approach scenario satisfied both of these conditions (scenario V7).

The preference of safety time over safety stock can easily be explained in this context, since the calculated weekly safety time values provided good buffers for the considered demand and supply uncertainties, without requiring the use of as much amount of material in stock as the safety stock buffer options.

Lastly, it is important to highlight that, in most policies, 'Avg.StockTransito' presented particularly high values, because the initial inventory levels of the different materials under study were well below the reorder points determined in section 5.2.6, which forced the algorithm to order a large amount of each material to meet the order up to level points. In fact, if one looks at the evolution of variable 'StockTransito' during the twenty weeks of the simulation, for any material, the amounts of ordered material at each review period and the amounts of material pending delivery tend to decrease and eventually stabilise overtime, as the amounts of material kept in stock get closer to the reorder and order up to level points. Each material's behaviour during the twenty weeks of the simulation for the top performance scenarios is properly detailed in Appendix XXI, whereas Figure 36 summarises its parameters – reorder and order up to level points, review periods and safety time buffers.

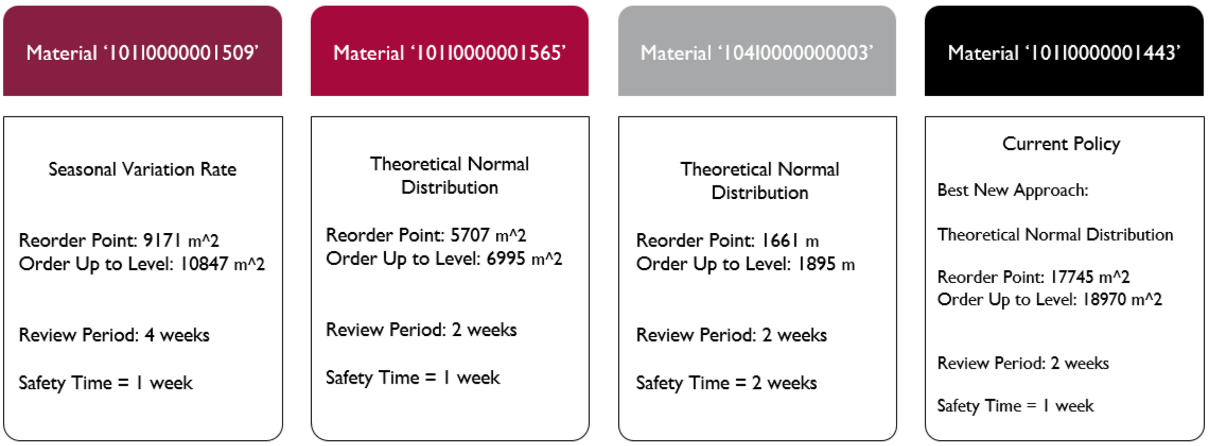


Figure 36: Top Performance Scenarios' Parameters – Preliminary Results

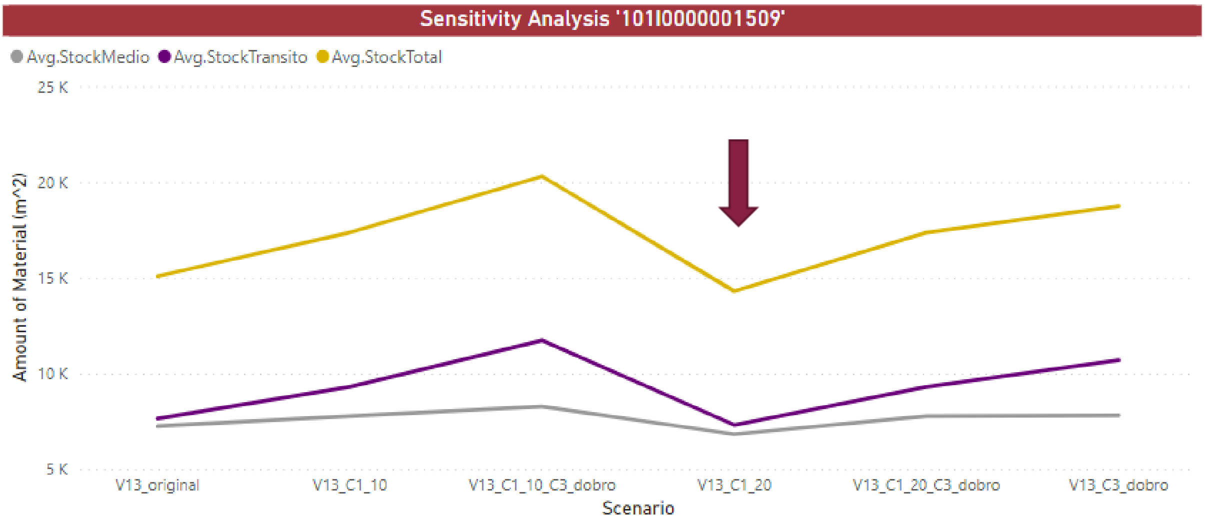
5.3.3 Sensitivity Analysis

In order to understand if the achieved results would vary significantly, in case other holding and ordering costs were considered, a sensitivity analysis, including five different combinations of C1 and C3 values, was conducted. These five alternative scenarios consist of:

- Dropping the company's internal interest rate for keeping material in stock to 10%, while maintaining the same materials' ordering costs (scenario C1_10);
- Increasing the company's internal interest rate for keeping material in stock to 20%, while maintaining C3 costs (scenario C1_20);
- Doubling each materials' ordering costs, but keeping the company's internal interest rate for holding material in stock equal to 14,75% (scenario C3_dobro);

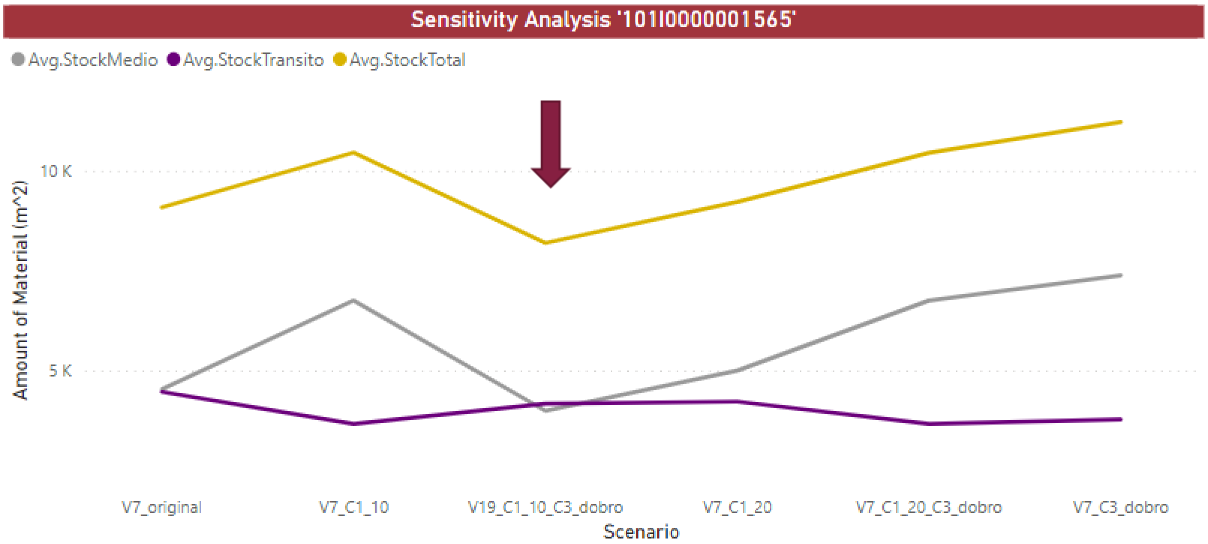
- Dropping the company's internal interest rate for keeping material in stock to 10% and doubling each materials' ordering costs (scenario C1_10_C3_dobro);
- Increasing the company's internal interest rate for holding material in stock to 20% and doubling C3 costs (scenario C1_20_C3_dobro).

Figures 37 to 40 show the sensitivity analysis' results obtained for each of the four materials under study, while Figure 41 details the new suggested policies after this complementary analysis.



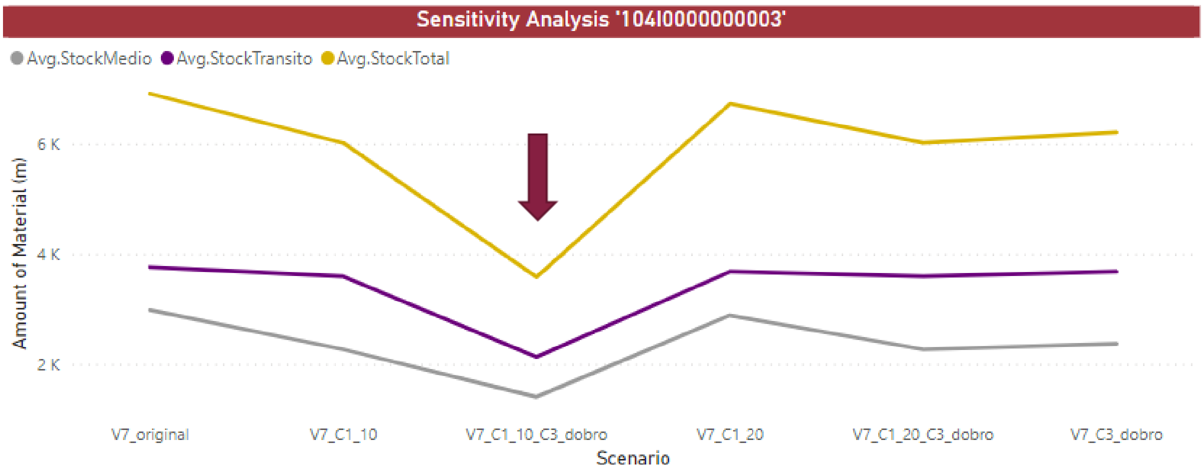
Scenario	Service_Level	Avg.StockMedio	Avg.StockTotal	Avg.StockTransito	Units of Measurement
V13	100,00%	7257,91	15085,76	7655,99	M2
V13_C1_20	100,00%	6839,58	14303,13	7314,90	M2
Reduction	0,00%	-418,33	-782,63	-341,09	M2

Figure 37: Sensitivity Analysis Material '101I0000001509'



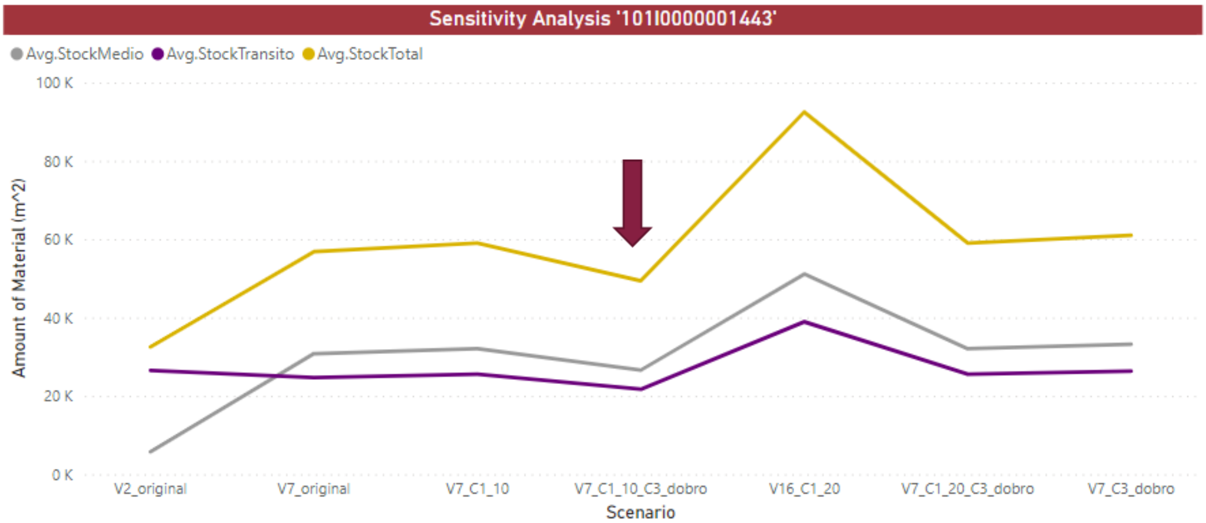
Scenario	Service_Level	Avg.StockMedio	Avg.StockTotal	Avg.StockTransito	Units of Measurement
V7	91,33%	4535,49	9085,39	4466,89	M2
V19_C1_10_C3_dobro	91,28%	3991,98	8193,68	4168,79	M2
Reduction	-0,04%	-543,51	-891,71	-298,10	M2

Figure 38: Sensitivity Analysis Material '101I0000001565'



Scenario	Service_Level	Avg.StockMedio	Avg.StockTotal	Avg.StockTransito	Units of Measurement
V7_original	63,93%	2981,13	6908,78	3758,36	M
V7_C1_10_C3_dobro	63,93%	1401,14	3580,13	2125,59	M
Reduction	0,00%	-1579,99	-3328,65	-1632,77	M

Figure 39: Sensitivity Analysis Material '104I0000000003'



Scenario	Service_Level	Avg.StockMedio	Avg.StockTotal	Avg.StockTransito	Units of Measurement
V2_original	99,45%	5734,99	32539,61	26519,06	M2
V7_original	99,45%	30820,12	56825,14	24676,48	M2
V7_C1_10_C3_dobro	99,45%	26604,21	49410,20	21707,63	M2
Reduction	0,00%	-4215,90	-7414,93	-2968,85	M2

Figure 40: Sensitivity Analysis Material '101I0000001443'

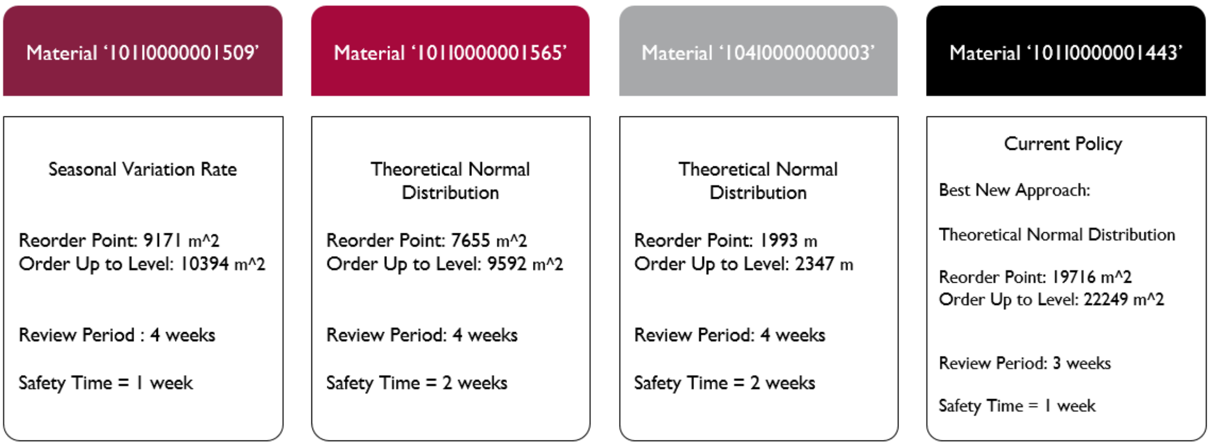


Figure 41: Top Performance Scenarios' Parameters – Sensitivity Analysis

When it comes to material '101I0000001509' (Figure 37), regardless of the values of C1 and C3 costs, the V13 approach still ensured the best trade-off between service level and material investment. Nevertheless, the lower order up to level point, obtained after increasing the internal interest rate for keeping material in stock to 20%, guaranteed the same service level as the V13 approach presented in the preliminary results (100%), though requiring less material to do so – the weekly average stock on hand was estimated to decrease 418,33 square metres.

On the other hand, in the case of material '101I0000001565' (Figure 38), although for most scenarios the V7 approach remained the best option, when the C1 internal interest rate dropped to 10% and C3 cost doubled its value, the V19 approach became an interesting alternative. In its essence, the V19 approach is exactly the same as the V7 – it uses a theoretical normal distribution to estimate demand and standard deviation during planning period, inventory level is reviewed based on a new revision period and safety time is the buffer of choice. The only difference between them relates to the significance level used to determine the safety time buffer - in the V19 approach, the significance level equals 99%, whereas in the V7 approach it equals 95%.

This means that, for material '101I0000001565', increasing its reorder and order up to level points, as well as its review period and safety time buffer, as a consequence of the C1_10_C3_dobro scenario, ensured a service level only 0,04% inferior to the one achieved in the preliminary analysis, while decreasing the weekly average stock on hand by 543,51 square metres.

In regard to material '104I0000000003' (Figure 39), no matter the scenario, the V7 approach outperformed all the others, as it did in the original analysis. Moreover, it was once again proved that the adoption of different parameters could deliver a more efficient result than the one previously achieved – the same service level could be guaranteed by having, on average, less 1.579,99 metres in inventory per week, if reorder and order up to level points increased just enough to compensate the longer suggested review period of 4 weeks.

Lastly, it came as no surprise that, regardless of the scenario under assessment, none of the new approaches outperformed the current policy in place for material '101I0000001443' (Figure 40). Nonetheless, it was possible to improve the best new approach scenario – the V7 was still the one ensuring the best trade-off between service level and the amount of required inventory, though for the C1_10_C3_dobro scenario, the increase in its review period, as well as in the reorder and order up to level points led to a remarkable decrease of the weekly average stock on hand by 4.215,90 square metres, dropping it to 26.604,21 square metres per week (still very far from the 5.734,99 square metres achieved by the company's current policy).

All points considered, this sensitivity analysis led to some very interesting results, since it not only allowed to increase the efficiency of the policies suggested during the preliminary analysis, as it also proved that the main choices behind them remain the same regardless of the new C1 and C3 costs. By not changing the choice of adopting theoretical normal distributions or the estimated seasonal variation rate; by maintaining the safety time as the buffer of choice against uncertainty; and by opting for new inventory review periods superior to one week, the presented policies proved to be stable solutions for this problem.

Furthermore, the results of this sensitivity analysis suggested the adoption of long inventory review periods for all materials, in particular a review period of four weeks was recommended to the three materials whose service levels were estimated to increase by the adoption of new inventory management policies. Each material's behaviour during the twenty weeks of simulation for the top performance scenarios in the sensitivity analysis is detailed in Appendix XXII.

5.4 Power BI Report – Other Features

As described in chapter 4, the data tables obtained from the company's MRP records allowed to create a Power BI Report, summarising key information about the performance levels of A-type raw materials. At that time, the importance of indicators such as 'NecDep_i1' and the variation rate of materials' needs to the company's service level diagnosis, as well as the conclusions drawn from them were properly highlighted and discussed.

Notwithstanding, the four data tables resulting from the extensive MRP data treatment detailed in Appendix III - the **Stock Out**, the **Summary**, the **Real** and the **ResOrd Tables** – also included other variables, not necessarily related to the scope of this Master's dissertation, but equally fundamental in providing further insight into the company's production system performance. Figures 42 to 44 show examples of some other information that was possible to obtain from these data tables.

Although the information was not directly presented in the **ResOrd Table**, the percentage of production orders associated with each project, raw material and seat part was obtained by crossing variable **'Dados.Elemento.MRP'** with the company's reference code dictionary. This allowed to understand which projects used larger amounts of the A-type raw materials under study, as well as the main car seat parts produced. Figure 42 summarises this information, firstly in a matrix that allows the drill-down of these indicators from project to seat part levels, and, secondly, in a ring chart that splits the 'ResOrd' records by car seat part. By analysing these elements, one can draw the conclusion most of the production orders in the dataset were associated with project 3701 and five particular seat parts - rear side bolster (ETL), front right seatback (ETD), front left seatback (EFE), front right seat bottom (AFD) and front left seat bottom (AFE).

Unit. Measurement	M				M2				UN			
Project ID Number	%ResOrd	Avg. Amount	Value Avg. Amount	Currency	%ResOrd	Avg. Amount	Value Avg. Amount	Currency	%ResOrd	Avg. Amount	Value Avg. Amount	Currency
⊟ **3701**	**25,38%**	**1,33**	**603,60**	**EUR**	**21,10%**	**7,92**	**7.044,02**	**EUR**				
⊟ **104I0000000003**	**21,31%**	**1,27**	**69,11**	**EUR**								
ETL	5,07%	1,40	75,82	EUR								
EFD	3,18%	0,75	40,62	EUR								
EFE	3,11%	0,76	41,10	EUR								
AFD	2,69%	1,48	80,46	EUR								
AFE	2,57%	1,54	83,75	EUR								
AT (3 Lugares)	2,47%	2,57	139,81	EUR								
ETD	0,64%	0,42	22,57	EUR								
ETE	0,63%	0,42	22,82	EUR								
ATD	0,47%	0,50	27,38	EUR								
ATE	0,47%	0,51	27,44	EUR								
⊞ **101I0000001565**					**21,10%**	**7,92**	**313,48**	**EUR**				
⊞ **106A0000000001**	**2,70%**	**1,34**	**13,11**	**EUR**								
⊞ **104I0000000035**	**1,37%**	**2,15**	**104,16**	**EUR**								
⊞ **0705**	**9,52%**	**28,27**	**12.865,42**	**EUR**	**18,53%**	**63,73**	**56.677,81**	**EUR**	**4,81%**	**145,20**	**47.711,63**	**EUR**
⊞ **0713**	**1,13%**	**28,19**	**12.828,80**	**EUR**	**9,21%**	**86,92**	**77.306,03**	**EUR**				
⊞ **5601**	**0,04%**	**0,05**	**430,08**	**EUR**	**5,47%**	**6,58**	**5.851,88**	**EUR**				
Total	**38,29%**	**35,11**	**15.974,04**	**EUR**	**54,88%**	**40,31**	**35.853,81**	**EUR**	**6,83%**	**132,92**	**43.677,16**	**EUR**

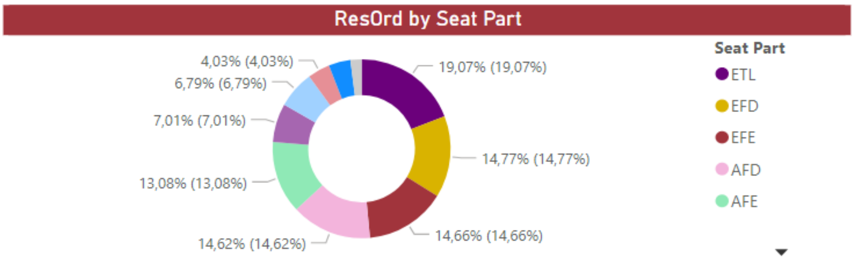


Figure 42: ResOrd by Project, Material and Seat Part

Additionally, it was also mentioned in this dissertation that one of the company's current struggles lies in the delay between producing seat covers and closing the respective 'ResOrd' requests in the system. Interestingly, the collected data also allowed to quantify the depth of this problem for the 63 A-type materials studied, as well as grouping the results by project or car seat cover. For instance, in the matrix presented in Figure 43, Leather Kits are the group of materials with a larger gap between their seat parts' production deadline and the date of the last MRP record in which these production orders can be found, (reaching almost 60 days on average). On the other hand, project 5503 seems to be the one struggling the most with this issue, since a 'ResOrd' order is, on average, closed 37 days after its original due date. Given these results, it is important to keep in mind that this does not mean that it is only when the production orders are closed that the seat covers' production is finished and they are sent to customers. On the contrary, these performance measures highlight that production itself and the information presented in the system are not in alignment and that the company should keep raising awareness amongst its collaborators about this issue, so that together they can understand the reasons behind this and work on a solution to improve the system's visibility over what truly happens in daily operations.

Along with this information, the developed Power BI Report also allows to assess this variable's evolution overtime (graphic shown in Figure 43), as well as its comparison with the median and maximum number of extra days it might take to close 'ResOrd' orders (graphic shown in Figure 44).

In the matrix of Figure 43, two other indicators can be found, referring to the fulfilment rate of 'ResOrd' orders known at the start of a week ('Original ResOrd Fulfilment Rate (weekly)') and 'Total ResOrd Fulfilment Rate (weekly)', which considers all 'ResOrd' orders registered during the course of that week ('ResOrd_i' and 'ResOrd_i1'). Naturally, since production is heavily impacted by the variation rate of materials' needs, 'Original ResOrd Fulfilment Rate (weekly)' is always higher than 'Total ResOrd Fulfilment Rate (weekly)'.

Group of Materials	%ResOrd Start of the Week	Original ResOrd Fulfilment Rate (weekly)	Total ResOrd Fulfilment Rate (weekly)	Avg. Number Extra Days to Close ResOrd	Avg. Number Extra Weeks to Close ResOrd
⊞ **Leather Kit**	**51,52%**	**47,63%**	**42,51%**	**59,63**	**8,52**
⊞ **Small Mat. - Velcro**	**68,41%**	**46,20%**	**43,68%**	**57,99**	**8,28**
⊞ **Cutting Mat. - Foam kits**	**56,48%**	**66,09%**	**62,41%**	**11,32**	**1,62**
⊞ **Cutting Mat. - Foam/Plush materials**	**51,82%**	**69,67%**	**64,36%**	**9,46**	**1,35**
⊟ **Leather**	**50,19%**	**68,85%**	**58,69%**	**7,43**	**1,06**
101T1000000119	45,88%	62,23%	44,30%	20,23	2,89
101T4000000342	58,98%	63,09%	57,74%	14,10	2,01
101I0000001967	50,90%	68,34%	65,48%	12,84	1,83
101C4000000034	24,10%	56,45%	30,21%	12,29	1,76
101T7000000261	38,37%	73,53%	55,91%	10,00	1,43
101H0000000131	50,98%	66,48%	55,06%	9,53	1,36
101I0000001810	55,93%	63,86%	60,72%	8,95	1,28
101I0000001509	55,76%	67,58%	61,51%	8,06	1,15
101D0000000332	47,48%	61,58%	50,99%	7,82	1,12
101C9000000236	53,51%	62,14%	51,73%	7,44	1,06
Total	**48,19%**	**69,87%**	**60,98%**	**7,79**	**1,11**

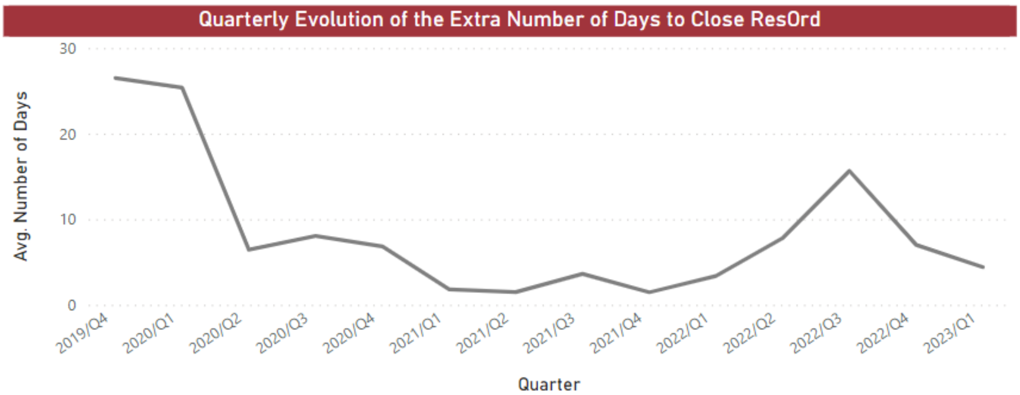


Figure 43: Number of Extra Days Necessary to Close ResOrd by Material

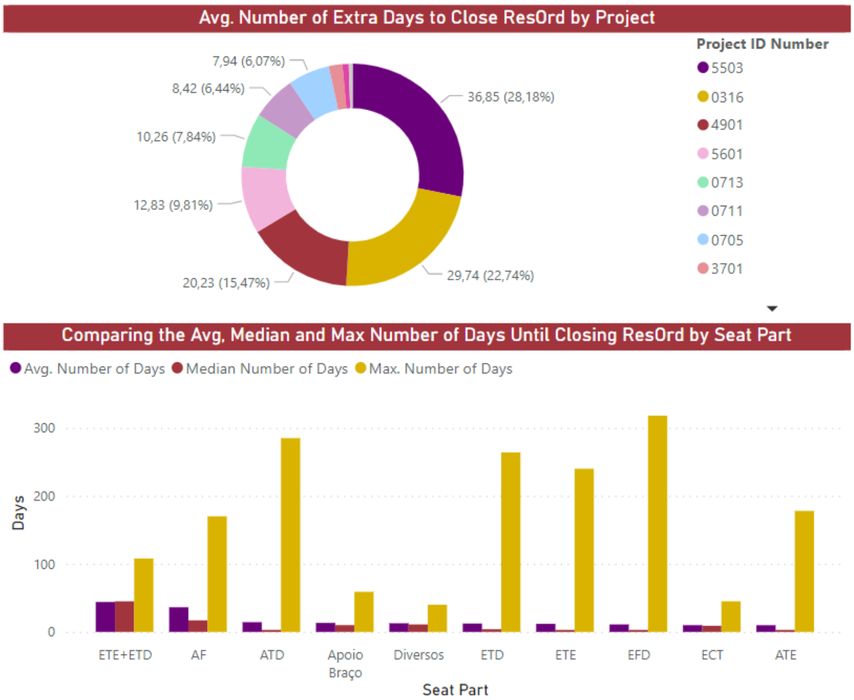


Figure 44: Number of Extra Days Necessary to Close ResOrd by Project and Seat Part

One final note about the potentialities of this Report relates to its interactivity and customisation options, depending on each user's preferences. Power BI is a business intelligence tool that naturally allows to filter information across visual elements, in order to understand possible connections and retrieve useful insights from the data at hand. In addition to its intrinsic abilities, the way this report was conceived allows the user to apply different filters to the data, including changing the way timely evolution of the different indicators is presented – information can be displayed by week, month, quarter, semester and year. The user can also decide if they wish to analyse data referring to the past three years or if they prefer to focus on what happened over a more recent or specific time period.

Appendix XXIII summarises the main steps that must be followed in order to keep this report up-to-date.

6. Conclusions and Future Work

This chapter summarises the main conclusions drawn from all the work presented in this dissertation, regarding raw materials inventory management policies and other contributions. A second section was also included to outline the direction of future research, should the company choose to continue on its journey towards data-driven decision making.

6.1 Conclusions

The purpose of this dissertation was two-fold – it intended to be a preliminary study on the formulation of raw materials' inventory management policies based on real demand and supply uncertainty data, collected from COINDU's information systems, as well as a study of the joint and separate adoption of safety stock and safety time buffers. Additionally, as this project is an important milestone in the company's transition towards data-driven decision making, a parallel goal of this analysis involved signalling the system's main vulnerabilities, concerning information sharing, data storage and data treatment.

In regard to the study of inventory management policies, assessing raw materials' historical service levels and supply quality was of top priority. So much so, the unstructured way data is currently stored in the company's information systems led to an intensive data gathering and treatment stages, before information about the performance of current inventory management policies and supply quality could be obtained. In fact, to better understand the achieved results, a Power BI Report was created, displaying several newly established KPIs, namely the unmet demand ratio, the average variation rates of materials' needs, the amount of missing material in comparison with the total amount of ordered material, and the risk of supply delay. It was only after this comprehensive system diagnosis that a DSS was conceived to analyse the trade-offs between inventory-related costs and achieved service levels, considering the separate and joint use of safety stocks and safety time buffers.

During the diagnosis stage, the assessment of current A-type materials' service levels uncovered several groups of materials with performance inferior to 90%, in particular Leather, Textile and Vinyl. Further analysis also revealed that these kinds of materials are, in general, quite vulnerable to short-term demand fluctuation.

These conclusions, combined with information about supply uncertainty, allowed to design and test the described DSS, by evaluating the performance of several new inventory management policies that followed periodic-review systems (R, s, S). The results of the simulation study revealed that, for some materials, there is room to improve current inventory management policies, whereas, for others, current policies may be worth keeping.

For materials referring to premium projects ('101I0000001565' and '104I0000000003', highly customisable seat covers, whose demand can be quite unpredictable), the service levels estimated during the simulation period were considerably improved by the adoption of new policies that increased the amount of inventory kept on hand, showing that the company's current strategy to deal with this kind of materials may not be the most adequate, since it is leading to inventory levels too low to account for sudden demand fluctuation.

On the other hand, the other two materials under study are associated with mass production projects and, even though, material '101I0000001509' is sometimes used in the project pertaining to material '101I0000001443', only the former's inventory management performance was successfully improved which may be explained by the difference in their production volumes. Material '101I0000001443' is used in one of the company's biggest projects, which makes its production lines run at full capacity all the time. This means that even though end-item demand may fluctuate considerably over time, the company must always maintain the highest production throughput possible, in order to meet customer demand, therefore, leading to more predictable raw materials' needs.

In sharp contrast, with respect to material '101I0000001509', its main project does not have as steady a production volume as that of material '101I0000001443' and end-item demand can fluctuate significantly ranging from lower to higher levels. In these cases, and similarly to what happened with materials used in premium projects, current inventory management policies were proven not to provide the best stock coverage, ultimately, compromising its estimated service levels.

These conclusions validate the remarks made in section 4.3 about the company's dynamic stocks policy - this method falls short of including demand and supply uncertainties in safety stock calculations, which has a great impact in the performance of raw materials associated with more volatile projects.

It is also noteworthy that this topic is deeply related to a particular piece of information that is unavailable in the system – COINDU's weekly production capacity. If current and historical values of weekly production capacity had been held in the company's information systems, it would have been possible to consider this variable as the top limit value for material demand. To put it plainly, should production capacity be available in the system and weekly material demand be superior to its value, then estimated weekly material demand could have been replaced by the weekly production capacity, since the amount of material required by production cannot exceed its manufacturing capacity. This could have led to inventory management policies that would have required less material to be kept in stock and that, consequently, would certainly be more competitive in situations similar to the one of material ‘101I0000001443’.

Furthermore, other conclusions can be drawn from this study, especially concerning new policies’ estimated review periods and safety buffer choice. When it comes to the review period results, both preliminary and sensitivity analyses show a clear preference for the adoption of longer review periods, in contrast with the company’s current review period of one week. In fact, for the three raw materials with improved inventory management policies, their estimated review period ultimately converged to four weeks after conducting the sensitivity analysis.

This tendency seems to indicate that if the company starts following inventory management policies similar to these, it may be able to increase service level performance and simultaneously reduce their raw materials’ collaborators workload, as well as possibly diversify the scope of their tasks, since they would not have to keep track of every material’s weekly inventory levels.

Regarding the preferable safety buffer, safety time was the unequivocal choice, since it was the safety buffer adopted in every material’s best performing policy, in both the preliminary and sensitivity analyses. This predominance may be slightly influenced by the fact that the simulation was conducted following a weekly basis, meaning that safety buffers of only a few days were not tested and the results were rounded up to their corresponding weekly value. A daily simulation could have led to situations in which the combination of safety stock and safety time would be the most efficient approach, guaranteeing the same service levels with a lower inventory for some items at least.

Notwithstanding, it is clear that, considering the way simulations were conducted, the safety time buffer allowed to fulfil customers’ demand, while requiring much lower inventory levels than the safety stock buffer itself.

Focusing, now, on the system’s vulnerabilities, throughout section 4, several issues were highlighted concerning information storage, namely:

- Key information not being available in the system – whether it refers to updated information about end-item demand or information about production itself (for instance, production capacity), End-Item and Raw Materials’ collaborators rely heavily on local files to access sensitive information;
- Lack of standardisation in files format– when studying the historical MRP records, it was found that information was not saved following the order used by the system to estimate inventory levels. Moreover, when SAP MRP records are transferred to SIAP, their information is stored

under a completely different format. To overcome issues like these, SAP and SIAP data underwent an intensive treatment stage, before datasets could be linked to one another and knowledge could be drawn from them.

This kind of problem allows to conclude that, throughout the years, the technological solutions developed by the company have been designed to accommodate each departments' needs without taking into account the full integration of the information available in the system. However, now that the company intends to take as much advantage as possible out of all available data, these glitches become big hurdles that must be addressed on the company's way towards data-driven decision making.

One final note should be addressed to the developed Power BI Report and proposed DSS. Both of these business intelligence tools were designed to help assessing raw materials' performance and to help keeping track of their KPIs over time.

6.2 Future Work

Considering the findings documented in this dissertation, it seems that, moving forward, COINDU must keep two main targets in mind. Primarily, their commitment towards data-driven decision making must be extended to their information systems. It is of the utmost importance to rethink the way information is shared within the company and how systems communicate between one another. By addressing these issues, the company will be able to open a series of possibilities, not just concerning decision making associated with raw materials inventory management policies, but also with any other topic, involving internal and, perhaps, external parties.

Secondly, regarding the future of this project per se, the results achieved by this study support the idea that the next stage of this work should focus on materials used in projects with medium to low production volumes. For now, premium projects, in particular, are good contenders to be the first real-life test subjects of new data-driven inventory management policies.

All in all, even though considerable progress remains to be made before COINDU's transition towards Industry 4.0 is fully completed, by employing the right resources, the company is perfectly capable of embracing this challenge and achieving their goal of a fully integrated system.

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APPENDIX I – TRANSFORMATION OF SIAP FILES

Examples of SAP and SIAP data files are shown in Tables 30 and 31, respectively.

Table 30: SAP Data Sample

Data MRP	Momento MRP	Centro	Material	Tipo de material	Planejador MRP	Depósito	Unid.medida básica	Mais/menos	Data	Data rem./fim base	Dta.reprogramação	Cód.element .MRP	Elemento MRP	Dados p/elemento MRP	Chave	Mensagem de exceção	Entrada/Necess.	Qtd.disponível
09/01/2022	04:24:58	1102	101I0000001443	Z010	151	1200	M2	-	21/01/2022	21/01/2022		SB	NecDep	20705N5H00I0IAB			-4,320	-222,712
09/01/2022	04:24:58	1102	101I0000001443	Z010	151	1200	M2	-	18/02/2022	18/02/2022		SB	NecDep	20705K5B01I0HAB			-6,328	-222,712
09/01/2022	04:24:58	1102	101I0000001443	Z010	151	1200	M2	-	06/05/2022	06/05/2022		SB	NecDep	20705G5B01I4CAC			-117,368	1 603,590
09/01/2022	04:24:58	1102	101I0000001443	Z010	151	1200	M2	-	17/06/2022	17/06/2022		SB	NecDep	20705K5C01I4CAB			-18,984	3 092,354
09/01/2022	04:24:58	1102	101I0000001443	Z010	151	1200	M2	-	29/07/2022	29/07/2022		SB	NecDep	20705G5H06I4CAA			-46,800	1 776,218
09/01/2022	04:24:58	1102	101I0000001443	Z010	151	1200	M2	-	16/09/2022	16/09/2022		SB	NecDep	20705G5H04I0IAB			-92,280	3 092,354
09/01/2022	04:24:58	1102	101I0000001443	Z010	151	1200	M2	-	14/10/2022	14/10/2022		SB	NecDep	20705N5H04I0IAB			-50,754	1 603,590
09/01/2022	04:24:58	1102	101I0000001443	Z010	151	1200	M2	-	19/05/2022	19/05/2022		SB	NecDep	20705N5B02I0IAE			-8,520	2 572,828
09/01/2022	04:24:58	1102	101I0000001443	Z010	151	1200	M2	-	20/05/2022	20/05/2022		SB	NecDep	20705P5G03I4CAB			-145,024	2 547,798
09/01/2022	04:24:58	1102	101I0000001443	Z010	151	1200	M2	-	26/05/2022	26/05/2022		SB	NecDep	20705N5B02I0IAE			-8,520	2 539,278
09/01/2022	04:24:58	1102	101I0000001443	Z010	151	1200	M2	-	27/05/2022	27/05/2022		SB	NecDep	20705P5G03I4CAB			-140,492	2 553,640
09/01/2022	04:24:58	1102	101I0000001443	Z010	151	1200	M2	-	27/05/2022	27/05/2022		SB	NecDep	20705P5H00I0HAA			-3,008	2 550,632
09/01/2022	04:24:58	1102	101I0000001443	Z010	151	1200	M2	-	02/06/2022	02/06/2022		SB	NecDep	20705N5B02I0IAE			-8,520	2 542,112
09/01/2022	04:24:58	1102	101I0000001443	Z010	151	1200	M2	-	03/06/2022	03/06/2022		SB	NecDep	20705N5H02I0IAB			-15,120	2 661,474

Table 31: SIAP Data Sample

MRP_TIME	PLANT	MATERIAL	MATL_TYPE	MRP_CTRLER	STORAGE_LOC	BASE_UOM	PLUS_MINUS	AVAIL_DATE	FINISH_DATE	RESCHED_DATE	MRP_ELEMENT_IND	MRP_ELEMENT	ELEMNT_DATA	EXCMSGKEY	EXCMESSAGE	REC_REQD_QTY	AVAIL_QTY1
044047	1102	101I0000001443	Z010	151		M2	B	20200101	00000000	00000000	WB		Estoq.			3513.720	3513.720
044047	1102	101I0000001443	Z010	151	1200	M2	-	20200217	20200217	00000000	SB	20705N5B01I0IAB	NecDep			14.920-	3697.643-
044047	1102	101I0000001443	Z010	151	1119	M2	+	20191218	20191218	20200103	QM	080002127707	LoteQM	U2	15	5.800	3563.640
044047	1102	101I0000001443	Z010	151	1200	M2	-	20200217	20200217	00000000	SB	20705N5B02I0IAB	NecDep			10.444-	3708.087-
044047	1102	101I0000001443	Z010	151	1200	M2	-	20200107	20200107	00000000	SB	20705G5F03I4CAB	NecDep			9.680-	1470.891-
044047	1102	101I0000001443	Z010	151	1200	M2	-	20200217	20200217	00000000	SB	20705N5C01I0IAB	NecDep			25.364-	3733.451-
044047	1102	101I0000001443	Z010	151	1200	M2	-	20200323	20200323	00000000	SB	20705N5D05I0IAB	NecDep			8.000-	3759.103-
044047	1102	101I0000001443	Z010	151	1200	M2	-	20200217	20200217	00000000	SB	20705N5D00I0IAB	NecDep			8.000-	3741.451-
044047	1102	101I0000001443	Z010	151	1200	M2	-	20200323	20200323	00000000	SB	20705N5F01I0IAC	NecDep			31.512-	3790.615-
044047	1102	101I0000001443	Z010	151	1200	M2	-	20200217	20200217	00000000	SB	20705N5D02I0IAB	NecDep			6.000-	3747.451-
044047	1102	101I0000001443	Z010	151	1200	M2	-	20200323	20200323	00000000	SB	20705N5G01I0IAC	NecDep			31.512-	3822.127-
044047	1102	101I0000001443	Z010	151	1200	M2	-	20200217	20200217	00000000	SB	20705N5D03I0IAB	NecDep			8.000-	3755.451-
044047	1102	101I0000001443	Z010	151	1200	M2	-	20200323	20200323	00000000	SB	20705N5H00I0IAB	NecDep			4.536-	3826.663-
044047	1102	101I0000001443	Z010	151	1200	M2	-	20200217	20200217	00000000	SB	20705N5D05I0IAB	NecDep			10.000-	3765.451-

By comparing both Tables 30 and 31, it is possible to understand that the names and column order of variables vary between samples, as well as the date format. When reading SAP files, the R program automatically converts the date entries to its standard date format of 'year-month-day'. However, when reading the SIAP files, it does not recognise these entries as a date, but rather as a numeric variable, thus forcing that change to be made manually. Another issue when analysing data types concerns the variable used to signal the increase or decrease of stock – 'Entrada.Necess'. Because of the minus operator's placement, the R program is not capable of making the conversion from character to numeric variable, so a workaround had to be built to deal with this issue. Figure 45 presents the code used for such transformations.

````
#Change Column Names and Order

colnames(df_merged)[1] <- "Data.MRP"
colnames(df_merged)[2] <- "Momento.MRP"
colnames(df_merged)[3] <- "Centro"
colnames(df_merged)[4] <- "Material"
colnames(df_merged)[5] <- "Tipo.de.Material"
colnames(df_merged)[6] <- "Planejador.MRP"
colnames(df_merged)[7] <- "Depósito"
colnames(df_merged)[8] <- "Unidade.medida.básica"
colnames(df_merged)[9] <- "Mais.menos"
colnames(df_merged)[10] <- "Data"
colnames(df_merged)[11] <- "Data.rem..fim.base"
colnames(df_merged)[12] <- "Dta.reprogramação"
colnames(df_merged)[13] <- "Cód.element.MRP"
colnames(df_merged)[15] <- "Elemento.MRP"
colnames(df_merged)[14] <- "Dados.p.elemento.MRP"
colnames(df_merged)[16] <- "Chave"
colnames(df_merged)[17] <- "Mensagem.de.exceção"
colnames(df_merged)[18] <- "Entrada.Necess."
colnames(df_merged)[19] <- "Qtd.disponível"

df_merged <- df_merged[,c(c(1:13),15,14,c(16:19))]
#Change Date Format

```{r}

df_merged$Data.MRP <- ymd(df_merged$Data.MRP)
df_merged$Data <- ymd(df_merged$Data)
df_merged$Data.rem..fim.base <- ymd(df_merged$Data.rem..fim.base)
df_merged$Dta.reprogramação <- ymd(df_merged$Dta.reprogramação)

```

#Filter Sunday's MRP Results

```{r}

domingos <- data.frame(domingos[-1, -c(1,2)])

colnames(domingos)[1] <- "Datas.SIAP"

domingos$Datas.SIAP <- as.Date(domingos$Datas.SIAP)

df_merged <- subset(df_merged, Data.MRP %in% domingos$Datas.SIAP)
#'EntradaNecess' Transformation

df_merged <- separate(data = df_merged, col = Entrada.Necess., into = c("Qtd", "Sinal"), sep = -1, remove = FALSE)

for (i in 1:nrow(df_merged)) {
  if(df_merged$Sinal[i] != "-"){
    df_merged$Entrada.Necess.[i] <- as.numeric(df_merged$Entrada.Necess.[i])
  }else if(df_merged$Sinal[i] == "-"){
    df_merged$Entrada.Necess.[i] <- as.numeric(df_merged$Qtd[i])
  }
}

df_merged <- df_merged[,-19]
df_merged$Entrada.Necess. <- as.numeric(df_merged$Entrada.Necess.)

for (i in 1:nrow(df_merged)) {
  if(df_merged$Sinal[i] == "-"){
    df_merged$Entrada.Necess.[i] <- (- df_merged$Entrada.Necess.[i])
  }
}
df_merged <- df_merged[,-19]


```
````

Figure 45: Sample of the Code in SIAP's Data Pre-processing

APPENDIX II – MRP RECORDS' DATA TREATMENT

The code used in the MRP records' data treatment is presented in Figures 46 to 49. It is noteworthy that a variable with the following MRP reading date was added to the dataset ('Data.Próx.Leitura'). This, aligned with two other variables giving the year's week number for the 'Data.MRP' and 'Data.Próx.Leitura' ('Semana.MRP' and 'Semana.Próx.Leitura', respectively), allowed for a better interpretation of each data entry, making it clear that in the end of week 'Semana.MRP', one is accessing what is expected to happen in week 'Semana.Próx.Leitura'.

```
#Data Treatment
```{r}
materials <- unique(df_merged$Material)

for (material in materials) {

  #Disregarding COINDU Arcos's Materials
  data <- subset(df_merged, Material == material & Elemento.MRP != "ReqCmp")

  lista_elementos <- unique(data$Elemento.MRP)

  #Ordering data entries based on 'Data.MRP', 'Data.Disponível' and 'Data.Movimento'

  data <- data[order(data$Data.MRP,data$Data, data$Data.rem..fim.base),]
  linhas <- nrow(data)

  #The initial stock for each material's reading is not the first line recorded. The next part of the algorithm rectifies this situation

  datasMRP <- data.frame(data %>% count(Data.MRP))
  counting <- 0

  ss <- FALSE

  for(nn in 1:length(lista_elementos)){
    if(lista_elementos[nn] == "EstSeg"){
      ss <- TRUE
      break
    }
  }
  if(ss == TRUE){
    for (j in 1:nrow(datasMRP)) {
      for (i in 1:linhas) {
        if(data$Data.MRP[i] == datasMRP$Data.MRP[j]){
          if(counting == 0){
            if(data$Mais.menos[i] == "B"){
              break
            }else{
              first_line <- i
              counting <- 1
            }
          }
          if(data$Mais.menos[i] == "B"){
            last_line <- i+1
            if(first_line != 1){
              data <- data[c(1:(first_line-1), i, last_line, c(first_line:(last_line-1)), c((last_line+1):nrow(data))),]
              counting <- 0
              break
            } else if(first_line ==1){
              data <- data[c(i, last_line, c(first_line:last_line-1), c(last_line+1:nrow(data))),]
              counting <- 0
              break
            }
          }
        }
      }
    }
  }
```

Figure 46: MRP Data Treatment – Part I
```

```r
}else{

  for (j in 1:nrow(datasMRP)) {
    for (i in 1:linhas) {
      if(data$Data.MRP[i] == datasMRP$Data.MRP[j]){
        if(counting == 0){
          if(data$Mais.menos[i] == "B"){
            break
          }else{
          first_line <- i
          counting <- 1
          }
        }
        if(data$Mais.menos[i] == "B"){
          last_line <- i
          if(first_line != 1){
            data <- data[c(1:(first_line-1),last_line, c(first_line:(last_line-1)), c((last_line+1):nrow(data))),]
            counting <- 0
            break
          } else if(first_line ==1){
            data <- data[c(last_line, c(first_line:last_line-1), c(last_line+1:nrow(data))),]
            counting <- 0
            break
          }
        }
      }
    }
  }
}
newnrow <- nrow(data)

data <- data[-c(linhas+1:newnrow),]

#Inventory Level Calculation: Replacing original variable 'Qtd.disponivel' by new variable 'Stock.Estimado'
for (i in 1:nrow(data)) {
  if(data$Mais.menos[i] == "B" & data$Elemento.MRP[i] == "Estoq."){
    data$Stock_Estimado[i] <- data$Entrada.Necess.[i]
  }
  else{
  data$Stock_Estimado[i] <- data$Stock_Estimado[i-1]+data$Entrada.Necess.[i]
  }
}

data <- data[,-c(2,19)]

#Assigning week number to variable 'Semana.MRP'

data <- data %>%
        mutate(date = as.Date(Data.MRP, format = "%Y-%m-%d")) %>%
        mutate(yearweek = as.integer(strftime(date, format = "%Y%V"))) %>%
        mutate(yearweek2 = ifelse(test = day(date) > 7 & substr(yearweek, 5, 6) == '01',
                                 yes  = yearweek + 100,
                                 no   = ifelse(test = month(date) == 1 & as.integer(substr(yearweek, 5, 6)) > 51,
                                               yes  = yearweek - 100,
                                               no   = yearweek)))


for (i in 1:nrow(data)) {
  if(data$yearweek[i] < data$yearweek2[i] ){
      data$yearweek2[i] <- data$yearweek[i]
  }

}


data <- data[, -c(19,20)]
colnames(data)[19] <- "Semana.MRP"

data <- data[, c(1,19, c(2:18))]
```

Figure 47: MRP Data Treatment – Part II

```
#New Database

GestãoStocks <- 0
GestãoStocks <- data.frame(GestãoStocks)
GestãoStocks$Data.MRP <- NA
GestãoStocks$Semana.MRP <- NA
GestãoStocks$Data.Próx.Leitura <- NA
GestãoStocks$Semana.Próx.Leitura <- NA
GestãoStocks$Centro <- NA
GestãoStocks$Material <- NA
GestãoStocks$Planeador <- NA
GestãoStocks$Depósito <- NA
GestãoStocks$Unid.Básica.Medida <- NA
GestãoStocks$Elemento.MRP <- NA
GestãoStocks$Dados.Elemento.MRP <- NA
GestãoStocks$Data.Movimento <- NA
GestãoStocks$Data.Disponível <- NA
GestãoStocks$Necessidade <- NA
GestãoStocks$Em.Trânsito <- NA
GestãoStocks$ControloQuali <- NA
GestãoStocks$Stock.Estimado <- NA

GestãoStocks <- GestãoStocks[,-1]
GestãoStocks <- GestãoStocks[1:nrow(data),]

#Ensuring date format
GestãoStocks$Data.MRP <- as.Date(as.character(GestãoStocks$Data.MRP), format = "%Y%m%d")
GestãoStocks$Data.Próx.Leitura <- as.Date(as.character(GestãoStocks$Data.Próx.Leitura),  format = "%Y%m%d")
GestãoStocks$Data.Movimento <- as.Date(as.character(GestãoStocks$Data.Movimento),  format = "%Y%m%d")
GestãoStocks$Data.Disponível <- as.Date(as.character(GestãoStocks$Data.Disponível),  format = "%Y%m%d")


lista <- unique(data[, c(1,2)])
lista$Data.MRP <- as.Date(format(lista$Data.MRP, "%Y-%m-%d"))

data$Data.MRP <- as.Date(format(data$Data.MRP, "%Y-%m-%d"))

data$Data <- as.Date(format(data$Data, "%Y-%m-%d"))

k <- 1

for (i in 1:nrow(lista)) {
  if(i != nrow(lista)){

    #Keeping entries with 'Data.Disponível' prior or equal to the following MRP reading
    filtro_data <- subset(data, (Data.MRP == lista$Data.MRP[i]) & (Data <= lista$Data.MRP[i+1]))

    linha1 <- k

    for (j in 1:nrow(filtro_data)) {
      GestãoStocks$Data.MRP[k] <- filtro_data$Data.MRP[j]
      GestãoStocks$Semana.MRP[k] <- filtro_data$Semana.MRP[j]
      GestãoStocks$Data.Próx.Leitura[k] <- lista$Data.MRP[i+1]
      GestãoStocks$Semana.Próx.Leitura[k] <- lista$Semana.MRP[i+1]
      GestãoStocks$Centro[k] <- filtro_data$Centro[j]
      GestãoStocks$Material[k] <- filtro_data$Material[j]
      GestãoStocks$Planeador[k] <- filtro_data$Planejador.MRP[j]
      GestãoStocks$Depósito[k] <- filtro_data$Depósito[j]
      GestãoStocks$Unid.Básica.Medida[k] <- filtro_data$Unidade.medida.básica[j]
      GestãoStocks$Elemento.MRP[k] <- filtro_data$Elemento.MRP[j]
      GestãoStocks$Dados.Elemento.MRP[k] <- filtro_data$Dados.p.elemento.MRP[j]
      GestãoStocks$Data.Movimento[k] <- filtro_data$Data.rem..fim.base[j]
      GestãoStocks$Data.Disponível[k] <- filtro_data$Data[j]
      #Splitting 'Entrada.Necess' variable into 'Necessidade', 'Em.Trânsito' and 'ControloQuali' variables

      if(filtro_data$Entrada.Necess.[j] >= 0){
        if(filtro_data$Elemento.MRP[j] != "Estoq."){
          if(filtro_data$Elemento.MRP[j] == "LoteQM"){
            GestãoStocks$Em.Trânsito[k] <- 0
            GestãoStocks$Necessidade[k] <- 0
            GestãoStocks$ControloQuali[k] <- filtro_data$Entrada.Necess.[j]
            GestãoStocks$Stock.Estimado[k] <- filtro_data$Stock_Estimado[j]
          }else{
          GestãoStocks$Em.Trânsito[k] <- filtro_data$Entrada.Necess.[j]
          GestãoStocks$Necessidade[k] <- 0
          GestãoStocks$ControloQuali[k] <- 0
          GestãoStocks$Stock.Estimado[k] <- filtro_data$Stock_Estimado[j]
          }
        }else{
          GestãoStocks$Em.Trânsito[k] <- 0
          GestãoStocks$Necessidade[k] <- 0
          GestãoStocks$ControloQuali[k] <- 0
          GestãoStocks$Stock.Estimado[k] <- filtro_data$Stock_Estimado[j]
        }
      }else if(filtro_data$Entrada.Necess.[j] < 0){
        GestãoStocks$Necessidade[k] <- filtro_data$Entrada.Necess.[j]
        GestãoStocks$Em.Trânsito[k] <- 0
        GestãoStocks$ControloQuali[k] <- 0
        GestãoStocks$Stock.Estimado[k] <- filtro_data$Stock_Estimado[j]
      }

      k <- k+1

    }
```

Figure 48: MRP Data Treatment – Part III

```
    }else if(i == nrow(lista)){

      #Keeping entries with 'Data.Disponível' prior or equal to the following MRP reading
      filtro_data <- subset(data, (Data.MRP == lista$Data.MRP[i]) & (Data <= lista$Data.MRP[i]+7))

      for (j in 1:nrow(filtro_data)) {
        GestãoStocks$Data.MRP[k] <- filtro_data$Data.MRP[j]
        GestãoStocks$Semana.MRP[k] <- filtro_data$Semana.MRP[j]
        GestãoStocks$Data.Próx.Leitura[k] <- lista$Data.MRP[i]+7
        GestãoStocks$Semana.Próx.Leitura[k] <- lista$Semana.MRP[i]+1
        GestãoStocks$Centro[k] <- filtro_data$Centro[j]
        GestãoStocks$Material[k] <- filtro_data$Material[j]
        GestãoStocks$Planeador[k] <- filtro_data$Planejador.MRP[j]
        GestãoStocks$Depósito[k] <- filtro_data$Depósito[j]
        GestãoStocks$Unid.Básica.Medida[k] <- filtro_data$Unidade.medida.básica[j]
        GestãoStocks$Elemento.MRP[k] <- filtro_data$Elemento.MRP[j]
        GestãoStocks$Dados.Elemento.MRP[k] <- filtro_data$Dados.p.elemento.MRP[j]
        GestãoStocks$Data.Movimento[k] <- filtro_data$Data.rem..fim.base[j]
        GestãoStocks$Data.Disponível[k] <- filtro_data$Data[j]

        #Splitting 'Entrada.Necess' variable into 'Necessidade', 'Em.Trânsito' and 'ControloQuali' variables

        if(filtro_data$Entrada.Necess.[j] >= 0){
          if(filtro_data$Elemento.MRP[j] != "Estoq."){
            if(filtro_data$Elemento.MRP[j] == "LoteQM"){
              GestãoStocks$Em.Trânsito[k] <- 0
              GestãoStocks$Necessidade[k] <- 0
              GestãoStocks$ControloQuali[k] <- filtro_data$Entrada.Necess.[j]
              GestãoStocks$Stock.Estimado[k] <- filtro_data$Stock_Estimado[j]
            }else{
            GestãoStocks$Em.Trânsito[k] <- filtro_data$Entrada.Necess.[j]
            GestãoStocks$Necessidade[k] <- 0
            GestãoStocks$ControloQuali[k] <- 0
            GestãoStocks$Stock.Estimado[k] <- filtro_data$Stock_Estimado[j]
            }
          }else{
            GestãoStocks$Em.Trânsito[k] <- 0
            GestãoStocks$Necessidade[k] <- 0
            GestãoStocks$ControloQuali[k] <- 0
            GestãoStocks$Stock.Estimado[k] <- filtro_data$Stock_Estimado[j]
          }
        }else if(filtro_data$Entrada.Necess.[j] < 0){
          GestãoStocks$Necessidade[k] <- filtro_data$Entrada.Necess.[j]
          GestãoStocks$Em.Trânsito[k] <- 0
          GestãoStocks$ControloQuali[k] <- 0
          GestãoStocks$Stock.Estimado[k] <- filtro_data$Stock_Estimado[j]
        }

        k <- k+1

      }
    }
  }

  GestãoStocks <- GestãoStocks[-c(k:nrow(GestãoStocks)),]

  #Exporting the new database for each material after the treatment is completed

  write.xlsx(GestãoStocks, file = paste0("GestãoStocks_",material,".xlsx"))

  rm(GestãoStocks)

}
```

Figure 49: MRP Data Treatment – Part IV

APPENDIX III – CREATION OF MRP DATA TABLES

After the initial treatment conducted to the historical MRP records, four different tables were created, in order to organise the available data and turn it into useful information.

To this purpose, the **Stock Out Table** signals the entries which resulted in a negative inventory level after MRP calculations, as well as it determines the amount of material out of stock. This table also distinguishes two inventory levels, based on the type of needs considered – the expected inventory level after each movement ('Stock.Estimado') and the most likely inventory level ('Stock.Expectável') – and helps to evaluate the possible shortage of materials in both scenarios.

The most likely inventory level only considers 'ResOrd' needs, while 'Stock.Estimado' also weighs the needs not yet confirmed by the customer ('NecDep'). This is an important distinction, since, in most cases, the customer will not confirm all quantities presented as 'NecDep', if any. As a result, the available stock is expected to be somewhere between the expected and most likely inventory levels, typically closer to the latter, in a week's time. The algorithm that accounts for these transformations is presented in Figure 50.

Nonetheless, despite all this treatment, the way data is still structured does not allow for, at the time of the MRP reading, a clear overall understanding of what is expected to happen to each material, in the course of the following week. So far, each MRP reading details the movements that are supposed to make the inventory level vary, but that information is not properly summarised, preventing oneself from (i) perceiving each material's total needs and how many of these are confirmed by the customer or expected values; (ii) comparing initial and final inventory levels (expected and most likely); (iii) comprehending the impact of stock outs (occurrence and quantity), or (iv) learning more about the average stock kept on hand.

These questions are put to rest by the **Summary Table** that relies on the Stock Out Table to outline each material's expected weekly behaviour, at the time of each MRP reading. By doing this, the MRP dates themselves become irrelevant, while the week numbers turn into the sole identifier of each MRP reading. Of course that, in hindsight, the Summary Table loses a lot of information regarding, for example, which end-items are behind raw materials demand. However, it should be kept in mind that this table, as any other future tables, does not replace the previous datasets, it only displays the same information under a different light, allowing for a bigger and better understanding of what is happening in the production system. Figures 51 and 52 detail the code used to create this table.

```
#Stock Out Table
```{r}

df_merged$Previsão.Quebra <- NA
df_merged$Severidade.Prevista <- NA
df_merged$Stock.Expectável <- NA
df_merged$Previsão.Quebra.Real <- NA
df_merged$Severidade.Quebra.Real <- NA
df_merged$Stock.Segurança <- NA

#Analysis to shortage of materials

Materials <- unique(df_merged$Material)

for (material in Materials) {

  ss <- 0

  verificacao <- subset(df_merged, Material == material & Elemento.MRP == "EstSeg")

  if(is.na(verificacao$Data.MRP[1]) == FALSE){
    ss <- 1
  }

  for (i in 1:nrow(df_merged)) {
    if(df_merged$Material[i] == material){
      if(ss == 1){
        for(jj in 1:nrow(verificacao)){
          if (df_merged$Data.MRP[i] == verificacao$Data.MRP[jj]){
            df_merged$Stock.Segurança[i] <- abs(verificacao$Necessidade[jj])
          }
        }
      }else{
        df_merged$Stock.Segurança[i] <- 0
      }

      #Considering Expected Inventory Level

      if(df_merged$Stock.Estimado[i] < 0){
        df_merged$Previsão.Quebra[i] <- 1 #Binary variable to signal the existence of material stock outs
      }else{
        df_merged$Previsão.Quebra[i] <- 0
      }
      #Calculating the amount of material out of stock
      if(i != 1){
        if(df_merged$Necessidade[i] < 0 & df_merged$Stock.Estimado[i] < 0){
          if(df_merged$Stock.Estimado[i-1] >= 0){
            df_merged$Severidade.Prevista[i] <- df_merged$Stock.Estimado[i]
          }else if(df_merged$Stock.Estimado[i-1] < 0){
            df_merged$Severidade.Prevista[i] <- df_merged$Necessidade[i]
          }
        } else{
          df_merged$Severidade.Prevista[i] <- 0
        }
      } else if(i == 1){
        if(df_merged$Stock.Estimado[i] < 0){
          df_merged$Severidade.Prevista[i] <- df_merged$Stock.Estimado[i]
        }else{
          df_merged$Severidade.Prevista[i] <- 0
        }
      }

      #Calculating The Most Likely Inventory Level


      if(df_merged$Elemento.MRP[i] == "Estoq."){
        df_merged$Stock.Expectável[i] <- df_merged$Stock.Estimado[i]
      }else if(df_merged$Elemento.MRP[i] != "NecDep"){
        df_merged$Stock.Expectável[i] <- df_merged$Stock.Expectável[i-1] + df_merged$Necessidade[i] + df_merged$Em.Trânsito[i] +
df_merged$ControloQuali[i]
      }else{
        df_merged$Stock.Expectável[i] <- df_merged$Stock.Expectável[i-1]
      }
      #Binary variable to signal the existence of material stock outs, considering the most likely inventory level

      if(df_merged$Stock.Expectável[i] < 0 & df_merged$Elemento.MRP[i] == "ResOrd"){
        df_merged$Previsão.Quebra.Real[i] <- 1
      }else{
        df_merged$Previsão.Quebra.Real[i] <- 0
      }

      #Calculating the amount of material out of stock, considering the most likely inventory level

      if(i != 1){
        if(df_merged$Necessidade[i] < 0 & df_merged$Stock.Expectável[i] < 0 & df_merged$Elemento.MRP[i] == "ResOrd"){
          if(df_merged$Stock.Expectável[i-1] >= 0){
            df_merged$Severidade.Quebra.Real[i] <- df_merged$Stock.Expectável[i]
          }else if(df_merged$Stock.Expectável[i-1] < 0){
            df_merged$Severidade.Quebra.Real[i] <- df_merged$Necessidade[i]
          }
        } else{
          df_merged$Severidade.Quebra.Real[i] <- 0
        }
      } else if(i == 1){
        if(df_merged$Stock.Expectável[i] < 0 & df_merged$Elemento.MRP[i] == "ResOrd"){
          df_merged$Severidade.Quebra.Real[i] <- df_merged$Stock.Expectável[i]
        }else{
          df_merged$Severidade.Quebra.Real[i] <- 0
        }
      }

    }
  }
}

```
```

Figure 50: Code used to Create the Stock Out Table

```{r}
#Declaring Summary Table Variables

Materials <- unique(df_merged$Material)

TabelaSumário <- 0
TabelaSumário <- data.frame(TabelaSumário)
TabelaSumário$Semana.MRP <- NA
TabelaSumário$Semana.Próx.Leitura <- NA
TabelaSumário$Material <- NA
TabelaSumário$Planeador <- NA
TabelaSumário$Unid.Básica.Medida <- NA
TabelaSumário$Stock.Segurança <- NA
TabelaSumário$Nec.Totais <- NA
TabelaSumário$Nec.Totais.Confirmadas <- NA
TabelaSumário$Nec.Totais.Esperadas <- NA
TabelaSumário$Qtd.Total.Trânsito <- NA
TabelaSumário$Qtd.Total.Quali <- NA
TabelaSumário$Stock.Semanal.Inicial <- NA
TabelaSumário$Stock.Final.Estimado <- NA
TabelaSumário$Stock.Médio.Estimado <- NA
TabelaSumário$Stock.Final.Expectável <- NA
TabelaSumário$Stock.Médio.Expectável <- NA
TabelaSumário$Quebras.Totais.Estimadas <- NA
TabelaSumário$Estimativa.Unid.Em.Falta.Total <- NA
TabelaSumário$Quebra.Nec.Confirmadas <- NA
TabelaSumário$Unid.Falta.Nec.Confirmadas <- NA
TabelaSumário$Severidade.Média.Quebra.Total <- NA
TabelaSumário$Severidade.Média.Quebra.Confirmada <- NA

TabelaSumário <- TabelaSumário[,-1]
TabelaSumário <- TabelaSumário[1:100000,]
```

```{r}
k <- 1

for (material in Materials) {
  data <- subset(df_merged, Material == material)
  semanas <- unique(data$Semana.MRP)

  for (semana in semanas) {
    filtro_semana <- subset(data, Semana.MRP == semana)

    TabelaSumário$Semana.MRP[k] <- filtro_semana$Semana.MRP[1]
    TabelaSumário$Semana.Próx.Leitura[k] <- filtro_semana$Semana.Próx.Leitura[1]
    TabelaSumário$Material[k] <- filtro_semana$Material[1]
    TabelaSumário$Planeador[k] <- filtro_semana$Planeador[1]
    TabelaSumário$Unid.Básica.Medida[k] <- filtro_semana$Unid.Básica.Medida[1]
    TabelaSumário$Stock.Segurança[k] <- filtro_semana$Stock.Segurança[1]

    TabelaSumário$Nec.Totais.Confirmadas[k] <- 0 #For orders with 'ResOrd' Status
    TabelaSumário$Nec.Totais.Esperadas[k] <- 0  #For orders with 'NecDep' Status
    for (i in 1:nrow(filtro_semana)) {
      if(filtro_semana$Elemento.MRP[i] == "ResOrd"){
        TabelaSumário$Nec.Totais.Confirmadas[k] <- TabelaSumário$Nec.Totais.Confirmadas[k] + abs(filtro_semana$Necessidade[i])
      } else if(filtro_semana$Elemento.MRP[i] == "NecDep"){
        TabelaSumário$Nec.Totais.Esperadas[k] <- TabelaSumário$Nec.Totais.Esperadas[k] + abs(filtro_semana$Necessidade[i])
      }
    }

    TabelaSumário$Nec.Totais[k] <- TabelaSumário$Nec.Totais.Confirmadas[k] + TabelaSumário$Nec.Totais.Esperadas[k]

    TabelaSumário$Qtd.Total.Quali[k] <- sum(filtro_semana$ControloQuali[1:nrow(filtro_semana)])

    TabelaSumário$Qtd.Total.Trânsito[k] <- sum(filtro_semana$Em.Trânsito[1:nrow(filtro_semana)])

    TabelaSumário$Stock.Médio.Estimado[k] <- mean(filtro_semana$Stock.Estimado[1:nrow(filtro_semana)])
    TabelaSumário$Stock.Médio.Expectável[k] <- mean(filtro_semana$Stock.Expectável[1:nrow(filtro_semana)])

    TabelaSumário$Quebras.Totais.Estimadas[k] <- sum(filtro_semana$Previsão.Quebra[1:nrow(filtro_semana)])
    TabelaSumário$Quebra.Nec.Confirmadas[k] <- sum(filtro_semana$Previsão.Quebra.Real[1:nrow(filtro_semana)])
```

Figure 51: Code used to Create the Summary Table – Part I

```
    TabelaSumário$Stock.Médio.Estimado[k] <- mean(filtro_semana$Stock.Estimado[1:nrow(filtro_semana)])
    TabelaSumário$Stock.Médio.Expectável[k] <- mean(filtro_semana$Stock.Expectável[1:nrow(filtro_semana)])

    TabelaSumário$Quebras.Totais.Estimadas[k] <- sum(filtro_semana$Previsão.Quebra[1:nrow(filtro_semana)])
    TabelaSumário$Quebra.Nec.Confirmadas[k] <- sum(filtro_semana$Previsão.Quebra.Real[1:nrow(filtro_semana)])


    TabelaSumário$Estimativa.Unid.Em.Falta.Total[k] <- sum(filtro_semana$Severidade.Prevista[1:nrow(filtro_semana)])
    TabelaSumário$Unid.Falta.Nec.Confirmadas[k] <- sum(filtro_semana$Severidade.Quebra.Real[1:nrow(filtro_semana)])

    TabelaSumário$Stock.Semanal.Inicial[k] <- filtro_semana$Stock.Estimado[1]
    TabelaSumário$Stock.Final.Estimado[k] <- filtro_semana$Stock.Estimado[nrow(filtro_semana)]
    TabelaSumário$Stock.Final.Expectável[k] <- filtro_semana$Stock.Expectável[nrow(filtro_semana)]

    if(TabelaSumário$Quebras.Totais.Estimadas[k] == 0){
      TabelaSumário$Severidade.Média.Quebra.Total[k] <- 0
    }else{
    TabelaSumário$Severidade.Média.Quebra.Total[k] <-
TabelaSumário$Estimativa.Unid.Em.Falta.Total[k]/TabelaSumário$Quebras.Totais.Estimadas[k]
    }

    if(TabelaSumário$Quebra.Nec.Confirmadas[k] == 0){
      TabelaSumário$Severidade.Média.Quebra.Confirmada[k] <- 0
    }else{
      TabelaSumário$Severidade.Média.Quebra.Confirmada[k] <-
TabelaSumário$Unid.Falta.Nec.Confirmadas[k]/TabelaSumário$Quebra.Nec.Confirmadas[k]
    }

    k <- k+1
  }
}

TabelaSumário <- TabelaSumário[-c(k:nrow(TabelaSumário)),]

```

Figure 52: Code used to Create the Summary Table – Part II

Furthermore, the third data table, **Real Table**, works as a bridge between what was supposed to occur and what truly happened during the course of each week. The logic behind how it works is better understood with a generic example.

Consider Material A1. At the end of week i, the MRP records hold this material's expected movements during week i+1 and, based on those, it estimates its inventory level's variation over that period of time, including its final stock level. This information is shown in the Real Table, in a similar fashion to the one found in the Summary Table.

Nevertheless, because this is a historical data assessment, one has access to what was registered in the system by the end of week i+1 and can compare that information to the one retrieved from week i. For instance, by comparing which production orders with 'Data.Disponível' prior to week i+1 are still active by that Sunday, one understands how much of Material A1 was actually consumed in the system during that week. The same analytical approach can be applied to other variables, including expected needs, scheduled deliveries and quality control batches.

Note that the use of the expression 'consumed in the system' is not random, since one of the company's current struggles lies in the fact that production does not close its orders immediately after their completion. This, of course, means the stock presented in the system is overestimated; however, so are the material's needs in the same amount – thus, even though the MRP data does not represent the real physical amount of material available, its coverage is still accurate.

This logic allowed to uncover a key situation to the service level estimation problem. If 'NecDep' production orders are unconfirmed costumer demand, it makes sense that, by the end of week i+1, there can no longer be any needs of this kind referring to week i+1 itself, since week i+1 has already come to an end and, in week i+2, the customer can only confirm orders from that same week onwards. So, the big question is, how can there be unconfirmed orders, related to weeks that have already come to an end?

The answer to this question is, in fact, quite simple. In these circumstances, these needs are, indeed, confirmed customer orders, but, because the system estimated a lack of materials to fulfil them, they were not allowed to be transformed, as they should, into 'ResOrd', remaining, therefore, with the 'NecDep' status. Hence, the Real Table includes the variable 'NecDep_i1' to account for material's quantities in this situation and to help to estimate, in the future, each material's service level performance.

Another peculiarity of this analysis regards the fact that it is possible to reach the final inventory level in the system by the end of each week, due to the fact that the initial stock on hand registered in the MRP reading of week i+1 is nothing but the final inventory available at the end of that same week.

Additionally, control variables were included in the Real Table in order to understand if this parallel analysis was being, somehow, deceptive. These variables determined the final inventory level reached according to the described logic, and enabled its comparison with the actual final stock on hand in the system by the end of week i+1. Although the results were not exactly the same for all periods, they only differed slightly. This relates to two major factors:

- In the initial data treatment stage, the MRP horizon was defined as weekly, meaning that records would only be retained for dates preceding the MRP reading and for the subsequent seven days. However, detailed analysis showed that sometimes, raw materials' deliveries scheduled for over this period are anticipated and, because they arrive and are approved by quality control before the next MRP reading, never appear on the collected records. This contributes to the cases in which the final stock on hand turns out to be superior to the one estimated by the control variables;
- The weekly data collection also means that specific movements that happen during the week are not registered on Sunday's MRP reading, only their consequences. For example, batches that were not released by quality control to production or production defects that resulted in the loss of material, both imply that the final inventory level will be inferior to what would be expected. Since the control variables do not have this information to take into account in the calculations, the expected inventory levels end up being overestimated.

Despite these limitations, the Real Table paints an insightful picture of the company's weekly dynamics and holds vital information to the materials' performance assessment carried out in section 4.4.2. The Real Table's algorithm is presented in Figures 53 to 58. Note that one key feature of this data table revolves around the fact that it distinguishes production orders and expected needs, known at the end of week i, from new orders and 'NecDep_i1' that appear in week i+1. Ensuring this, however, was no trivial task, since the production orders do not have a unique ID number linked to them.

Consequently, it was necessary to define a criterion to identify the same 'ResOrd' and 'NecDep' entries. An example of the rule put in place is highlighted in Figure 54, basically consisting in assuring the same 'Elemento.MRP', material number and 'Data.Disponível' between consecutive readings, as well as validating the variable 'Check' as equal to 0. This last condition guarantees that, if more than one entry matches the other conditions, each record will be assigned only once and by order of appearance. Note that, the quantities requested in each order are not a good variable to be taken into consideration, because, in between weeks, the production orders may be partially fulfilled, meaning that the MRP reading at the end of week i+1 may present an inferior need to the quantity originally requested at the end of week i for the same production order.

```
```{r}

TabelaReal <- 0
TabelaReal <- data.frame(TabelaReal)
TabelaReal$Material <- NA
TabelaReal$Planeador <- NA
TabelaReal$Unid.Básica.Medida <- NA
TabelaReal$Stock.Segurança <- NA
TabelaReal$Semana<- NA


TabelaReal$ResOrd.Semana_i <- NA #production orders to week i+1 that are already confirmed in the system in the end of week i
TabelaReal$ResOrd.Transitadas <- NA #production orders to week i+1 that remain in the system by the end of that week
TabelaReal$Cump.ResOrd <- NA #the fraction of known production orders to week i+1 that were closed by the end of that week
TabelaReal$ResOrd.Novas_Semana_i1 <- NA #new production orders to week i+1 that were unaccounted for in the end of week i, but that
appear as 'not closed' by the end of week i+1 (that is why it is possible to know about their existence)

TabelaReal$NecDep.Semana_i <- NA #customer's unconfirmed needs by the end of week i, referring to week i+1
TabelaReal$NecDep.Semana_i1 <- NA #customer's unconfirmed needs by the end of week i+1, referring to that same week

TabelaReal$Cump.ResOrd.NecDep_i1 <- NA #the fraction of known production orders to week i+1 that were closed by the end of that
week, considering NecDep.Semana_i1

TabelaReal$Qtd.Prev.Rececionar <- NA #material's scheduled deliveries that are expected to become available to production during
week i+1
TabelaReal$Qtd.OG.Rececionada <- NA #the amount of material expected to be delivered and successfully supplied during week i+1
TabelaReal$Receção.Transitada <- NA #the amount of material expected to be delivered, but that was not successfully supplied by the
end of week i+1
TabelaReal$Percent.Receções.Programadas <- NA # Qtd.OG.Rececionada/Qtd.Prev.Rececionar

TabelaReal$NovasReceções_i1 <- NA #a delivery that was pushed forward to week i+1, but that has not arrived by the end of that week
(that is why there is a record of this change)
TabelaReal$Receções.Total.Est <- NA #TabelaReal$Qtd.Prev.Rececionar + TabelaReal$NovasReceções_i1

TabelaReal$Percent.Receções.Totais <- #TabelaReal$Qtd.OG.Rececionada/TabelaReal$Receções.Total.Est

TabelaReal$LotesQM.Semana_i <- NA #material's batches expected to get quality's approval by the end of week i+1, hence becoming
available to production
TabelaReal$LotesQM.Transitados <- NA #amount of material expected to get quality's approval by the end of week i+1, but that have
not become available to production by the end of that week
TabelaReal$LotesQM.Fechados <- NA #TabelaReal$LotesQM.Semana_i - TabelaReal$LotesQM.Transitados
TabelaReal$LotesQM.Percent.Semana_i <- NA #TabelaReal$LotesQM.Fechados/TabelaReal$LotesQM.Semana_i
TabelaReal$LotesQM.Semana_i1 <- NA #new batches that had not transitioned to quality inspection by the end of week i, but that went
to quality inspection during week i+1. These batches were expected to be approved during week i+1, but that did not happen and that
is why their records can be found on Sunday's reading
TabelaReal$LOtesQM.Total.Est <- NA #TabelaReal$LotesQM.Semana_i+TabelaReal$LotesQM.Semana_i1
TabelaReal$LotesQM.Percent.Est <- NA #TabelaReal$LotesQM.Fechados/LOtesQM.Total.Est

TabelaReal$Stock.Inicial <- NA #Initial stock of week i+1, obtained on Sunday of week i
TabelaReal$Stock.Final.Estimado <- NA #Expected inventory level after considering all expected movements (the same as in the
Summary Table)
```

Figure 53: Code used to Create the Real Table – Part I
```

```
TabelaReal$Stock.Final.Expectável <- NA #The most likely inventory level considering only ResOrd (the same as in the Summary Table)
TabelaReal$Stock.Final.Real <- NA #MRP's initial stock on hand in the end of week i+1

TabelaReal$Balanço_Sem_NecDep <- NA #Final stock control variable, not considering the difference between NecDep.Semana_i and
NecDep.Semana_i1
TabelaReal$Balanço_Com_NecDep <- NA #Final stock control variable, considering the difference between NecDep.Semana_i and
NecDep.Semana_i1

TabelaReal <- TabelaReal[,-1]
TabelaReal <- TabelaReal[1:100000,]


```
```{r}

k <- 1

for (material in Materials) {

  filtro_material <- subset(df_merged, Material == material)
  semanas_material <- unique(filtro_material$Semana.Próx.Leitura)
  lista <- unique(filtro_material$Semana.MRP)

  for (semana in semanas_material) {
    if(semana != semanas_material[length(semanas_material)]){
      if (semana != semanas_material[1]) {
        filtro_semana_i <- subset(filtro_material, Semana.MRP == semanas_material[which(semanas_material == semana)-1])
        filtro_semana_i1 <- subset(filtro_material, Semana.MRP == semana)

        if(is.na(filtro_semana_i$Data.MRP[1]) == FALSE){

          TabelaReal$Material[k] <- material
          TabelaReal$Planeador[k] <- filtro_material$Planeador[1]
          TabelaReal$Unid.Básica.Medida[k] <- filtro_material$Unid.Básica.Medida[1]
          TabelaReal$Semana[k] <- semana

          #Values Retrieved from the Summary Table
          for (i in 1:nrow(TabelaSumário)) {
            if(TabelaSumário$Semana.Próx.Leitura[i] == semana & TabelaSumário$Material[i] == material){
              TabelaReal$ResOrd.Semana_i[k] <- TabelaSumário$Nec.Totais.Confirmadas[i]
              TabelaReal$NecDep.Semana_i[k] <- TabelaSumário$Nec.Totais.Esperadas[i]
              TabelaReal$Qtd.Prev.Recepcionar[k] <- TabelaSumário$Qtd.Total.Trânsito[i]
              TabelaReal$LotesQM.Semama_i[k] <- TabelaSumário$Qtd.Total.Quali[i]
              TabelaReal$Stock.Inicial[k] <- TabelaSumário$Stock.Semanal.Inicial[i]
              TabelaReal$Stock.Final.Estimado[k] <- TabelaSumário$Stock.Final.Estimado[i]
              TabelaReal$Stock.Final.Expectável[k] <- TabelaSumário$Stock.Final.Expectável[i]
              TabelaReal$Stock.Segurança[k] <- TabelaSumário$Stock.Segurança[i]
            }
          }
          #Transitioned Production Orders from one week to the next

          TabelaReal$ResOrd.Transitadas[k] <- 0
          filtro_semana_i1$Check <- 0

          for (j in 1:nrow(filtro_semana_i)) {
            for (n in 1:nrow(filtro_semana_i1)) {
              if(filtro_semana_i$Elemento.MRP[j] == "ResOrd" & filtro_semana_i1$Elemento.MRP[n] == "ResOrd" &
filtro_semana_i$Material[j] == filtro_semana_i1$Material[n] & filtro_semana_i$Data.Disponível[j] ==
filtro_semana_i1$Data.Disponível[n] & filtro_semana_i1$Check[n] == 0){
                TabelaReal$ResOrd.Transitadas[k] <- TabelaReal$ResOrd.Transitadas[k] + abs(filtro_semana_i1$Necessidade[n])
                filtro_semana_i1$Check[n] <- 1
              }
            }
          }

          #New Production Orders

          TabelaReal$ResOrd.Novas_Semana_i1[k] <- 0

          for (n in 1:nrow(filtro_semana_i1)) {
            if(filtro_semana_i1$Elemento.MRP[n] == "ResOrd" & filtro_semana_i1$Check[n] == 0 & filtro_semana_i1$Data.Disponível[n]
< filtro_semana_i1$Data.MRP[n]){
              TabelaReal$ResOrd.Novas_Semana_i1[k] <- TabelaReal$ResOrd.Novas_Semana_i1[k] + abs(filtro_semana_i1$Necessidade[n])
            }
          }
          #Fraction of the known production orders to week i+1 that were closed (not considering NecDep.Semana_i1)

          if(TabelaReal$ResOrd.Semana_i[k] != 0){
            TabelaReal$Cump.ResOrd[k] <-
(TabelaReal$ResOrd.Semana_i[k]-TabelaReal$ResOrd.Transitadas[k])/TabelaReal$ResOrd.Semana_i[k]
          }else{
            TabelaReal$Cump.ResOrd[k] <- 1
          }

          #Customer's unconfirmed needs by the end of week i+1

          TabelaReal$NecDep.Semana_i1[k] <- 0

          for (n in 1:nrow(filtro_semana_i1)) {
            if(filtro_semana_i1$Data.Disponível[n] < filtro_semana_i1$Data.MRP[n] & filtro_semana_i1$Elemento.MRP[n] == "NecDep"){
              TabelaReal$NecDep.Semana_i1[k] <- TabelaReal$NecDep.Semana_i1[k] + abs(filtro_semana_i1$Necessidade[n])
            }
          }
```

Figure 54: Code used to Create the Real Table – Part II

```
        #Fraction of the known production orders to week i+1 that were closed (considering NecDep.Semana_i1)

        if(TabelaReal$NecDep.Semana_i1[k] > 0){
          TabelaReal$Cump.ResOrd.NecDep_i1[k] <-
(TabelaReal$ResOrd.Semana_i[k]-TabelaReal$ResOrd.Transitadas[k])/(TabelaReal$ResOrd.Semana_i[k]+TabelaReal$NecDep.Semana_i1[k])
        }else{
          TabelaReal$Cump.ResOrd.NecDep_i1[k] <- TabelaReal$Cump.ResOrd[k]
        }

        #Amount of In-transit Material
        TabelaReal$Receção.Transitada[k] <- 0
        TabelaReal$NovasReceções_i1[k] <- 0

        for (j in 1:nrow(filtro_semana_i1)) {
          for (n in 1:nrow(filtro_semana_i)) {
            if(filtro_semana_i1$Data.Disponivel[j] < filtro_semana_i1$Data.MRP[j] &
filtro_semana_i1$Em.Trânsito[j]==filtro_semana_i$Em.Trânsito[n] & filtro_semana_i1$Check[j] == 0){
            TabelaReal$Receção.Transitada[k] <- TabelaReal$Receção.Transitada[k] + filtro_semana_i1$Em.Trânsito[j]
            filtro_semana_i1$Check[j] <- 1
            }
          }
        }

        #Deliveries that had been pushed forward, but that have not arrived
        for (j in 1:nrow(filtro_semana_i1)) {
          if(filtro_semana_i1$Data.Disponivel[j] < filtro_semana_i1$Data.MRP[j] &  filtro_semana_i1$Check[j] == 0){
            TabelaReal$NovasReceções_i1[k] <- TabelaReal$NovasReceções_i1[k] + filtro_semana_i1$Em.Trânsito[j]
            filtro_semana_i1$Check[j] <- 1
          }
        }

        if(TabelaReal$Qtd.Prev.Rececionar[k] >= TabelaReal$Receção.Transitada[k]){
          TabelaReal$Qtd.OG.Rececionada[k] <- TabelaReal$Qtd.Prev.Rececionar[k] - TabelaReal$Receção.Transitada[k]
        } else if(TabelaReal$Qtd.Prev.Rececionar[k] < TabelaReal$Receção.Transitada[k]){
          TabelaReal$Qtd.OG.Rececionada[k] <- 0
        }

        #Fraction of successfully supplied expected deliveries
        if(TabelaReal$Qtd.Prev.Rececionar[k] != 0 ){
          TabelaReal$Percent.Receções.Programadas[k] <- TabelaReal$Qtd.OG.Rececionada[k]/TabelaReal$Qtd.Prev.Rececionar[k]
        }else if (TabelaReal$Qtd.Prev.Rececionar[k] == 0){
          if(TabelaReal$Qtd.OG.Rececionada[k] == 0 & TabelaReal$Receção.Transitada[k] == 0){
            TabelaReal$Percent.Receções.Programadas[k] <- 1
          }else if(TabelaReal$Qtd.OG.Rececionada[k] != 0){
            TabelaReal$Percent.Receções.Programadas[k] <- 1
          }else if(TabelaReal$Qtd.OG.Rececionada[k] == 0 & TabelaReal$Receção.Transitada[k] != 0){
            TabelaReal$Percent.Receções.Programadas[k] <- 0
          }
        }

        #New delivery total, considering pushed forward deliveries that were not successfully supplied

        TabelaReal$Receções.Total.Est[k] <- TabelaReal$Qtd.Prev.Rececionar[k] + TabelaReal$NovasReceções_i1[k]

        #Fraction of successfully supplied deliveries, considering the new total

        if(TabelaReal$Receções.Total.Est[k] != 0){
          TabelaReal$Percent.Receções.Totais[k] <- TabelaReal$Qtd.OG.Rececionada[k]/TabelaReal$Receções.Total.Est[k]
        }else{
          TabelaReal$Percent.Receções.Totais[k] <- 1
        }

        #Quality Control Batches - batch numbers are unique

        TabelaReal$LotesQM.Transitados[k] <- 0

        for (j in 1:nrow(filtro_semana_i1)) {
          for (n in 1:nrow(filtro_semana_i)) {
            if(filtro_semana_i$Elemento.MRP[n] != "Estoq."){
              if(filtro_semana_i1$Data.Disponivel[j] < filtro_semana_i1$Data.MRP[j] &
filtro_semana_i1$Dados.Elemento.MRP[j]==filtro_semana_i$Dados.Elemento.MRP[n]){
            TabelaReal$LotesQM.Transitados[k] <- TabelaReal$LotesQM.Transitados[k] + filtro_semana_i1$ControloQuali[j]
              }
            }
          }
        }

        TabelaReal$LotesQM.Fechados[k] <- TabelaReal$LotesQM.Semama_i[k] - TabelaReal$LotesQM.Transitados[k]

        if(TabelaReal$LotesQM.Semana_i[k] == 0){
          TabelaReal$LotesQM.Percent.Semana_i[k] <- 1
        }else{
          TabelaReal$LotesQM.Percent.Semana_i[k] <- TabelaReal$LotesQM.Fechados[k]/TabelaReal$LotesQM.Semama_i[k]
        }

        TabelaReal$LotesQM.Semana_i1[k] <- 0

        for (j in 1:nrow(filtro_semana_i1)) {
          if(filtro_semana_i1$Data.Disponivel[j] < filtro_semana_i1$Data.MRP[j]){
            TabelaReal$LotesQM.Semana_i1[k] <- TabelaReal$LotesQM.Semana_i1[k] + filtro_semana_i1$ControloQuali[j]
          }
        }
```

Figure 55: Code used to Create the Real Table – Part III

```
          TabelaReal$LotesQM.Total.Est[k] <- TabelaReal$LotesQM.Semama_i[k] + TabelaReal$LotesQM.Semana_i1[k]

          if(TabelaReal$LotesQM.Total.Est[k] == 0){
            TabelaReal$LotesQM.Percent.Est[k] <- 1
          }else{
            TabelaReal$LotesQM.Percent.Est[k] <- TabelaReal$LotesQM.Fechados[k]/TabelaReal$LotesQM.Total.Est[k]
          }

          TabelaReal$Stock.Final.Real[k] <- filtro_semana_i1$Stock.Estimado[1]

          #Final Stock Control Variables

          if(TabelaReal$Qtd.OG.Rececionada[k]>=TabelaReal$LotesQM.Semana_i1[k]){
            TabelaReal$Balanço_Sem_NecDep[k] <- TabelaReal$Stock.Inicial[k] -
(TabelaReal$ResOrd.Semana_i[k]-TabelaReal$ResOrd.Transitadas[k])+(TabelaReal$Qtd.OG.Rececionada[k]-TabelaReal$LotesQM.Semana_i1[k])
+TabelaReal$LotesQM.Fechados[k]
          }else{
            TabelaReal$Balanço_Sem_NecDep[k] <- TabelaReal$Stock.Inicial[k] -
(TabelaReal$ResOrd.Semana_i[k]-TabelaReal$ResOrd.Transitadas[k])+TabelaReal$Qtd.OG.Rececionada[k]+TabelaReal$LotesQM.Fechados[k]
          }


          if(TabelaReal$NecDep.Semana_i[k] >= TabelaReal$NecDep.Semana_i1[k]){
            if(TabelaReal$Qtd.OG.Rececionada[k]>=TabelaReal$LotesQM.Semana_i1[k]){
              TabelaReal$Balanço_Com_NecDep[k] <- TabelaReal$Stock.Inicial[k] -
(TabelaReal$ResOrd.Semana_i[k]-TabelaReal$ResOrd.Transitadas[k]) - (TabelaReal$NecDep.Semana_i[k] -
TabelaReal$NecDep.Semana_i1[k])+(TabelaReal$Qtd.OG.Rececionada[k]-TabelaReal$LotesQM.Semana_i1[k])+TabelaReal$LotesQM.Fechados[k]
            }else{
              TabelaReal$Balanço_Com_NecDep[k] <- TabelaReal$Stock.Inicial[k] -
(TabelaReal$ResOrd.Semana_i[k]-TabelaReal$ResOrd.Transitadas[k]) - (TabelaReal$NecDep.Semana_i[k] -
TabelaReal$NecDep.Semana_i1[k])+TabelaReal$Qtd.OG.Rececionada[k]+TabelaReal$LotesQM.Fechados[k]
            }
          }else{
            if(TabelaReal$Qtd.OG.Rececionada[k]>=TabelaReal$LotesQM.Semana_i1[k]){
              TabelaReal$Balanço_Com_NecDep[k] <- TabelaReal$Stock.Inicial[k] -
(TabelaReal$ResOrd.Semana_i[k]-TabelaReal$ResOrd.Transitadas[k]) -
0+(TabelaReal$Qtd.OG.Rececionada[k]-TabelaReal$LotesQM.Semana_i1[k])+TabelaReal$LotesQM.Fechados[k]
            }else{
              TabelaReal$Balanço_Com_NecDep[k] <- TabelaReal$Stock.Inicial[k] -
(TabelaReal$ResOrd.Semana_i[k]-TabelaReal$ResOrd.Transitadas[k]) -
0+TabelaReal$Qtd.OG.Rececionada[k]+TabelaReal$LotesQM.Fechados[k]
            }
          }


          k <- k+1
        }

      }else if (semana == semanas_material[1]) {
        filtro_semana_i <- subset(filtro_material, Semana.MRP == lista[1])
        filtro_semana_i1 <- subset(filtro_material, Semana.MRP == semana)

        if(is.na(filtro_semana_i$Data.MRP[1]) == FALSE){

          TabelaReal$Material[k] <- material
          TabelaReal$Planeador[k] <- filtro_material$Planeador[1]
          TabelaReal$Unid.Básica.Medida[k] <- filtro_material$Unid.Básica.Medida[1]
          TabelaReal$Semana[k] <- semana
          #Values Retrieved from the Summary Table
          for (i in 1:nrow(TabelaSumário)) {
            if(TabelaSumário$Semana.Próx.Leitura[i] == semana & TabelaSumário$Material[i] == material){
              TabelaReal$ResOrd.Semana_i[k] <- TabelaSumário$Nec.Totais.Confirmadas[i]
              TabelaReal$NecDep.Semana_i[k] <- TabelaSumário$Nec.Totais.Esperadas[i]
              TabelaReal$Qtd.Prev.Rececionar[k] <- TabelaSumário$Qtd.Total.Trânsito[i]
              TabelaReal$LotesQM.Semama_i[k] <- TabelaSumário$Qtd.Total.Quali[i]
              TabelaReal$Stock.Inicial[k] <- TabelaSumário$Stock.Semanal.Inicial[i]
              TabelaReal$Stock.Final.Estimado[k] <- TabelaSumário$Stock.Final.Estimado[i]
              TabelaReal$Stock.Final.Expectável[k] <- TabelaSumário$Stock.Final.Expectável[i]
            }
          }

          #Transitioned Production Orders from one week to the next

          TabelaReal$ResOrd.Transitadas[k] <- 0
          filtro_semana_i1$Check <- 0

          for (j in 1:nrow(filtro_semana_i)) {
            for (n in 1:nrow(filtro_semana_i1)) {
              if(filtro_semana_i$Elemento.MRP[j] == "ResOrd" & filtro_semana_i1$Elemento.MRP[n] == "ResOrd" &
filtro_semana_i$Material[j] == filtro_semana_i1$Material[n] & filtro_semana_i$Data.Disponível[j] ==
filtro_semana_i1$Data.Disponível[n] & filtro_semana_i1$Check[n] == 0){
                TabelaReal$ResOrd.Transitadas[k] <- TabelaReal$ResOrd.Transitadas[k] + abs(filtro_semana_i1$Necessidade[n])
                filtro_semana_i1$Check[n] <- 1
              }
            }
          }
```

Figure 56: Code used to Create the Real Table – Part IV

```
#New Production Orders

TabelaReal$ResOrd.Novas_Semana_i1[k] <- 0

for (n in 1:nrow(filtro_semana_i1)) {
  if(filtro_semana_i1$Elemento.MRP[n] == "ResOrd" & filtro_semana_i1$Check[n] == 0 & filtro_semana_i1$Data.Disponivel[n]
< filtro_semana_i1$Data.MRP[n]){
    TabelaReal$ResOrd.Novas_Semana_i1[k] <- TabelaReal$ResOrd.Novas_Semana_i1[k] + abs(filtro_semana_i1$Necessidade[n])
  }
}

#Fraction of the known production orders to week i+1 that were closed (not considering NecDep.Semana_i1)

if(TabelaReal$ResOrd.Semana_i[k] != 0){
  TabelaReal$Cump.ResOrd[k] <-
(TabelaReal$ResOrd.Semana_i[k]-TabelaReal$ResOrd.Transitadas[k])/TabelaReal$ResOrd.Semana_i[k]
}else{
  TabelaReal$Cump.ResOrd[k] <- 1
}

#Customer's unconfirmed needs by the end of week i+1

TabelaReal$NecDep.Semana_i1[k] <- 0

for (n in 1:nrow(filtro_semana_i1)) {
  if(filtro_semana_i1$Data.Disponivel[n] < filtro_semana_i1$Data.MRP[n] & filtro_semana_i1$Elemento.MRP[n] == "NecDep"){
    TabelaReal$NecDep.Semana_i1[k] <- TabelaReal$NecDep.Semana_i1[k] + abs(filtro_semana_i1$Necessidade[n])
  }
}

#Fraction of the known production orders to week i+1 that were closed (considering NecDep.Semana_i1)

if(TabelaReal$NecDep.Semana_i1[k] > 0){
  TabelaReal$Cump.ResOrd.NecDep_i1[k] <-
(TabelaReal$ResOrd.Semana_i[k]-TabelaReal$ResOrd.Transitadas[k])/(TabelaReal$ResOrd.Semana_i[k]+TabelaReal$NecDep.Semana_i1[k])
}else{
  TabelaReal$Cump.ResOrd.NecDep_i1[k] <- TabelaReal$Cump.ResOrd[k]
}

#Amount of In-transit Material
TabelaReal$Receção.Transitada[k] <- 0
TabelaReal$NovasReceções_i1[k] <- 0

for (j in 1:nrow(filtro_semana_i1)) {
  for (n in 1:nrow(filtro_semana_i)) {
    if(filtro_semana_i1$Data.Disponivel[j] < filtro_semana_i1$Data.MRP[j] &
filtro_semana_i1$Em.Trânsito[j]==filtro_semana_i$Em.Trânsito[n] & filtro_semana_i1$Check[j] == 0){
    TabelaReal$Receção.Transitada[k] <- TabelaReal$Receção.Transitada[k] + filtro_semana_i1$Em.Trânsito[j]
    filtro_semana_i1$Check[j] <- 1
    }
  }
}

#Deliveries that had been pushed forward, but that have not arrived
for (j in 1:nrow(filtro_semana_i1)) {
  if(filtro_semana_i1$Data.Disponivel[j] < filtro_semana_i1$Data.MRP[j] &  filtro_semana_i1$Check[j] == 0){
    TabelaReal$NovasReceções_i1[k] <- TabelaReal$NovasReceções_i1[k] + filtro_semana_i1$Em.Trânsito[j]
  }
}

if(TabelaReal$Qtd.Prev.Rececionar[k] >= TabelaReal$Receção.Transitada[k]){
  TabelaReal$Qtd.OG.Rececionada[k] <- TabelaReal$Qtd.Prev.Rececionar[k] - TabelaReal$Receção.Transitada[k]
} else if(TabelaReal$Qtd.Prev.Rececionar[k] < TabelaReal$Receção.Transitada[k]){
  TabelaReal$Qtd.OG.Rececionada[k] <- 0
}

#Fraction of successfully supplied expected deliveries
if(TabelaReal$Qtd.Prev.Rececionar[k] != 0 ){
  TabelaReal$Percent.Receções.Programadas[k] <- TabelaReal$Qtd.OG.Rececionada[k]/TabelaReal$Qtd.Prev.Rececionar[k]
}else if (TabelaReal$Qtd.Prev.Rececionar[k] == 0){
  if(TabelaReal$Qtd.OG.Rececionada[k] == 0 & TabelaReal$Receção.Transitada[k] == 0){
    TabelaReal$Percent.Receções.Programadas[k] <- 1
  }else if(TabelaReal$Qtd.OG.Rececionada[k] != 0){
    TabelaReal$Percent.Receções.Programadas[k] <- 1
  }else if(TabelaReal$Qtd.OG.Rececionada[k] == 0 & TabelaReal$Receção.Transitada[k] != 0){
    TabelaReal$Percent.Receções.Programadas[k] <- 0
  }
}

#New delivery total, considering pushed forward deliveries that were not successfully supplied

TabelaReal$Receções.Total.Est[k] <- TabelaReal$Qtd.Prev.Rececionar[k] + TabelaReal$NovasReceções_i1[k]

#Fraction of successfully supplied deliveries, considering the new total

if(TabelaReal$Receções.Total.Est[k] != 0){
  TabelaReal$Percent.Receções.Totais[k] <- TabelaReal$Qtd.OG.Rececionada[k]/TabelaReal$Receções.Total.Est[k]
}else{
  TabelaReal$Percent.Receções.Totais[k] <- 1
}
```

Figure 57: Code used to Create the Real Table – Part V

```
        #Quality Control Batches - batch numbers are unique

        TabelaReal$LotesQM.Transitados[k] <- 0

        for (j in 1:nrow(filtro_semana_i1)) {
          for (n in 1:nrow(filtro_semana_i)) {
            if(filtro_semana_i$Elemento.MRP[n] != "Estoq."){
              if(filtro_semana_i1$Data.Disponivel[j] < filtro_semana_i1$Data.MRP[j] &
filtro_semana_i1$Dados.Elemento.MRP[j]==filtro_semana_i$Dados.Elemento.MRP[n]){
            TabelaReal$LotesQM.Transitados[k] <- TabelaReal$LotesQM.Transitados[k] + filtro_semana_i1$ControloQuali[j]
              }
            }
          }
        }

        TabelaReal$LotesQM.Fechados[k] <- TabelaReal$LotesQM.Semama_i[k] - TabelaReal$LotesQM.Transitados[k]

        if(TabelaReal$LotesQM.Semana_i[k] == 0){
          TabelaReal$LotesQM.Percent.Semana_i[k] <- 1
        }else{
          TabelaReal$LotesQM.Percent.Semana_i[k] <- TabelaReal$LotesQM.Fechados[k]/TabelaReal$LotesQM.Semama_i[k]
        }

        TabelaReal$LotesQM.Semana_i1[k] <- 0

        for (j in 1:nrow(filtro_semana_i1)) {
          if(filtro_semana_i1$Data.Disponivel[j] < filtro_semana_i1$Data.MRP[j]){
            TabelaReal$LotesQM.Semana_i1[k] <- TabelaReal$LotesQM.Semana_i1[k] + filtro_semana_i1$ControloQuali[j]
          }
        }
        TabelaReal$LOtesQM.Total.Est[k] <- TabelaReal$LotesQM.Semama_i[k] + TabelaReal$LotesQM.Semana_i1[k]

        if(TabelaReal$LOtesQM.Total.Est[k] == 0){
          TabelaReal$LotesQM.Percent.Est[k] <- 1
        }else{
          TabelaReal$LotesQM.Percent.Est[k] <- TabelaReal$LotesQM.Fechados[k]/TabelaReal$LOtesQM.Total.Est[k]
        }

        TabelaReal$Stock.Final.Real[k] <- filtro_semana_i1$Stock.Estimado[1]

        #Final Stock Control Variables

        if(TabelaReal$Qtd.OG.Rececionada[k]>=TabelaReal$LotesQM.Semana_i1[k]){
          TabelaReal$Balanço_Sem_NecDep[k] <- TabelaReal$Stock.Inicial[k] -
(TabelaReal$ResOrd.Semana_i[k]-TabelaReal$ResOrd.Transitadas[k])+(TabelaReal$Qtd.OG.Rececionada[k]-TabelaReal$LotesQM.Semana_i1[k])
+TabelaReal$LotesQM.Fechados[k]
        }else{
          TabelaReal$Balanço_Sem_NecDep[k] <- TabelaReal$Stock.Inicial[k] -
(TabelaReal$ResOrd.Semana_i[k]-TabelaReal$ResOrd.Transitadas[k])+TabelaReal$Qtd.OG.Rececionada[k]+TabelaReal$LotesQM.Fechados[k]
        }

        if(TabelaReal$NecDep.Semana_i[k] >= TabelaReal$NecDep.Semana_i1[k]){
          if(TabelaReal$Qtd.OG.Rececionada[k]>=TabelaReal$LotesQM.Semana_i1[k]){
            TabelaReal$Balanço_Com_NecDep[k] <- TabelaReal$Stock.Inicial[k] -
(TabelaReal$ResOrd.Semana_i[k]-TabelaReal$ResOrd.Transitadas[k]) - (TabelaReal$NecDep.Semana_i[k] -
TabelaReal$NecDep.Semana_i1[k])+(TabelaReal$Qtd.OG.Rececionada[k]-TabelaReal$LotesQM.Semana_i1[k])+TabelaReal$LotesQM.Fechados[k]
          }else{
            TabelaReal$Balanço_Com_NecDep[k] <- TabelaReal$Stock.Inicial[k] -
(TabelaReal$ResOrd.Semana_i[k]-TabelaReal$ResOrd.Transitadas[k]) - (TabelaReal$NecDep.Semana_i[k] -
TabelaReal$NecDep.Semana_i1[k])+TabelaReal$Qtd.OG.Rececionada[k]+TabelaReal$LotesQM.Fechados[k]
          }
        }else{
          if(TabelaReal$Qtd.OG.Rececionada[k]>=TabelaReal$LotesQM.Semana_i1[k]){
            TabelaReal$Balanço_Com_NecDep[k] <- TabelaReal$Stock.Inicial[k] -
(TabelaReal$ResOrd.Semana_i[k]-TabelaReal$ResOrd.Transitadas[k]) -
0+(TabelaReal$Qtd.OG.Rececionada[k]-TabelaReal$LotesQM.Semana_i1[k])+TabelaReal$LotesQM.Fechados[k]
          }else{
            TabelaReal$Balanço_Com_NecDep[k] <- TabelaReal$Stock.Inicial[k] -
(TabelaReal$ResOrd.Semana_i[k]-TabelaReal$ResOrd.Transitadas[k]) -
0+TabelaReal$Qtd.OG.Rececionada[k]+TabelaReal$LotesQM.Fechados[k]
          }
        }


        k <- k+1

      }
    }
  }
 }
}


TabelaReal <- TabelaReal[-c(k:nrow(TabelaReal)),]
...
```

Figure 58: Code used to Create the Real Table – Part VI

Lastly, **ResOrd Table** was created to keep track of production orders and compare the last time they appear on an MRP reading with their production's original due date. As aforementioned, production does not close its orders immediately after their completion, which leads to an unreal order backlog volume.

Although the analysis enabled by this table is not directly related to the raw materials' current service levels, it presents itself as a good opportunity to quantify the magnitude of this problem and raise the collaborators' awareness to it.

The idea behind the ResOrd Table is to have a historical record of all production orders (of the 'ResOrd' type), with information concerning (i) the material requested; (ii) the process, semi-finished good or end-item generating its needs and (iii) the amount required; (iv) its production's original due date, and (v) the last time they appear on an MRP reading.

In order to achieve this without having an ID number unique to each order, it was necessary to use the same strategy as described for the Real Table. Nevertheless, it was found that the same combination of variables 'Data.MRP', 'Material', 'Dados.Elemento.MRP' and 'Data.Disponível' does not always return one single entry. This happens because, in the same MRP reading, two orders can, sometimes, differ in their requested quantity alone.

To cope with these situations, it was created a secondary table that combines these separate entries into one (by adding each entry's needs, as highlighted in red in Figure 60), thus ensuring that each combination of 'Data.MRP', 'Material', 'Dados.Elemento.MRP' and 'Data.Disponível' only matches one production order at a time.

It is only after this treatment that ResOrd table is ready to be created – the complete list of production orders is filtered by each combination of 'Material', 'Elemento.MRP' (it is, for all cases, 'ResOrd'), 'Dados.Elemento.MRP' and 'Data.Disponível', and the last 'Data.MRP' found is the last time each production order appears in an MRP reading (orange highlight in Figure 60).

The R script and some key features of the algorithm responsible for creating the ResOrd Table are detailed in Figures 59 and 60, while the results obtained in Power BI are discussed in section 5.4.

````
```{r}

df_merged <- read.csv2("D:/Análise_Stock_compilações/Quebras/SAP_MateriaisA_Quebra_compilado.csv", header = TRUE)

ordens <- subset(df_merged, Elemento.MRP == "ResOrd")

ordens <- ordens[,c(1,2,7,11,12,14,15)]
ordens$Data.MRP <- gsub("-", "/", ordens$Data.MRP)

ordens$soma <- 0

lista_ordens_soma <- 0
lista_ordens_soma <- data.frame(lista_ordens_soma)
lista_ordens_soma$Material <- NA
lista_ordens_soma$Elemento.MRP <- NA
lista_ordens_soma$Dados.Elemento.MRP <- NA
lista_ordens_soma$Data.DisponÃ.vel <- NA
lista_ordens_soma$Qtd.Ordem <- NA
lista_ordens_soma$Última.Data <- NA
lista_ordens_soma <- lista_ordens_soma[,-1]
lista_ordens_soma <- lista_ordens_soma[1:500000,]

k <- 1
````

Figure 59: Code used to Create the ResOrd Table – Part I
````

```r
for (i in 1:nrow(ordens)) {
  if(ordens$soma[i] == 0){
    soma_ordens <- subset(ordens, Data.MRP == ordens$Data.MRP[i]& Material == ordens$Material[i] & Dados.Elemento.MRP ==
ordens$Dados.Elemento.MRP[i] & Data.DisponÃ.vel == ordens$Data.DisponÃ.vel[i])
    if(nrow(soma_ordens) != 1){
      lista_ordens_soma$Material[k] <- soma_ordens$Material[1]
      lista_ordens_soma$Elemento.MRP[k] <- ordens$Elemento.MRP[i]
      lista_ordens_soma$Dados.Elemento.MRP[k] <- soma_ordens$Dados.Elemento.MRP[1]
      lista_ordens_soma$Data.DisponÃ.vel[k] <- soma_ordens$Data.DisponÃ.vel[1]
      lista_ordens_soma$Qtd.Ordem[k] <- abs(sum(soma_ordens$Necessidade[1:nrow(soma_ordens)]))

      for (index in soma_ordens$X) {
        m <- which(ordens$X == index)
        ordens$soma[m] <- 1
      }


      k <- k+1

    }else{
      lista_ordens_soma$Material[k] <- soma_ordens$Material[1]
      lista_ordens_soma$Elemento.MRP[k] <- ordens$Elemento.MRP[i]
      lista_ordens_soma$Dados.Elemento.MRP[k] <- soma_ordens$Dados.Elemento.MRP[1]
      lista_ordens_soma$Data.DisponÃ.vel[k] <- soma_ordens$Data.DisponÃ.vel[1]
      lista_ordens_soma$Qtd.Ordem[k] <- soma_ordens$Necessidade[1]

      ordens$soma[i] <- 1

      k <- k+1
    }
  }
}

lista_ordens_soma <- lista_ordens_soma[-c(k:nrow(lista_ordens_soma)),]
write.xlsx(lista_ordens_soma, file = "Lista Ordens Soma.xlsx")

```
```{r}

lista_ordens_soma <- lista_ordens_soma[,-6]

lista_ordens_soma$Última.Data <- NA

for (i in 1:nrow(lista_ordens_soma)) {

  filtro_ordens <- subset(ordens, Material == lista_ordens_soma$Material[i] & Elemento.MRP == lista_ordens_soma$Elemento.MRP[i] &
Dados.Elemento.MRP == lista_ordens_soma$Dados.Elemento.MRP[i] &  Data.DisponÃ.vel == lista_ordens_soma$Data.DisponÃ.vel[i])
  lista_ordens_soma$Última.Data[i] <- filtro_ordens$Data.MRP[nrow(filtro_ordens)]
}

write.csv2(lista_ordens_soma, file = "Ordens_em_Aberto.csv")
write.xlsx(lista_ordens_soma, file = "Ordens_em_Aberto.xlsx")

```

Figure 60: Code used to Create the ResOrd Table – Part II

APPENDIX IV – INITIAL ME3L R TREATMENT

The initial data treatment performed to the output of the ME3L transaction was ensured by the implementation of the algorithm shown in Figure 61.

```
#Initial ME3L Treatment
## Structuring Data

```{r}

data <- read_excel("ME3L.xlsx")
data <- data.frame(data)

lista_fornec <- read_excel("Lista Fornecedores SAP.xlsx", sheet = "MP_Fornecedores") #auxiliary file with information regarding each
supplier
lista_fornec <- data.frame(lista_fornec)

lista_compras <- read_excel("Lista Fornecedores SAP.xlsx", sheet = "MP_Compras") #delivery ID numbers' auxiliary information
lista_compras <- data.frame(lista_compras)

```

```{r}

#Delete unnecessary columns

data <- data[,-c(c(2:5), 9, 10, c(12:17), c(23:25), 27, 28, c(31:36))]
data <- data[-1,]

data$Fornecedor <- 0
data$DocCompras <- 0

#Assign the correct Supplier and Delivery ID number information to the 1st line of each section

for (i in 1:nrow(data)) {
  for (j in 1:nrow(lista_fornec)) {
    if(data[i, 1] == lista_fornec[j,1]){
      data$Fornecedor[i+3] <- lista_fornec[j,1]
    }
  }
  for (j in 1:nrow(lista_compras)) {
    if(data[i, 1] == lista_compras[j,1]){
      data$DocCompras[i+2] <- lista_compras[j,1]
    }
  }
}
#Introduce this information in all entries with the same supplier and delivery ID number

data <- na.omit(data)

for (i in 2:nrow(data)) {

  if (data$Fornecedor[i] == 0){
    data$Fornecedor[i] <- data$Fornecedor[i-1]
  }
  if (data$DocCompras[i] == 0){
    data$DocCompras[i] <- data$DocCompras[i-1]
  }
}
```

```{r}

write.xlsx(data, file = "ME3L_Tratada_R(1).xlsx")

```
```

Figure 61: Code used in Initial ME3L Data Treatment

However, as shown in Table 32, its results did not return the supplier ID and its name as separate variables (**'Fornecedor'**), just like the delivery ID number was not presented alone in each entry (**'DocCompras')**.

Table 32: Sample of the Data Table Obtained After Initial R Treatment

Divisão.da.re	Data.do.documento	Material	Grupo.de.me	UM.pedido	Preço.líquido	Moeda	Unidade.de.p	Qtd.divisão	Data.de.remessa	Quantidade.a	Qtd.entrada	Fornecedor		DocCompras
1	08/09/2020	101I00000015	100	M2	39,75	EUR	1	1200	18/09/2020	1200	1200	Fornecedor/centro fornecedor 70077 Fornecedor 1		Documento de compras 5500039331
2	08/09/2020	101I00000015	100	M2	39,75	EUR	1	900	25/09/2020	900	900	Fornecedor/centro fornecedor 70077 Fornecedor 1		Documento de compras 5500039331
3	08/09/2020	101I00000015	100	M2	39,75	EUR	1	809,12	02/10/2020	809,12	809,12	Fornecedor/centro fornecedor 70077 Fornecedor 1		Documento de compras 5500039331
4	08/09/2020	101I00000015	100	M2	39,75	EUR	1	704,91	09/10/2020	704,91	704,91	Fornecedor/centro fornecedor 70077 Fornecedor 1		Documento de compras 5500039331
5	08/09/2020	101I00000015	100	M2	39,75	EUR	1	803,01	16/10/2020	803,01	803,01	Fornecedor/centro fornecedor 70077 Fornecedor 1		Documento de compras 5500039331
6	08/09/2020	101I00000015	100	M2	39,75	EUR	1	900	23/10/2020	900	900	Fornecedor/centro fornecedor 70077 Fornecedor 1		Documento de compras 5500039331
7	08/09/2020	101I00000015	100	M2	39,75	EUR	1	1661,33	30/10/2020	1661,33	1661,33	Fornecedor/centro fornecedor 70077 Fornecedor 1		Documento de compras 5500039331
8	08/09/2020	101I00000015	100	M2	39,75	EUR	1	1046,48	06/11/2020	1046,48	1046,48	Fornecedor/centro fornecedor 70077 Fornecedor 1		Documento de compras 5500039331

To swiftly deal with this problem, KNIME Analytics Platform was put into good use, by creating and implementing the workflow presented in Figure 62. The nodes responsible for this successful transformation are the two 'Cell splitters by position', which guarantee the split of the original character string into different columns, as exemplified in Figure 63 for original variable **'DocCompras'**. The rest of the nodes eliminate auxiliary variables created during this process, as well as reorganise the columns into a more suitable order.

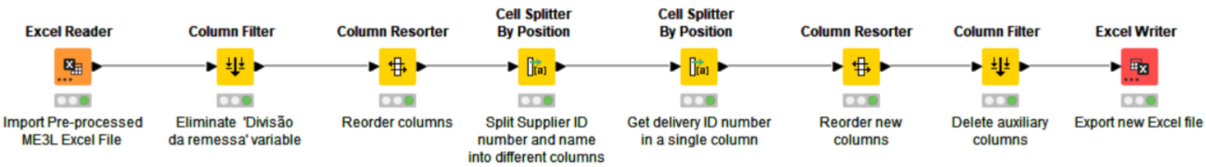


Figure 62: ME3L KNIME Workflow

S aux	S Doc Compras
Documento de compras	5500045767
Documento de compras	5500045767
Documento de compras	5500045767
Documento de compras	5500045767
Documento de compras	5500045767
Documento de compras	5500045767
Documento de compras	5500045767
Documento de compras	5500045767
Documento de compras	5500045767
Documento de compras	5500045767

Figure 63: Example of the Output given by the Cell Splitter Nodes

The output obtained after the KNIME data treatment is presented in Table 33.

Table 33: Sample of the Data Table Obtained After KNIME Treatment

Doc Compras	Data.do.documento	Material	Grupo.de.mercadorias	Preço.líquido	Moeda	Unidade.d	Data.de.remessa	Cód forne	Descr. Fornecedor	Qtd.divisão	UM.pedido	Quantidade.anterior	Qtd.entrada
5500039331	2020-09-08	101I0000001565	100	39,75	EUR	1	2020-09-18	70077	Fornecedor 1	1200	M2	1200	1200
5500039331	2020-09-08	101I0000001565	100	39,75	EUR	1	2020-09-25	70077	Fornecedor 1	900	M2	900	900
5500039331	2020-09-08	101I0000001565	100	39,75	EUR	1	2020-10-02	70077	Fornecedor 1	809,12	M2	809,12	809,12
5500039331	2020-09-08	101I0000001565	100	39,75	EUR	1	2020-10-09	70077	Fornecedor 1	704,91	M2	704,91	704,91
5500039331	2020-09-08	101I0000001565	100	39,75	EUR	1	2020-10-16	70077	Fornecedor 1	803,01	M2	803,01	803,01
5500039331	2020-09-08	101I0000001565	100	39,75	EUR	1	2020-10-23	70077	Fornecedor 1	900	M2	900	900
5500039331	2020-09-08	101I0000001565	100	39,75	EUR	1	2020-10-30	70077	Fornecedor 1	1661,33	M2	1661,33	1661,33

Appendix V – ME3L's EDA Algorithm

The algorithm used in the EDA performed to ME3L's data, as well as the addition of variables **'Estado'** and **'Ano.Semana.Entrega'** is shown in Figures 64 to 66.

````
#EDA - ME3L
```{r}

ME3L<- data.frame(read_excel("D:/COINDU/Dados_Projetos/Materiais_ClasseA/AnáliseFornecimento/ME3L_Tratada_Knime(2) -
Completo.xlsx"))

#Check variables' data types

cat("Tipos de Variáveis Antes:", "\n")
cat("\n")
str(ME3L)

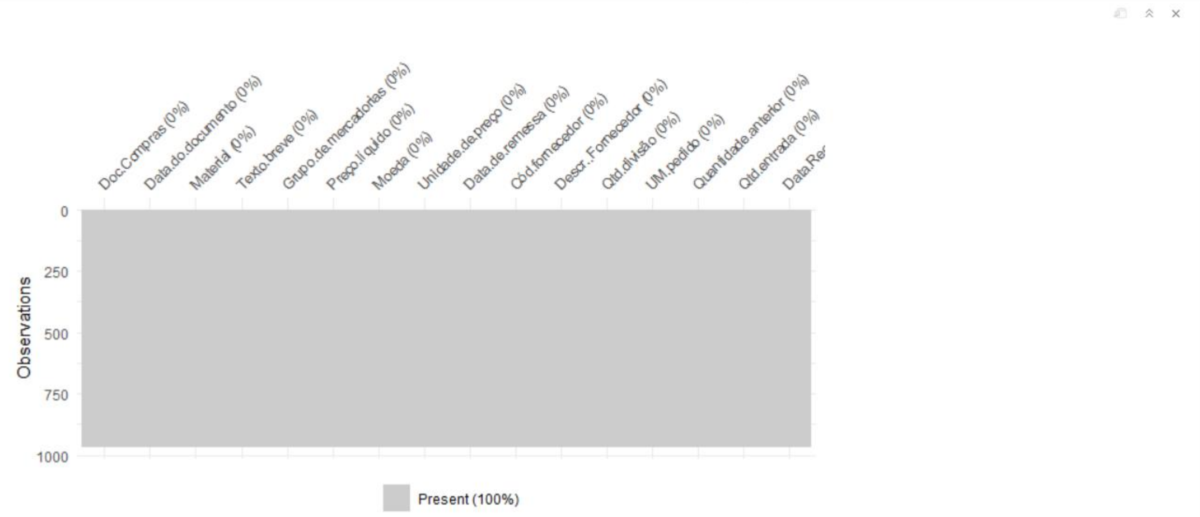
#Change variables' data types
ME3L$Data.do.documento <- as.Date(as.character(ME3L$Data.do.documento))
ME3L$Data.de.remessa <- as.Date(as.character(ME3L$Data.de.remessa))
ME3L$Doc.Compras <- as.factor(ME3L$Doc.Compras)
ME3L$Material <- as.factor(ME3L$Material)
ME3L$Texto.breve <- as.factor(ME3L$Texto.breve)
ME3L$Grupo.de.mercadorias <- as.factor(ME3L$Grupo.de.mercadorias)
ME3L$Moeda <- as.factor(ME3L$Moeda)
ME3L$Cód.fornecedor <- as.factor(ME3L$Cód.fornecedor)
ME3L$Descr..Fornecedor <- as.factor(ME3L$Descr..Fornecedor)
ME3L$UM.pedido <- as.factor(ME3L$UM.pedido)
ME3L$Data.Recolha.Dados <- "2023-06-27"
ME3L$Data.Recolha.Dados <- as.Date(as.character(ME3L$Data.Recolha.Dados))

cat("\n")
cat("Tipos de Variáveis Depois:", "\n")
cat("\n")

str(ME3L)

```
```{r}
#Check missing values

vis_miss(ME3L)
```
````




````
```{r}

summary(ME3L)
```
````

Figure 64: Code used in ME3L's EDA – Part I

```
     Doc.Compras    Data.do.documento               Material     Grupo.de.mercadorias Preço.liquido    Moeda
 5500038823:145    Min.   :2020-09-04    104I0000000003:145    100:396             Min.   : 0.00    EUR:967
 5500039331:136    1st Qu.:2021-09-09    101I0000001443:136    116:304             1st Qu.:22.62
 5500039413:136    Median :2022-06-23    101I0000001565:136    118:267             Median :39.53
 5500039618:124    Mean   :2022-04-25    101I0000001509:124                        Mean   :32.22
 5500043208: 66    3rd Qu.:2023-01-26    102I0000000083:119                        3rd Qu.:41.28
 5500044219: 66    Max.   :2023-06-23    102B0000000001: 66                        Max.   :53.12
 (Other)   :294                          (Other)       :241
 Unidade.de.preço Data.de.remessa       Cód.fornecedor  Qtd.divisão       UM.pedido Quantidade.anterior  Qtd.entrada
 Min.   :1        Min.   :2020-09-17    70238  :145    Min.   :    0.06   M :571    Min.   :    0.06    Min.   :   0.0
 1st Qu.:1        1st Qu.:2021-12-09    70077  :136    1st Qu.:  400.00   M2:396    1st Qu.:  400.00    1st Qu.:   0.0
 Median :1        Median :2022-11-17    70363  :136    Median :  900.00             Median :  900.00    Median : 493.2
 Mean   :1        Mean   :2022-09-11    70134  :132    Mean   : 1615.56             Mean   : 1615.56    Mean   : 965.6
 3rd Qu.:1        3rd Qu.:2023-06-22    70428  :124    3rd Qu.: 2000.00             3rd Qu.: 2000.00    3rd Qu.:1200.0
 Max.   :1        Max.   :2024-06-14    71093  :119    Max.   :10000.00             Max.   :10000.00    Max.   :7500.0
                                        (Other):175
 Data.Recolha.Dados
 Min.   :2023-06-27
 1st Qu.:2023-06-27
 Median :2023-06-27
 Mean   :2023-06-27
 3rd Qu.:2023-06-27
 Max.   :2023-06-27
```

```{r}
#Assigning values to variable 'Status'

for (i in 1:nrow(ME3L)) {
  if(ME3L$Qtd.divisão[i] == 0 & ME3L$Qtd.entrada[i] == 0){
    ME3L$Estado[i] <- "Cancelled"
  }else if(ME3L$Data.de.remessa[i] > ME3L$Data.Recolha.Dados[i] & ME3L$Qtd.divisão[i] != 0){
    ME3L$Estado[i] <- "Scheduled"
  }else if(ME3L$Data.de.remessa[i] > ME3L$Data.Recolha.Dados[i] & ME3L$Qtd.divisão[i] != 0 & ME3L$Qtd.entrada[i] ==
ME3L$Qtd.divisão[i]){
    ME3L$Estado[i] <- "Fulfilled"
  }else if(ME3L$Data.de.remessa[i] < ME3L$Data.Recolha.Dados[i] & ME3L$Qtd.divisão[i] == ME3L$Qtd.entrada[i] &
ME3L$Qtd.divisão[i] != 0){
    ME3L$Estado[i] <- "Fulfilled"
  }else if(ME3L$Data.de.remessa[i] < ME3L$Data.Recolha.Dados[i] & ME3L$Qtd.divisão[i] != ME3L$Qtd.entrada[i] &
ME3L$Qtd.divisão[i] != 0){
    ME3L$Estado[i] <- "Delayed"
  }else if(ME3L$Data.de.remessa[i] == ME3L$Data.Recolha.Dados[i] & ME3L$Qtd.entrada[i] == 0 & ME3L$Qtd.divisão[i] != 0){
    ME3L$Estado[i] <- "Scheduled"
  }else if(ME3L$Data.de.remessa[i] == ME3L$Data.Recolha.Dados[i] & ME3L$Qtd.divisão[i] == ME3L$Qtd.entrada[i] &
ME3L$Qtd.divisão[i] != 0){
    ME3L$Estado[i] <- "Fulfilled"
  }else if(ME3L$Data.de.remessa[i] == ME3L$Data.Recolha.Dados[i] & ME3L$Qtd.divisão[i] != ME3L$Qtd.entrada[i] &
ME3L$Qtd.entrada[i] != 0){
    ME3L$Estado[i] <- "Scheduled"
  }else{
    ME3L$Estado[i] <- "ERROR"
  }
}

#Bar plot

plotdata <- ME3L %>%
  count(Estado) %>%
  mutate(pct = n / sum(n),
         pctlabel = paste0(round(pct*100,2), "%"))

# plot the bars as percentages,
# in decending order with bar labels
ggplot(plotdata,
       aes(x = reorder(Estado, -pct),
           y = pct)) +
  geom_bar(stat = "identity") +
  geom_text(aes(label = pctlabel),
            vjust = -0.25) +
  scale_y_continuous(labels = percent) +
  labs(x = "Status",
       y = "Percent",
       title  = "Order Status")

```

Figure 65: Code used in ME3L's EDA – Part II

```{r}
# Assigning week number to variable 'Data.de.remessa'

ME3L <- ME3L %>%
        mutate(date = as.Date(Data.de.remessa, format = "%Y-%m-%d")) %>%
        mutate(yearweek = as.integer(strftime(date, format = "%Y%V"))) %>%
        mutate(yearweek2 = ifelse(test = day(date) > 7 & substr(yearweek, 5, 6) == '01',
                                yes  = yearweek + 100,
                                no   = ifelse(test = month(date) == 1 & as.integer(substr(yearweek, 5, 6)) > 51,
                                              yes  = yearweek - 100,
                                              no   = yearweek)))


ME3L <- ME3L[, -c(18,19)]
colnames(ME3L)[18] <- "Ano/Semana Entrega"

ME3L <- ME3L[, c(c(1:9), 18, c(10:17))]

ME3L <- ME3L[order(ME3L$Data.de.remessa),]
```

```{r}
#Exporting database

write.xlsx(data.frame(ME3L), file = "ME3L_Final.xlsx")
```

Figure 66: Code used in ME3L's EDA – Part III

APPENDIX VI – MB51'S DATA TREATMENT ALGORITHM

The algorithm used to transform the MB51 data is shown in Figures 67 and 68.

```
#MB51 Data Treatment
```{r}

MB51 <- data.frame(read_excel("MB51.XLSX"))
MB51 <- MB51[,-c(4,6,16, c(18:21))]
MB51 <- MB51[,c(13,2,4,3,12,9,8,1,5,10,6,7,11,14)]


#Check variables' data types

cat("Tipos de Variáveis Antes:", "\n")
cat("\n")
str(MB51)

#Change variables' data types
MB51$Pedido <- as.factor(MB51$Pedido)
MB51$Data.do.documento <- as.Date(as.character(MB51$Data.do.documento))
MB51$Data.de.lançamento <- as.Date(as.character(MB51$Data.de.lançamento))
MB51$Material <- as.factor(MB51$Material)
MB51$Texto.breve.material <- as.factor(MB51$Texto.breve.material)
MB51$Referência <- as.factor(MB51$Referência)
MB51$Lote <- as.factor(MB51$Lote)
MB51$Fornecedor <- as.factor(MB51$Fornecedor)
MB51$Unid.medida.básica <- as.factor(MB51$Unid.medida.básica)
MB51$UM.registro <- as.factor(MB51$UM.registro)
MB51$Moeda <- as.factor(MB51$Moeda)
MB51$Unid.prç.pedido <- as.factor(MB51$Unid.prç.pedido)

cat("\n")
cat("Tipos de Variáveis Depois:", "\n")
cat("\n")

str(MB51)
```
```

```
```{r}
#Check missing values

vis_miss(MB51, warn_large_data = FALSE)
```
```

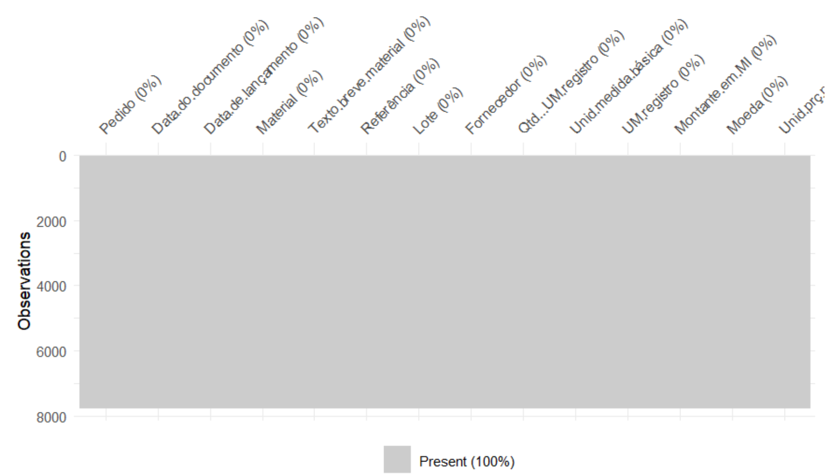


Figure 67: Code used in MB51 Transformation – Part I

```{r}
summary(MB51)
```

```
       Pedido         Data.do.documento      Data.de.lançamento              Material          Referência          Lote     
 5500043208:1921    Min.    :2019-01-07    Min.    :2019-01-07    105I0000000405:1921    3000708279:  88    00K2K8A:    1  
 5500043222: 974    1st Qu.:2022-01-11    1st Qu.:2022-01-14    101I0000001443:1342    3000699740:  84    00K2L0A:    1  
 5500039413: 861    Median :2022-11-07    Median :2022-11-11    105I0000000403: 992    3000693735:  83    00K2L1A:    1  
 5500043312: 775    Mean    :2022-05-10    Mean    :2022-05-12    102I0000000124: 834    3000712271:  78    00K2L2A:    1  
 5500044220: 607    3rd Qu.:2023-03-06    3rd Qu.:2023-03-08    101I0000001565: 660    3000686750:  76    00K2WTA:    1  
 5500022577: 481    Max.    :2023-06-07    Max.    :2023-06-07    102B0000000002: 613    3000709154:  71    00K2WUA:    1  
 (Other)    :2144                                                (Other)        :1401    (Other)    :7283    (Other):7757  
   Fornecedor      Qtd...UM.registro  Unid.medida.básica  UM.registro  Montante.em.MI       Moeda       Unid.prç.pedido
 71093   :2696    Min.   :  2.16      M :5239             M :5239      Min.   :    0.26    EUR:7763    M :3232      
 70363   :1342    1st Qu.: 35.50      M2:2524             M2:2524      1st Qu.:  338.80                M2:4531      
 70134   :1034    Median : 54.00                                       Median :  938.93                             
 70099   : 974    Mean   :132.46                                       Mean   : 4587.55                             
 70077   : 660    3rd Qu.:165.79                                       3rd Qu.: 6636.98                             
 70428   : 522    Max.   :720.49                                       Max.   :31509.19                             
 (Other): 535                                                                                                        
```

```{r}
#Aggregate entries with the same reference and batch numbers

MB51_semLotes <- MB51[,-c(6,7)]

MB51_grouped <- MB51_semLotes %>% group_by(Pedido, Data.do.documento, Data.de.lançamento, Material, Texto.breve.material,
Fornecedor, Unid.medida.básica, UM.registro, Moeda, Unid.prç.pedido) %>%
  summarise(Qtd_Total_Registada = sum(Qtd...UM.registro),
            Montante.MI.Total = sum(Montante.em.MI))

MB51_grouped <- MB51_grouped[, c(c(1:6), 11, 7, 8, 12, 9, 10)]

summary(MB51_grouped)
```

```{r}
#Current Value of Montantes MI variable

MM60 <- data.frame(read_excel("C:/Users/Sara Sa/OneDrive -
COINDU/COINDU/Dados_Projetos/Materiais_ClasseA/MM60_MP_classeA_final.xlsx"))

for (i in 1:nrow(MB51_grouped)) {
  for (j in 1:nrow(MM60)) {
    if(MB51_grouped$Material[i] == MM60$Material[j]){
      MB51_grouped$Montante.MI.Total.Atual[i] <- (MM60$Preço[j]/MM60$Unidade.de.preço[j]) * MB51_grouped$Qtd_Total_Registada[i]
    }
  }
}

MB51_grouped <- MB51_grouped[, c(c(1:10), 13, 11, 12)]
```

```{r}

# Assigning week number to variable 'Data.de.lançamento'

MB51_grouped <- MB51_grouped %>%
        mutate(date = as.Date(Data.de.lançamento, format = "%Y-%m-%d")) %>%
        mutate(yearweek = as.integer(strftime(date, format = "%Y%V"))) %>%
        mutate(yearweek2 = ifelse(test = day(date) > 7 & substr(yearweek, 5, 6) == '01',
                                  yes  = yearweek + 100,
                                  no   = ifelse(test = month(date) == 1 & as.integer(substr(yearweek, 5, 6)) > 51,
                                                yes  = yearweek - 100,
                                                no   = yearweek)))


MB51_grouped <- MB51_grouped[, -c(14,15)]
colnames(MB51_grouped)[14] <- "Ano/Semana Entrega"

MB51_grouped <- MB51_grouped[, c(c(1:3),14, c(4:13))]
MB51_grouped <- MB51_grouped[order(MB51_grouped$Data.de.lançamento),]

```

```{r}

#Exporting database

write.xlsx(data.frame(MB51_grouped), file = "MB51_Final.xlsx")
write.xlsx(data.frame(MB51), file = "MB51_com_Lotes.xlsx")
```

Figure 68: Code used in MB51 Transformation – Part II

APPENDIX VII – USAGE OF 'BALANÇO' AND 'QTD_COMPENSADA'

Table 34 illustrates the use and meaning of 'Balanço' and 'Qtd_Compensada' variables.

Table 34: Usage of the 'Balanço' and 'Qtd_Compensada' Variables

Pedido_Compra	Material	Data_Remessa	Semana_Ped	Cód_Fornece	Qtd_Divisão	Data_Lançam	Semana_Rea	Qtd_Registad	Unid_Medida	Qtd_Pendent	Qtd_Exceden	Balanço	Atraso	Atraso_Sema	Avanço	Avanço_Sem	Qtd_Compensada
5500039331	101I0000001565	02/10/2022	202206	70077	900	02/08/2022	202206	900,46	M2	0	0,46	217,55	0	0	0	0	0
5500039331	101I0000001565	02/17/2022	202207	70077	800	02/16/2022	202207	807,76	M2	0	7,76	225,31	0	0	0	0	0
5500039331	101I0000001565	02/18/2022	202207	70077	225,31	02/16/2022	202207	225,31	M2	0	0	0	0	0	0	0	225,31
5500039331	101I0000001565	02/24/2022	202208	70077	700	02/22/2022	202208	701,74	M2	0	1,74	1,74	0	0	0	0	0
5500039331	101I0000001565	03/03/2022	202209	70077	800	03/01/2022	202209	436,56	M2	363,44	0	-361,7	0	0	0	0	0
5500039331	101I0000001565	03/03/2022	202209	70077	800	03/07/2022	202210	368,12	M2	0	4,68	6,42	1	0,5714286	0	0	-363,44
5500039331	101I0000001565	03/10/2022	202210	70077	700	03/08/2022	202210	703,62	M2	0	3,62	10,04	0	0	0	0	0
5500039331	101I0000001565	03/24/2022	202212	70077	800	03/23/2022	202212	830,27	M2	0	30,27	40,31	0	0	0	0	0
5500039331	101I0000001565	03/31/2022	202213	70077	850	04/01/2022	202213	853,56	M2	0	3,56	43,87	0	0	0	0	0
5500039331	101I0000001565	04/07/2022	202214	70077	700	04/06/2022	202214	699,74	M2	0,26	0	43,61	0	0	0	0	0
5500039331	101I0000001565	04/14/2022	202215	70077	500	04/15/2022	202215	502,31	M2	0	2,31	45,92	0	0	0	0	0

In the first highlighted line, an order of 225,31 square metres of material '101I0000001565' was requested for February 18th, 2022. The algorithm matched that order with one arrived on February 16th, 2022 and that had already been assigned to another order requested for February 17th. This happened because the inventory balance after this last arrival met the order requested for February 18th, in other words this is one of those situations in which an order does not match one delivery in particular; instead, its requested amount had been building over time. As a result, this surplus of material was assigned to the highlighted order and the value of variable 'Balanço' was turned to zero. Since variables 'Qtd_Excedente' and 'Qtd_Pendente' could not have been used for this purpose (the requested amount of material was the exact amount delivered), 'Qtd_Compensada' assumed the order quantity value, as a way of compensating for the exceeding 225,31 square metres in the previous entry.

The second highlighted line illustrates the use of 'Qtd_Excedente' to compensate for situations of lack of material. In this case, 800 square metres of the same material were requested for March 3rd, 2022. However, this order was fulfilled during the course of two weeks and, specifically, between the first and second replenishments, 361,70 square metres were missing (considering the excess that, at the time, existed in balance). Consequently, the following arrival of 368,12 square metres compensated for this negative balance, corresponding to an extra 4,68 square metres when in comparison to the original amount of requested material. The 363,44 square metres missing after the first arrival needed, therefore, to be accounted for, which was, once again, possible due to 'Qtd_Compensada'.

It is noteworthy, though, that when 'Qtd_Compensada' refers to the use of extra units in balance, it assumes a positive value, but when it compensates for amounts of missing material, it is assigned a negative value instead.

APPENDIX VIII – COMBINING ME3L AND MB51 TRANSACTIONS

Figure 69 shows a diagram that summarises the validations included in the code responsible for combining ME3L and MB51 transactions. Note that the conditions stated in this diagram are simplifications of the real conditions used and that they only intend to illustrate the scenarios included in this algorithm.

Having this in mind and as shown in Figure 69, the algorithm assesses each line of both transactions in parallel, comparing a requested delivery in line i of ME3L transaction with the potential receiving report in line j of MB51 transaction. This activity can be divided into four main possible moments – comparing past values of variable **'Balanço'**; if this is proven fruitless, verifying if **'Qtd_Total_Registada'** in line j is equal to '**Qtd.divisão'** in line i; if, instead, **'Qtd_Total_Registada'** in line j is inferior or superior to '**Qtd.divisão'** in line i, then it evaluates their respective possibilities.

As a result, in the first part of the algorithm, it assesses:

1. If any of the previously matched entries registered an excess of material equal to '**Qtd.divisão'** in line i. Should this condition be validated, the delivery request i will also be assigned to that entry, setting the amount of delivered material to the value of '**Qtd.divisão'** and compensating **'Balanço'** with the help of variable **'Qtd_Compensada'**;
2. If '**Qtd.divisão'** in line i is different from **'Qtd_Total_Registada'** in line j, but there is enough material in **'Balanço'** to fulfil this delivery, then the ME3L request is linked to the last delivery of material responsible for the positive amount of stock. Once again, **'Qtd_Compensada'** is used to correct the inventory level;
3. If there is a certain amount of inventory missing that equals **'Qtd_Total_Registada'** in line j and '**Qtd.divisão'** in line i equals the amount of delivered material in the following receiving report, then a new entry to include record j must be created. However, it does not relate to any entry of ME3L transaction and will directly compensate for the shortage of material in **'Balanço'** by setting a negative value to variable **'Qtd_Compensada'**.

In case of one of these conditions is met, and similarly to what happens in all possible scenarios, the information is combined accordingly, the new dataset is incremented in one line and the algorithm proceeds to the following iteration to allocate the rest of the unmatched entries.

Nevertheless, if what happened does not fit into any of these options, the next thing to confirm is the simplest possible case - '**Qtd.divisão'** and **'Qtd_Total_Registada'** equalling the same value. In this situation, the algorithm only has to fill in the new dataset's variables with the corresponding values from both transactions.

The third set of possible scenarios is defined under the condition of **'Qtd_Total_Registada'** in line j being inferior to '**Qtd.divisão'** in line i, and includes:

1. The possibility of records not following the same sequence in both datasets and that the receiving report matching the delivery request in line i can, instead, be found in line j+1 of the MB51 transaction. In this case, line i of the ME3L transaction is combined with line j+1 of MB51 transaction;
2. The possibility of two deliveries covering the same ME3L request. Note that the comparison is made considering a value 3% superior to '**Qtd.divisão'**, because, sometimes, the ME3L request is fulfilled with a slightly extra amount of material. In these situations, both entries j and j+1 are allocated to delivery request i in the same iteration;
3. The possibility of two deliveries covering the requested amount in ME3L transaction with an excess of material that compensates for the missing amount when matching the following entries of both transactions (line i+1 of ME3L with line j+2 of MB51). Under these circumstances, entries j and j+1 are also allocated to delivery request i in the same iteration;
4. The possibility of two deliveries covering not all, but most of the requested amount in ME3L transaction. In these circumstances, the amount of material missing is compensated by the surplus of material obtained when matching line i+1 of ME3L with line j+2 of MB51 transactions. Both j and j+1 entries are allocated to delivery request i in the same iteration.
5. If neither of the previous possibilities is met, then that means the amount of delivered material was indeed inferior to the one requested and entries i and j are matched accordingly.

Lastly, **'Qtd_Total_Registada'** in line j may be superior to '**Qtd.divisão'** in line i and so, before assigning these entries to one another, it is important to understand if:

1. Once again, the records are mixed and the amount of requested material in line i can, instead, be found as delivered in line j+1 of the MB51 transaction. Here, line i of ME3L transaction is also combined with line j+1 of MB51 transaction;
2. Receiving report j is covering two delivery requests, referring to entries i and i+1 in ME3L transaction. Should this happen, the MB51 entry j must be split between the two ME3L entries, according to the respective values of variable '**Qtd.divisão'**, and both lines i and i+1 are allocated to receiving report j in the same iteration.

It is only if these conditions fail to be met that it is assumed that the amount of delivered material was indeed superior to the one requested and entries i and j are properly matched.

While assigning ME3L and MB51 entries, the algorithm also assesses if the materials were delivered on time, with some delay, or a few days in advance. For that matter, it assigns value 1 to binary variables **'Atraso'** or **'Avanço'**, in case the matching receiving report's date week number is different from the week number of the scheduled delivery request – if it is superior, then **'Atraso'** equals one; if it is inferior, it will be **'Avanço'** the one equalling one. The amount of weeks delayed or ahead of time is also calculated and assigned to variables **'Atraso_semanas'** and **'Avanço_semanas'** when the respective binary variables **'Atraso'** or **'Avanço'** equal one. Should one delivery request of ME3L transaction match more than one MB51 receiving report, the assessment will be made based on the date of the last MB51 entry.

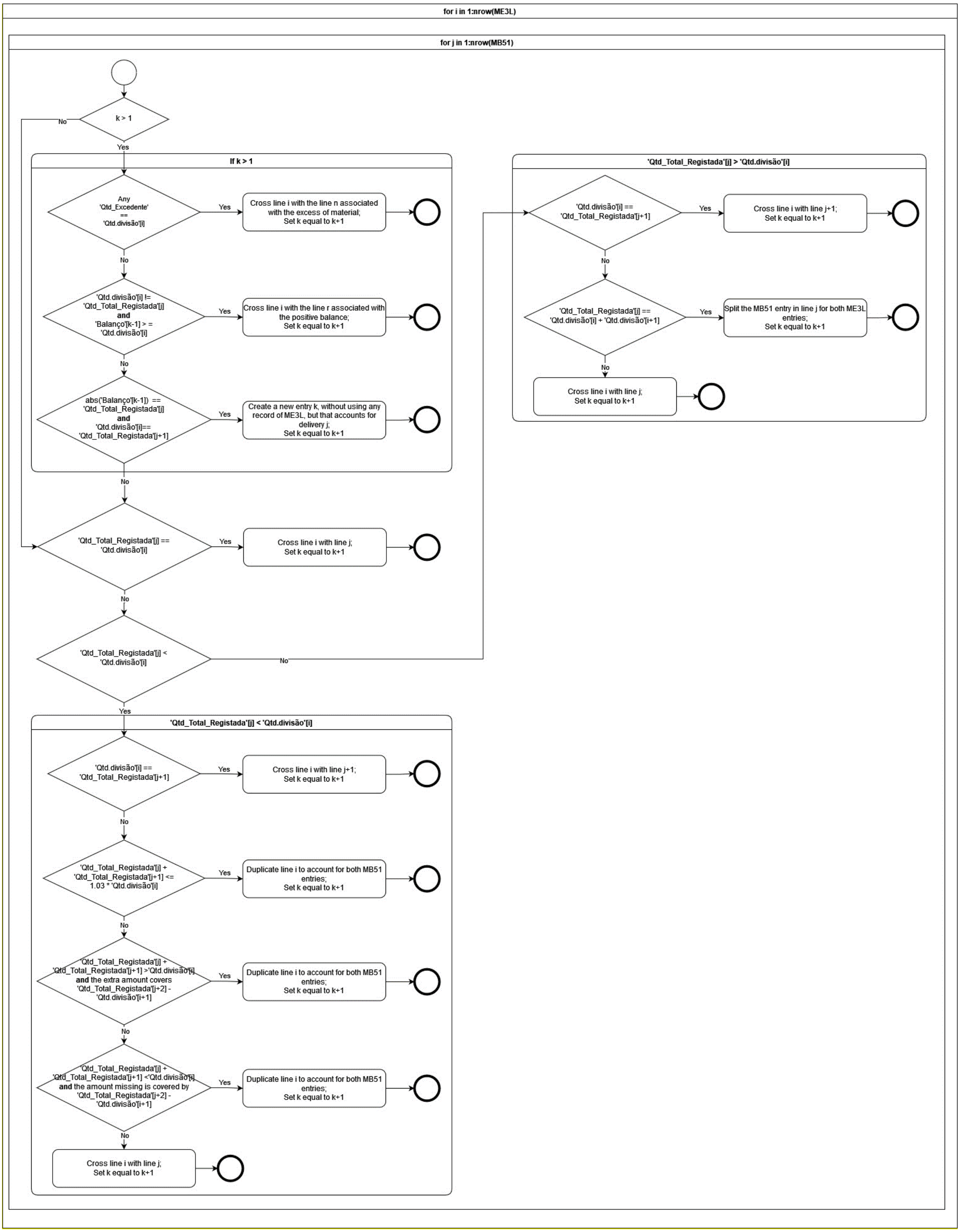


Figure 69: Scenarios included in ME3L and MB51's Foundational Crossing Algorithm

Figures 70 to 90 detail the foundational R code that allowed to combine ME3L and MB51 transactions. It is noteworthy, though, that the initial part of the code, illustrated in Figure 70, excludes entries for which there are no matches between transactions – deliveries scheduled into the future that appear in ME3L transaction, but not in MB51; older receiving reports that the system holds in MB51 transaction, but not in ME3L.

````
```{r}

ME3L <- data.frame(read_excel("ME3L_Final.xlsx"))
MB51 <- data.frame(read_excel("MB51_Final.xlsx"))

#Exclude from ME3L delivery requests to be fulfilled in the future

ME3L <- subset(ME3L, (Data.de.remessa <= Data.Recolha.Dados & Estado != "Pendente"))

#Exclude from MB51 receiving reports with delivery dates prior to the first scheduled deliveries of ME3L transaction

startingDate <- 0
startingDate <- data.frame(startingDate)
startingDate$Material <- NA
startingDate$ME3L <- NA
startingDate$MB51 <- NA
startingDate <- startingDate[,-1]
startingDate <- startingDate[1:9,]

startingDate$Material <- unique(MB51$Material)
k <- 1

for (material in startingDate$Material) {
  filtro_me3l <- subset(ME3L, Material == material)
  startingDate$ME3L[k] <- filtro_me3l$Ano.Semana.Entrega[1]
  filtro_mb51 <- subset(MB51, Material == material)
  startingDate$MB51[k] <- filtro_mb51$Ano.Semana.Entrega[1]
  k <- k+1
}

materiais_a_corrigir <- subset(startingDate, MB51 < ME3L)

MB51$Eliminar <- FALSE

for (i in 1:nrow(MB51)) {
  for (j in 1:7) {
    if(materiais_a_corrigir$Material[j] == MB51$Material[i]){
      if(MB51$Ano.Semana.Entrega[i] < materiais_a_corrigir$ME3L[j]){
        MB51$Eliminar[i] <- TRUE
        break
      }else{
        MB51$Eliminar[i] <- FALSE
        break
      }
    }
  }
}

MB51 <- subset(MB51, Eliminar == FALSE)

```
````

Figure 70: Code used to Combine ME3L and MB51 Transactions – Part I

```
## Algorithm to Cross Information from both Datasets
```{r}

#New Dataset

EncomendasMaterial <- 0
EncomendasMaterial <- data.frame(EncomendasMaterial)
EncomendasMaterial$Pedido_Compra <- NA
EncomendasMaterial$Data_Doc_Compra <- NA
EncomendasMaterial$Material <- NA
EncomendasMaterial$Descrição <- NA
EncomendasMaterial$Grupo_Mercadorias <- NA
EncomendasMaterial$Preço_Líquido <- NA
EncomendasMaterial$Moeda <- NA
EncomendasMaterial$Unid_Preço <- NA
EncomendasMaterial$Data_Remessa <- NA
EncomendasMaterial$Semana_Pedido_Entrega <- NA
EncomendasMaterial$Cód_Fornecedor <- NA
EncomendasMaterial$Descrição_Fornecedor <- NA
EncomendasMaterial$Qtd_Divisão <- NA
EncomendasMaterial$Unid_Medida_Pedido <- NA
EncomendasMaterial$Qtd_Anterior <- NA
EncomendasMaterial$Qtd_Entrada_Total <- NA
EncomendasMaterial$Data_Doc_Receção <- NA
EncomendasMaterial$Data_Lançamento <- NA
EncomendasMaterial$Semana_Real_Entrega <- NA
EncomendasMaterial$Qtd_Registada <- NA
EncomendasMaterial$Unid_Medida_Básica <- NA
EncomendasMaterial$Unid_Registo <- NA
EncomendasMaterial$Montante.MI.Total <- NA
EncomendasMaterial$Montante.MI.Total.Atual <- NA
EncomendasMaterial$Moeda <- NA
EncomendasMaterial$Unid_Preço_Pedido <- NA
EncomendasMaterial$Qtd_Pendente <- 0
EncomendasMaterial$Qtd_Excedente <- 0
EncomendasMaterial$Balanço <- 0
EncomendasMaterial$Atraso <- 0
EncomendasMaterial$Atraso_Semanas <- 0
EncomendasMaterial$Avanço <- 0
EncomendasMaterial$Avanço_Semanas <- 0
EncomendasMaterial$Qtd_Compensada <- 0


EncomendasMaterial <- EncomendasMaterial[,-1]
EncomendasMaterial <- EncomendasMaterial[1:10149,]

MB51$Check <- 0
ME3L$Check <- 0

EncomendasMaterial$Data_Doc_Compra <- as.Date(as.character(EncomendasMaterial$Data_Doc_Compra))
EncomendasMaterial$Data_Remessa <- as.Date(as.character(EncomendasMaterial$Data_Remessa))
EncomendasMaterial$Data_Doc_Receção <- as.Date(as.character(EncomendasMaterial$Data_Doc_Receção))
EncomendasMaterial$Data_Lançamento <- as.Date(as.character(EncomendasMaterial$Data_Lançamento))

```
```

Figure 71: Code used to Combine ME3L and MB51 Transactions – Part II

```{r}
#The algorithm is prepared to run for several materials, though it ran individually

pedidos_MB51 <- unique(MB51$Pedido)
k <- 1

#for (material in startingDate$Material) {
  #for (pedido in pedidos_MB51) {
    filtro_me3l <- subset(ME3L, (Material == "101I0000001565") & (Doc.Compras == "5500039331"))
    filtro_mb51 <- subset(MB51, (Material == "101I0000001565") & (Pedido == "5500039331"))

    if(nrow(filtro_mb51) != 0 & nrow(filtro_me3l) != 0){
      kk <- k #saves the value of variable k, when it finds a new valid combination of 'Material' and 'Pedido'. In this case it will always equal 1
      for (i in 1:nrow(filtro_me3l)) {
        for (j in 1:nrow(filtro_mb51)) {

          #At the start of each iteration, it compares past values of variable 'Balanço'

          if(k > kk){
            for (n in kk:(k-1)) {
              if(EncomendasMaterial$Qtd_Excedente[n] == filtro_me3l$Qtd.divisão[i] & filtro_me3l$Ano.Semana.Entrega[i] != filtro_mb51$Ano.Semana.Entrega[j] & filtro_me3l$Qtd.divisão[i] != filtro_mb51$Qtd_Total_Registada[j] & filtro_me3l$Check[i] == 0 & filtro_mb51$Check[j] == 0){ #variables 'Check' help distinguishing entries that have already been assigned from those that have not
                EncomendasMaterial$Pedido_Compra[k] <- EncomendasMaterial$Pedido_Compra[n]
                EncomendasMaterial$Data_Doc_Compra[k] <- filtro_me3l$Data.do.documento[i]
                EncomendasMaterial$Material[k] <- filtro_me3l$Material[i]
                EncomendasMaterial$Descrição[k] <- filtro_me3l$Texto.breve[i]
                EncomendasMaterial$Grupo_Mercadorias[k] <- filtro_me3l$Grupo.de.mercadorias[i]
                EncomendasMaterial$Preço_Líquido[k] <- filtro_me3l$Preço.líquido[i]
                EncomendasMaterial$Moeda[k] <- filtro_me3l$Moeda[i]
                EncomendasMaterial$Unid_Preço[k] <- filtro_me3l$Unidade.de.preço[i]
                EncomendasMaterial$Data_Remessa[k] <- filtro_me3l$Data.de.remessa[i]
                EncomendasMaterial$Semana_Pedido_Entrega[k] <- filtro_me3l$Ano.Semana.Entrega[i]
                EncomendasMaterial$Cód_Fornecedor[k] <- filtro_me3l$Cód.fornecedor[i]
                EncomendasMaterial$Descrição_Fornecedor[k] <- filtro_me3l$Descr..Fornecedor[i]
                EncomendasMaterial$Qtd_Divisão[k] <- filtro_me3l$Qtd.divisão[i]
                EncomendasMaterial$Unid_Medida_Pedido[k] <- filtro_me3l$UM.pedido[i]
                EncomendasMaterial$Qtd_Anterior[k] <- filtro_me3l$Quantidade.anterior[i]
                EncomendasMaterial$Qtd_Entrada_Total[k] <- filtro_me3l$Qtd.entrada[i]
                EncomendasMaterial$Data_Doc_Receção[k] <- EncomendasMaterial$Data_Doc_Receção[n]
                EncomendasMaterial$Data_Lançamento[k] <-  EncomendasMaterial$Data_Lançamento[n]
                EncomendasMaterial$Semana_Real_Entrega[k] <- EncomendasMaterial$Semana_Real_Entrega[n]
                EncomendasMaterial$Qtd_Registada[k] <- filtro_me3l$Qtd.divisão[i]
                EncomendasMaterial$Unid_Medida_Básica[k] <- EncomendasMaterial$Unid_Medida_Básica[n]
                EncomendasMaterial$Unid_Registo[k] <- EncomendasMaterial$Unid_Registo[n]
                EncomendasMaterial$Montante.MI.Total[k] <- EncomendasMaterial$Montante.MI.Total[n]
                EncomendasMaterial$Montante.MI.Total.Atual[k] <- EncomendasMaterial$Montante.MI.Total.Atual[n]
                EncomendasMaterial$Moeda[k] <- EncomendasMaterial$Moeda[k][n]
                EncomendasMaterial$Unid_Preço_Pedido[k] <- EncomendasMaterial$Unid_Preço_Pedido[n]

                EncomendasMaterial$Qtd_Compensada[k] <- EncomendasMaterial$Qtd_Excedente[n]
                #The assumption is that the amount of material requested was the exact amount delivered

                EncomendasMaterial$Qtd_Pendente[k] <- 0
                EncomendasMaterial$Qtd_Excedente[k] <- 0

               #Assessing possible delays or anticipation of deliveries

               if(EncomendasMaterial$Semana_Real_Entrega[k] != filtro_me3l$Ano.Semana.Entrega[i]){
                  if(EncomendasMaterial$Semana_Real_Entrega[k] > filtro_me3l$Ano.Semana.Entrega[i]){
                    EncomendasMaterial$Atraso[k] <- 1
                    EncomendasMaterial$Atraso_Semanas[k] <- as.numeric(difftime(EncomendasMaterial$Data_Lançamento[k], EncomendasMaterial$Data_Remessa[k], units = "weeks"))
                    EncomendasMaterial$Avanço[k] <- 0
                    EncomendasMaterial$Avanço_Semanas[k] <- 0
               } else if (EncomendasMaterial$Semana_Real_Entrega[k] < filtro_me3l$Ano.Semana.Entrega[i]){
                    EncomendasMaterial$Avanço[k] <- 1
                    EncomendasMaterial$Avanço_Semanas[k] <- as.numeric(difftime(EncomendasMaterial$Data_Remessa[k], EncomendasMaterial$Data_Lançamento[k], units = "weeks"))
                    EncomendasMaterial$Atraso[k] <- 0
                    EncomendasMaterial$Atraso_Semanas[k] <- 0
               }
               }else{
                  EncomendasMaterial$Atraso[k] <- 0
                  EncomendasMaterial$Atraso_Semanas[k] <- 0
                  EncomendasMaterial$Avanço[k] <- 0
                  EncomendasMaterial$Avanço_Semanas[k] <- 0
               }

               EncomendasMaterial$Balanço[k] <- round(EncomendasMaterial$Qtd_Excedente[k]-EncomendasMaterial$Qtd_Pendente[k]-EncomendasMaterial$Qtd_Compensada[k]+EncomendasMaterial$Balanço[k-1],3)

                filtro_me3l$Check[i] <- 1
                k <- k+1
                break
```

Figure 72: Code used to Combine ME3L and MB51 Transactions – Part III

```
              }else if (filtro_mb51$Check[j] == 0 & EncomendasMaterial$Balanço[k-1] >= filtro_me3l$Qtd.divisão[i] &
filtro_me3l$Qtd.divisão[i] != filtro_mb51$Qtd_Total_Registada[j] & filtro_me3l$Check[i] == 0 ){

                EncomendasMaterial$Pedido_Compra[k] <- filtro_me3l$Doc.Compras[i]
                EncomendasMaterial$Data_Doc_Compra[k] <- filtro_me3l$Data.do.documento[i]
                EncomendasMaterial$Material[k] <- filtro_me3l$Material[i]
                EncomendasMaterial$Descrição[k] <- filtro_me3l$Texto.breve[i]
                EncomendasMaterial$Grupo_Mercadorias[k] <- filtro_me3l$Grupo.de.mercadorias[i]
                EncomendasMaterial$Preço_Líquido[k] <- filtro_me3l$Preço.liquido[i]
                EncomendasMaterial$Moeda[k] <- filtro_me3l$Moeda[i]
                EncomendasMaterial$Unid_Preço[k] <- filtro_me3l$Unidade.de.preço[i]
                EncomendasMaterial$Data_Remessa[k] <- filtro_me3l$Data.de.remessa[i]
                EncomendasMaterial$Semana_Pedido_Entrega[k] <- filtro_me3l$Ano.Semana.Entrega[i]
                EncomendasMaterial$Cód_Fornecedor[k] <- filtro_me3l$Cód.fornecedor[i]
                EncomendasMaterial$Descrição_Fornecedor[k] <- filtro_me3l$Descr..Fornecedor[i]
                EncomendasMaterial$Qtd_Divisão[k] <- filtro_me3l$Qtd.divisão[i]
                EncomendasMaterial$Unid_Medida_Pedido[k] <- filtro_me3l$UM.pedido[i]
                EncomendasMaterial$Qtd_Anterior[k] <- filtro_me3l$Quantidade.anterior[i]
                EncomendasMaterial$Qtd_Entrada_Total[k] <- filtro_me3l$Qtd.entrada[i]
                EncomendasMaterial$Data_Doc_Receção[k] <- NA #associated to several documents, not just one

                n <- k-1

                for (r in kk:n) {
                  if(EncomendasMaterial$Qtd_Excedente[r] > 0){
                    last_exc <- r
                  }
                }

                EncomendasMaterial$Data_Lançamento[k] <- EncomendasMaterial$Data_Lançamento[last_exc]#it can be filled with
information from the last delivery of material responsible for the positive amount of stock (n)

                EncomendasMaterial$Semana_Real_Entrega[k] <- EncomendasMaterial$Semana_Real_Entrega[last_exc] #it can be filled
with information from the last delivery of material responsible for the positive amount of stock (n)
                EncomendasMaterial$Qtd_Registada[k] <- filtro_me3l$Qtd.divisão[i]
                EncomendasMaterial$Unid_Medida_Básica[k] <- EncomendasMaterial$Unid_Medida_Básica[last_exc]
                EncomendasMaterial$Unid_Registo[k] <- EncomendasMaterial$Unid_Registo[last_exc]
                EncomendasMaterial$Montante.MI.Total[k] <- (EncomendasMaterial$Montante.MI.Total[last_exc] /
EncomendasMaterial$Qtd_Registada[last_exc]) * filtro_me3l$Qtd.divisão[i]
                EncomendasMaterial$Montante.MI.Total.Atual[k] <- (EncomendasMaterial$Montante.MI.Total.Atual[last_exc] /
EncomendasMaterial$Qtd_Registada[last_exc]) * filtro_me3l$Qtd.divisão[i]
                EncomendasMaterial$Moeda[k] <- EncomendasMaterial$Moeda[last_exc]
                EncomendasMaterial$Unid_Preço_Pedido[k] <- EncomendasMaterial$Unid_Preço_Pedido[last_exc]

                #The assumption is that the amount of material requested was the exact amount delivered in the course of several
entries

                EncomendasMaterial$Qtd_Pendente[k] <- 0
                EncomendasMaterial$Qtd_Excedente[k] <- 0
                EncomendasMaterial$Qtd_Compensada[k] <- filtro_me3l$Qtd.divisão[i]
               #Assessing possible delays or anticipation of deliveries

               if(EncomendasMaterial$Semana_Real_Entrega[k] != filtro_me3l$Ano.Semana.Entrega[i]){
                  if(EncomendasMaterial$Semana_Real_Entrega[k] > filtro_me3l$Ano.Semana.Entrega[i]){
                    EncomendasMaterial$Atraso[k] <- 1
                    EncomendasMaterial$Atraso_Semanas[k] <- as.numeric(difftime(EncomendasMaterial$Data_Lançamento[k],
EncomendasMaterial$Data_Remessa[k], units = "weeks"))
                    EncomendasMaterial$Avanço[k] <- 0
                    EncomendasMaterial$Avanço_Semanas[k] <- 0
               } else if (EncomendasMaterial$Semana_Real_Entrega[k] < filtro_me3l$Ano.Semana.Entrega[i]){
                    EncomendasMaterial$Avanço[k] <- 1
                    EncomendasMaterial$Avanço_Semanas[k] <- as.numeric(difftime(EncomendasMaterial$Data_Remessa[k],
EncomendasMaterial$Data_Lançamento[k], units = "weeks"))
                    EncomendasMaterial$Atraso[k] <- 0
                    EncomendasMaterial$Atraso_Semanas[k] <- 0
               }
               }else{
                  EncomendasMaterial$Atraso[k] <- 0
                  EncomendasMaterial$Atraso_Semanas[k] <- 0
                  EncomendasMaterial$Avanço[k] <- 0
                  EncomendasMaterial$Avanço_Semanas[k] <- 0
               }
               EncomendasMaterial$Balanço[k] <-
round(EncomendasMaterial$Qtd_Excedente[k]-EncomendasMaterial$Qtd_Pendente[k]-EncomendasMaterial$Qtd_Compensada[k]+
EncomendasMaterial$Balanço[k-1],3)

                filtro_me3l$Check[i] <- 1
                k <- k+1
                break
```

Figure 73: Code used to Combine ME3L and MB51 Transactions – Part IV

```
            }else if (filtro_mb51$Check[j] == 0 & j != nrow(filtro_mb51) & abs(EncomendasMaterial$Balanço[k-1]) ==
filtro_mb51$Qtd_Total_Registada[j] & filtro_me3l$Qtd.divisão[i] == round(filtro_mb51$Qtd_Total_Registada[j+1],0) &
filtro_mb51$Check[j] == 0 & filtro_mb51$Check[j+1] == 0){

                EncomendasMaterial$Pedido_Compra[k] <- NA
                EncomendasMaterial$Data_Doc_Compra[k] <- NA
                EncomendasMaterial$Material[k] <- EncomendasMaterial$Material[k-1]
                EncomendasMaterial$Descrição[k] <- EncomendasMaterial$Descrição[k-1]
                EncomendasMaterial$Grupo_Mercadorias[k] <- EncomendasMaterial$Grupo_Mercadorias[k-1]
                EncomendasMaterial$Preço_Liquido[k] <- EncomendasMaterial$Preço_Liquido[k-1]
                EncomendasMaterial$Moeda[k] <- EncomendasMaterial$Moeda[k-1]
                EncomendasMaterial$Unid_Preço[k] <- EncomendasMaterial$Unid_Preço[k-1]
                EncomendasMaterial$Data_Remessa[k] <- NA
                EncomendasMaterial$Semana_Pedido_Entrega[k] <- NA
                EncomendasMaterial$Cód_Fornecedor[k] <- EncomendasMaterial$Cód_Fornecedor[k-1]
                EncomendasMaterial$Descrição_Fornecedor[k] <- EncomendasMaterial$Descrição_Fornecedor[k-1]
                EncomendasMaterial$Qtd_Divisão[k] <- NA
                EncomendasMaterial$Unid_Medida_Pedido[k] <- EncomendasMaterial$Unid_Medida_Pedido[k-1]
                EncomendasMaterial$Qtd_Anterior[k] <- NA
                EncomendasMaterial$Qtd_Entrada_Total[k] <- NA
                EncomendasMaterial$Data_Doc_Receção[k] <- NA #this delivery does not exist in ME3L

                EncomendasMaterial$Data_Lançamento[k] <- filtro_mb51$Data.de.lançamento[j]
                EncomendasMaterial$Semana_Real_Entrega[k] <- filtro_mb51$Ano.Semana.Entrega[j]
                EncomendasMaterial$Qtd_Registada[k] <- filtro_mb51$Qtd_Total_Registada[j]
                EncomendasMaterial$Unid_Medida_Básica[k] <- filtro_mb51$Unid.medida.básica[j]
                EncomendasMaterial$Unid_Registo[k] <- filtro_mb51$UM.registro[j]
                EncomendasMaterial$Montante.MI.Total[k] <- filtro_mb51$Montante.MI.Total[j]
                EncomendasMaterial$Montante.MI.Total.Atual[k] <- filtro_mb51$Montante.MI.Total.Atual[j]
                EncomendasMaterial$Moeda[k] <- filtro_mb51$Moeda[j]
                EncomendasMaterial$Unid_Preço_Pedido[k] <- filtro_mb51$Unid.prç.pedido[j]

                EncomendasMaterial$Qtd_Pendente[k] <- 0
                EncomendasMaterial$Qtd_Excedente[k] <- 0
                EncomendasMaterial$Qtd_Compensada[k] <- -filtro_mb51$Qtd_Total_Registada[j]#to compensate the shortage of
material in 'Balanço'

               #Assigning possible delays or anticipation of deliveries

               if(EncomendasMaterial$Semana_Real_Entrega[k] != filtro_me3l$Ano.Semana.Entrega[i]){
                  if(EncomendasMaterial$Semana_Real_Entrega[k] > filtro_me3l$Ano.Semana.Entrega[i]){
                     EncomendasMaterial$Atraso[k] <- 1
                     EncomendasMaterial$Atraso_Semanas[k] <- as.numeric(difftime(EncomendasMaterial$Data_Lançamento[k],
EncomendasMaterial$Data_Remessa[k], units = "weeks"))
                     EncomendasMaterial$Avanço[k] <- 0
                     EncomendasMaterial$Avanço_Semanas[k] <- 0
               } else if (EncomendasMaterial$Semana_Real_Entrega[k] < filtro_me3l$Ano.Semana.Entrega[i]){
                     EncomendasMaterial$Avanço[k] <- 1
                     EncomendasMaterial$Avanço_Semanas[k] <- as.numeric(difftime(EncomendasMaterial$Data_Remessa[k],
EncomendasMaterial$Data_Lançamento[k], units = "weeks"))
                     EncomendasMaterial$Atraso[k] <- 0
                     EncomendasMaterial$Atraso_Semanas[k] <- 0
               }
               }else{
                  EncomendasMaterial$Atraso[k] <- 0
                  EncomendasMaterial$Atraso_Semanas[k] <- 0
                  EncomendasMaterial$Avanço[k] <- 0
                  EncomendasMaterial$Avanço_Semanas[k] <- 0
               }
               EncomendasMaterial$Balanço[k] <-
round(EncomendasMaterial$Qtd_Excedente[k]-EncomendasMaterial$Qtd_Pendente[k]-EncomendasMaterial$Qtd_Compensada[k]+
EncomendasMaterial$Balanço[k-1],3)

                filtro_mb51$Check[j] <- 1
                k <- k+1
                break

            }

          }
        }
```

Figure 74: Code used to Combine ME3L and MB51 Transactions – Part V

```
        #In case requested and delivered quantities are the same
        if((filtro_mb51$Qtd_Total_Registada[j] == filtro_me3l$Qtd.divisão[i]) & filtro_mb51$Check[j] == 0 &
filtro_me3l$Check[i] == 0){

        EncomendasMaterial$Pedido_Compra[k] <- filtro_mb51$Pedido[j]
        EncomendasMaterial$Data_Doc_Compra[k] <- filtro_me3l$Data.do.documento[i]
        EncomendasMaterial$Material[k] <- filtro_me3l$Material[i]
        EncomendasMaterial$Descrição[k] <- filtro_me3l$Texto.breve[i]
        EncomendasMaterial$Grupo_Mercadorias[k] <- filtro_me3l$Grupo.de.mercadorias[i]
        EncomendasMaterial$Preço_Líquido[k] <- filtro_me3l$Preço.líquido[i]
        EncomendasMaterial$Moeda[k] <- filtro_me3l$Moeda[i]
        EncomendasMaterial$Unid_Preço[k] <- filtro_me3l$Unidade.de.preço[i]
        EncomendasMaterial$Data_Remessa[k] <- filtro_me3l$Data.de.remessa[i]
        EncomendasMaterial$Semana_Pedido_Entrega[k] <- filtro_me3l$Ano.Semana.Entrega[i]
        EncomendasMaterial$Cód_Fornecedor[k] <- filtro_me3l$Cód.fornecedor[i]
        EncomendasMaterial$Descrição_Fornecedor[k] <- filtro_me3l$Descr..Fornecedor[i]
        EncomendasMaterial$Qtd_Divisão[k] <- filtro_me3l$Qtd.divisão[i]
        EncomendasMaterial$Unid_Medida_Pedido[k] <- filtro_me3l$UM.pedido[i]
        EncomendasMaterial$Qtd_Anterior[k] <- filtro_me3l$Quantidade.anterior[i]
        EncomendasMaterial$Qtd_Entrada_Total[k] <- filtro_me3l$Qtd.entrada[i]
        EncomendasMaterial$Data_Doc_Receção[k] <- filtro_mb51$Data.do.documento[j]
        EncomendasMaterial$Data_Lançamento[k] <- filtro_mb51$Data.de.lançamento[j]
        EncomendasMaterial$Semana_Real_Entrega[k] <- filtro_mb51$Ano.Semana.Entrega[j]
        EncomendasMaterial$Qtd_Registada[k] <- filtro_mb51$Qtd_Total_Registada[j]
        EncomendasMaterial$Unid_Medida_Básica[k] <- filtro_mb51$Unid.medida.básica[j]
        EncomendasMaterial$Unid_Registo[k] <- filtro_mb51$UM.registro[j]
        EncomendasMaterial$Montante.MI.Total[k] <- filtro_mb51$Montante.MI.Total[j]
        EncomendasMaterial$Montante.MI.Total.Atual[k] <- filtro_mb51$Montante.MI.Total.Atual[j]
        EncomendasMaterial$Moeda[k] <- filtro_mb51$Moeda[j]
        EncomendasMaterial$Unid_Preço_Pedido[k] <- filtro_mb51$Unid.prç.pedido[j]

        EncomendasMaterial$Qtd_Pendente[k] <- 0
        EncomendasMaterial$Qtd_Excedente[k] <- 0
        EncomendasMaterial$Qtd_Compensada[k] <- 0

        #Assigning possible delays or anticipation of deliveries

        if(filtro_mb51$Ano.Semana.Entrega[j] != filtro_me3l$Ano.Semana.Entrega[i]){
          if(filtro_mb51$Ano.Semana.Entrega[j] > filtro_me3l$Ano.Semana.Entrega[i]){
            EncomendasMaterial$Atraso[k] <- 1
            EncomendasMaterial$Atraso_Semanas[k] <- as.numeric(difftime(EncomendasMaterial$Data_Lançamento[k],
EncomendasMaterial$Data_Remessa[k], units = "weeks"))
            EncomendasMaterial$Avanço[k] <- 0
            EncomendasMaterial$Avanço_Semanas[k] <- 0
          } else if (filtro_mb51$Ano.Semana.Entrega[j] < filtro_me3l$Ano.Semana.Entrega[i]){
            EncomendasMaterial$Avanço[k] <- 1
            EncomendasMaterial$Avanço_Semanas[k] <- as.numeric(difftime(EncomendasMaterial$Data_Remessa[k],
EncomendasMaterial$Data_Lançamento[k], units = "weeks"))
            EncomendasMaterial$Atraso[k] <- 0
            EncomendasMaterial$Atraso_Semanas[k] <- 0
          }
        }else{
          EncomendasMaterial$Atraso[k] <- 0
          EncomendasMaterial$Atraso_Semanas[k] <- 0
          EncomendasMaterial$Avanço[k] <- 0
          EncomendasMaterial$Avanço_Semanas[k] <- 0
        }

        if(k==kk){
          EncomendasMaterial$Balanço[k] <-
round(EncomendasMaterial$Qtd_Excedente[k]-EncomendasMaterial$Qtd_Pendente[k]-EncomendasMaterial$Qtd_Compensada[k],3)
        }else{
          EncomendasMaterial$Balanço[k] <-
round(EncomendasMaterial$Qtd_Excedente[k]-EncomendasMaterial$Qtd_Pendente[k]-EncomendasMaterial$Qtd_Compensada[k]+
EncomendasMaterial$Balanço[k-1],3)
        }

        filtro_mb51$Check[j] <- 1
        filtro_me3l$Check[i] <- 1
        k <- k+1
        break
```

Figure 75: Code used to Combine ME3L and MB51 Transactions – Part VI

```
        #When the amount delivered seems to be inferior to the one requested

        }else if (filtro_mb51$Qtd_Total_Registada[j] < filtro_me3l$Qtd.divisão[i] & filtro_mb51$Check[j] == 0 &
filtro_me3l$Check[i] == 0){
          if(j != nrow(filtro_mb51)){
            if(filtro_mb51$Qtd_Total_Registada[j+1] == filtro_me3l$Qtd.divisão[i] & filtro_mb51$Check[j] == 0 &
filtro_mb51$Check[j+1] == 0 & filtro_mb51$Data.de.lançamento[j] == filtro_mb51$Data.de.lançamento[j+1]){

              EncomendasMaterial$Pedido_Compra[k] <- filtro_mb51$Pedido[j+1]
              EncomendasMaterial$Data_Doc_Compra[k] <- filtro_me3l$Data.do.documento[i]
              EncomendasMaterial$Material[k] <- filtro_me3l$Material[i]
              EncomendasMaterial$Descrição[k] <- filtro_me3l$Texto.breve[i]
              EncomendasMaterial$Grupo_Mercadorias[k] <- filtro_me3l$Grupo.de.mercadorias[i]
              EncomendasMaterial$Preço_Líquido[k] <- filtro_me3l$Preço.líquido[i]
              EncomendasMaterial$Moeda[k] <- filtro_me3l$Moeda[i]
              EncomendasMaterial$Unid_Preço[k] <- filtro_me3l$Unidade.de.preço[i]
              EncomendasMaterial$Data_Remessa[k] <- filtro_me3l$Data.de.remessa[i]
              EncomendasMaterial$Semana_Pedido_Entrega[k] <- filtro_me3l$Ano.Semana.Entrega[i]
              EncomendasMaterial$Cód_Fornecedor[k] <- filtro_me3l$Cód.fornecedor[i]
              EncomendasMaterial$Descrição_Fornecedor[k] <- filtro_me3l$Descr..Fornecedor[i]
              EncomendasMaterial$Qtd_Divisão[k] <- filtro_me3l$Qtd.divisão[i]
              EncomendasMaterial$Unid_Medida_Pedido[k] <- filtro_me3l$UM.pedido[i]
              EncomendasMaterial$Qtd_Anterior[k] <- filtro_me3l$Quantidade.anterior[i]
              EncomendasMaterial$Qtd_Entrada_Total[k] <- filtro_me3l$Qtd.entrada[i]
              EncomendasMaterial$Data_Doc_Receção[k] <- filtro_mb51$Data.do.documento[j+1]
              EncomendasMaterial$Data_Lançamento[k] <- filtro_mb51$Data.de.lançamento[j+1]
              EncomendasMaterial$Semana_Real_Entrega[k] <- filtro_mb51$Ano.Semana.Entrega[j+1]
              EncomendasMaterial$Qtd_Registada[k] <- filtro_mb51$Qtd_Total_Registada[j+1]
              EncomendasMaterial$Unid_Medida_Básica[k] <- filtro_mb51$Unid.medida.básica[j+1]
              EncomendasMaterial$Unid_Registo[k] <- filtro_mb51$UM.registro[j+1]
              EncomendasMaterial$Montante.MI.Total[k] <- filtro_mb51$Montante.MI.Total[j+1]
              EncomendasMaterial$Montante.MI.Total.Atual[k] <- filtro_mb51$Montante.MI.Total.Atual[j+1]
              EncomendasMaterial$Moeda[k] <- filtro_mb51$Moeda[j+1]
              EncomendasMaterial$Unid_Preço_Pedido[k] <- filtro_mb51$Unid.prç.pedido[j+1]
              #The amount of material requested was the exact amount delivered

              EncomendasMaterial$Qtd_Pendente[k] <- 0
              EncomendasMaterial$Qtd_Excedente[k] <- 0

              EncomendasMaterial$Qtd_Compensada[k] <- 0

             #Assigning possible delays or anticipation of deliveries

             if(filtro_mb51$Ano.Semana.Entrega[j+1] != filtro_me3l$Ano.Semana.Entrega[i]){
                if(filtro_mb51$Ano.Semana.Entrega[j+1] > filtro_me3l$Ano.Semana.Entrega[i]){
                  EncomendasMaterial$Atraso[k] <- 1
                  EncomendasMaterial$Atraso_Semanas[k] <- as.numeric(difftime(EncomendasMaterial$Data_Lançamento[k],
EncomendasMaterial$Data_Remessa[k], units = "weeks"))
                  EncomendasMaterial$Avanço[k] <- 0
                  EncomendasMaterial$Avanço_Semanas[k] <- 0
             } else if (filtro_mb51$Ano.Semana.Entrega[j+1] < filtro_me3l$Ano.Semana.Entrega[i]){
                  EncomendasMaterial$Avanço[k] <- 1
                  EncomendasMaterial$Avanço_Semanas[k] <- as.numeric(difftime(EncomendasMaterial$Data_Remessa[k],
EncomendasMaterial$Data_Lançamento[k], units = "weeks"))
                  EncomendasMaterial$Atraso[k] <- 0
                  EncomendasMaterial$Atraso_Semanas[k] <- 0
             }
             }else{
                EncomendasMaterial$Atraso[k] <- 0
                EncomendasMaterial$Atraso_Semanas[k] <- 0
                EncomendasMaterial$Avanço[k] <- 0
                EncomendasMaterial$Avanço_Semanas[k] <- 0
             }
             if(k==kk){
                EncomendasMaterial$Balanço[k] <-
round(EncomendasMaterial$Qtd_Excedente[k]-EncomendasMaterial$Qtd_Pendente[k]-EncomendasMaterial$Qtd_Compensada[k],3)
              }else{
                EncomendasMaterial$Balanço[k] <-
round(EncomendasMaterial$Qtd_Excedente[k]-EncomendasMaterial$Qtd_Pendente[k]-EncomendasMaterial$Qtd_Compensada[k]+
EncomendasMaterial$Balanço[k-1],3)
              }

              filtro_mb51$Check[j+1] <- 1
              filtro_me3l$Check[i] <- 1
              k <- k+1
              break
```

Figure 76: Code used to Combine ME3L and MB51 Transactions – Part VII

```
              }else if(round((filtro_mb51$Qtd_Total_Registada[j+1] + filtro_mb51$Qtd_Total_Registada[j]),3) <=
1.03*filtro_me3l$Qtd.divisão[i] & filtro_mb51$Check[j] == 0 & filtro_mb51$Check[j+1] == 0){

                EncomendasMaterial$Pedido_Compra[k] <- filtro_mb51$Pedido[j]
                EncomendasMaterial$Data_Doc_Compra[k] <- filtro_me3l$Data.do.documento[i]
                EncomendasMaterial$Material[k] <- filtro_me3l$Material[i]
                EncomendasMaterial$Descrição[k] <- filtro_me3l$Texto.breve[i]
                EncomendasMaterial$Grupo_Mercadorias[k] <- filtro_me3l$Grupo.de.mercadorias[i]
                EncomendasMaterial$Preço_Liquido[k] <- filtro_me3l$Preço.líquido[i]
                EncomendasMaterial$Moeda[k] <- filtro_me3l$Moeda[i]
                EncomendasMaterial$Unid_Preço[k] <- filtro_me3l$Unidade.de.preço[i]
                EncomendasMaterial$Data_Remessa[k] <- filtro_me3l$Data.de.remessa[i]
                EncomendasMaterial$Semana_Pedido_Entrega[k] <- filtro_me3l$Ano.Semana.Entrega[i]
                EncomendasMaterial$Cód_Fornecedor[k] <- filtro_me3l$Cód.fornecedor[i]
                EncomendasMaterial$Descrição_Fornecedor[k] <- filtro_me3l$Descr..Fornecedor[i]
                EncomendasMaterial$Qtd_Divisão[k] <- filtro_me3l$Qtd.divisão[i]
                EncomendasMaterial$Unid_Medida_Pedido[k] <- filtro_me3l$UM.pedido[i]
                EncomendasMaterial$Qtd_Anterior[k] <- filtro_me3l$Quantidade.anterior[i]
                EncomendasMaterial$Qtd_Entrada_Total[k] <- filtro_me3l$Qtd.entrada[i]
                EncomendasMaterial$Data_Doc_Receção[k] <- filtro_mb51$Data.do.documento[j]
                EncomendasMaterial$Data_Lançamento[k] <- filtro_mb51$Data.de.lançamento[j]
                EncomendasMaterial$Semana_Real_Entrega[k] <- filtro_mb51$Ano.Semana.Entrega[j]
                EncomendasMaterial$Qtd_Registada[k] <- filtro_mb51$Qtd_Total_Registada[j]
                EncomendasMaterial$Unid_Medida_Básica[k] <- filtro_mb51$Unid.medida.básica[j]
                EncomendasMaterial$Unid_Registo[k] <- filtro_mb51$UM.registro[j]
                EncomendasMaterial$Montante.MI.Total[k] <- filtro_mb51$Montante.MI.Total[j]
                EncomendasMaterial$Montante.MI.Total.Atual[k] <- filtro_mb51$Montante.MI.Total.Atual[j]
                EncomendasMaterial$Moeda[k] <- filtro_mb51$Moeda[j]
                EncomendasMaterial$Unid_Preço_Pedido[k] <- filtro_mb51$Unid.prç.pedido[j]
                #It depends if it was delivered on the same week or not

                if(filtro_mb51$Ano.Semana.Entrega[j+1] == EncomendasMaterial$Semana_Pedido_Entrega[k]){

                  EncomendasMaterial$Qtd_Pendente[k] <- 0
                  EncomendasMaterial$Qtd_Excedente[k] <- 0 #if it needs 2 entries to fulfill the requested amount, then after
the first delivery it will never have excess of material. Material may be missing it is not delivered in the originally
scheduled week.

                  EncomendasMaterial$Qtd_Compensada[k] <- 0

                  #Assigning possible delays or anticipation of deliveries

                  if(filtro_mb51$Ano.Semana.Entrega[j] != filtro_me3l$Ano.Semana.Entrega[i]){
                    if(filtro_mb51$Ano.Semana.Entrega[j] > filtro_me3l$Ano.Semana.Entrega[i]){
                      EncomendasMaterial$Atraso[k] <- 1
                      EncomendasMaterial$Atraso_Semanas[k] <- as.numeric(difftime(EncomendasMaterial$Data_Lançamento[k],
EncomendasMaterial$Data_Remessa[k], units = "weeks"))
                      EncomendasMaterial$Avanço[k] <- 0
                      EncomendasMaterial$Avanço_Semanas[k] <- 0

                    } else if (filtro_mb51$Ano.Semana.Entrega[j] < filtro_me3l$Ano.Semana.Entrega[i]){
                      EncomendasMaterial$Avanço[k] <- 1
                      EncomendasMaterial$Avanço_Semanas[k] <- as.numeric(difftime(EncomendasMaterial$Data_Remessa[k],
EncomendasMaterial$Data_Lançamento[k], units = "weeks"))
                      EncomendasMaterial$Atraso[k] <- 0
                      EncomendasMaterial$Atraso_Semanas[k] <- 0
                    }
                  }else{
                    EncomendasMaterial$Atraso[k] <- 0
                    EncomendasMaterial$Atraso_Semanas[k] <- 0
                    EncomendasMaterial$Avanço[k] <- 0
                    EncomendasMaterial$Avanço_Semanas[k] <- 0
                  }
                  if(k==kk){
                    EncomendasMaterial$Balanço[k] <-
round(EncomendasMaterial$Qtd_Excedente[k]-EncomendasMaterial$Qtd_Pendente[k]-EncomendasMaterial$Qtd_Compensada[k],3)
                  }else{
                    EncomendasMaterial$Balanço[k] <-
round(EncomendasMaterial$Qtd_Excedente[k]-EncomendasMaterial$Qtd_Pendente[k]-EncomendasMaterial$Qtd_Compensada[k]+
EncomendasMaterial$Balanço[k-1],3)
                  }

                  filtro_mb51$Check[j] <- 1
                  k <- k+1
                }else{
```

Figure 77: Code used to Combine ME3L and MB51 Transactions – Part VIII

```
                  #Assigning possible delays or anticipation of deliveries

                  if(filtro_mb51$Ano.Semana.Entrega[j] != filtro_me3l$Ano.Semana.Entrega[i]){
                    if(filtro_mb51$Ano.Semana.Entrega[j] > filtro_me3l$Ano.Semana.Entrega[i]){
                      EncomendasMaterial$Atraso[k] <- 1
                      EncomendasMaterial$Atraso_Semanas[k] <- as.numeric(difftime(EncomendasMaterial$Data_Lançamento[k],
EncomendasMaterial$Data_Remessa[k], units = "weeks"))
                      EncomendasMaterial$Avanço[k] <- 0
                      EncomendasMaterial$Avanço_Semanas[k] <- 0
                      EncomendasMaterial$Qtd_Pendente[k] <- EncomendasMaterial$Qtd_Divisão[k] -
EncomendasMaterial$Qtd_Registada[k]
                      EncomendasMaterial$Qtd_Excedente[k] <- 0
                      EncomendasMaterial$Qtd_Compensada[k] <- 0
                    } else if (filtro_mb51$Ano.Semana.Entrega[j] < filtro_me3l$Ano.Semana.Entrega[i]){
                      EncomendasMaterial$Avanço[k] <- 1
                      EncomendasMaterial$Avanço_Semanas[k] <- as.numeric(difftime(EncomendasMaterial$Data_Remessa[k],
EncomendasMaterial$Data_Lançamento[k], units = "weeks"))
                      EncomendasMaterial$Atraso[k] <- 0
                      EncomendasMaterial$Atraso_Semanas[k] <- 0
                      EncomendasMaterial$Qtd_Pendente[k] <- 0
                      EncomendasMaterial$Qtd_Excedente[k] <- 0
                      EncomendasMaterial$Qtd_Compensada[k] <- 0
                    }
                  }else{
                    EncomendasMaterial$Atraso[k] <- 0
                    EncomendasMaterial$Atraso_Semanas[k] <- 0
                    EncomendasMaterial$Avanço[k] <- 0
                    EncomendasMaterial$Avanço_Semanas[k] <- 0
                    EncomendasMaterial$Qtd_Pendente[k] <- EncomendasMaterial$Qtd_Divisão[k] -
EncomendasMaterial$Qtd_Registada[k]
                    EncomendasMaterial$Qtd_Excedente[k] <- 0
                    EncomendasMaterial$Qtd_Compensada[k] <- 0
                  }
                  if(k==kk){
                    EncomendasMaterial$Balanço[k] <-
round(EncomendasMaterial$Qtd_Excedente[k]-EncomendasMaterial$Qtd_Pendente[k]-EncomendasMaterial$Qtd_Compensada[k],3)
                  }else{
                    EncomendasMaterial$Balanço[k] <-
round(EncomendasMaterial$Qtd_Excedente[k]-EncomendasMaterial$Qtd_Pendente[k]-EncomendasMaterial$Qtd_Compensada[k]+
EncomendasMaterial$Balanço[k-1],3)
                  }
                  filtro_mb51$Check[j] <- 1
                  k <- k+1

                }

                #Assigning second MB51 entry

                EncomendasMaterial$Pedido_Compra[k] <- filtro_mb51$Pedido[j+1]
                EncomendasMaterial$Data_Doc_Compra[k] <- filtro_me3l$Data.do.documento[i]
                EncomendasMaterial$Material[k] <- filtro_me3l$Material[i]
                EncomendasMaterial$Descrição[k] <- filtro_me3l$Texto.breve[i]
                EncomendasMaterial$Grupo_Mercadorias[k] <- filtro_me3l$Grupo.de.mercadorias[i]
                EncomendasMaterial$Preço_Líquido[k] <- filtro_me3l$Preço.líquido[i]
                EncomendasMaterial$Moeda[k] <- filtro_me3l$Moeda[i]
                EncomendasMaterial$Unid_Preço[k] <- filtro_me3l$Unidade.de.preço[i]
                EncomendasMaterial$Data_Remessa[k] <- filtro_me3l$Data.de.remessa[i]
                EncomendasMaterial$Semana_Pedido_Entrega[k] <- filtro_me3l$Ano.Semana.Entrega[i]
                EncomendasMaterial$Cód_Fornecedor[k] <- filtro_me3l$Cód.fornecedor[i]
                EncomendasMaterial$Descrição_Fornecedor[k] <- filtro_me3l$Descr..Fornecedor[i]
                EncomendasMaterial$Qtd_Divisão[k] <- filtro_me3l$Qtd.divisão[i]
                EncomendasMaterial$Unid_Medida_Pedido[k] <- filtro_me3l$UM.pedido[i]
                EncomendasMaterial$Qtd_Anterior[k] <- filtro_me3l$Quantidade.anterior[i]
                EncomendasMaterial$Qtd_Entrada_Total[k] <- filtro_me3l$Qtd.entrada[i]
                EncomendasMaterial$Data_Doc_Receção[k] <- filtro_mb51$Data.do.documento[j+1]
                EncomendasMaterial$Data_Lançamento[k] <- filtro_mb51$Data.de.lançamento[j+1]
                EncomendasMaterial$Semana_Real_Entrega[k] <- filtro_mb51$Ano.Semana.Entrega[j+1]
                EncomendasMaterial$Qtd_Registada[k] <- filtro_mb51$Qtd_Total_Registada[j+1]
                EncomendasMaterial$Unid_Medida_Básica[k] <- filtro_mb51$Unid.medida.básica[j+1]
                EncomendasMaterial$Unid_Registo[k] <- filtro_mb51$UM.registro[j+1]
                EncomendasMaterial$Montante.MI.Total[k] <- filtro_mb51$Montante.MI.Total[j+1]
                EncomendasMaterial$Montante.MI.Total.Atual[k] <- filtro_mb51$Montante.MI.Total.Atual[j+1]
                EncomendasMaterial$Moeda[k] <- filtro_mb51$Moeda[j+1]
                EncomendasMaterial$Unid_Preço_Pedido[k] <- filtro_mb51$Unid.prç.pedido[j+1]

                if(k != kk){
                  if(EncomendasMaterial$Qtd_Registada[k] < EncomendasMaterial$Qtd_Pendente[k-1]){
                    EncomendasMaterial$Qtd_Pendente[k] <-
EncomendasMaterial$Qtd_Divisão[k]-EncomendasMaterial$Qtd_Registada[k-1]-EncomendasMaterial$Qtd_Registada[k]
                    EncomendasMaterial$Qtd_Excedente[k] <- 0
                    EncomendasMaterial$Qtd_Compensada[k] <- -EncomendasMaterial$Qtd_Pendente[k-1]
                  }else{
                    EncomendasMaterial$Qtd_Pendente[k] <- 0
                    EncomendasMaterial$Qtd_Excedente[k] <-
round(EncomendasMaterial$Qtd_Registada[k]-(EncomendasMaterial$Qtd_Divisão[k]-EncomendasMaterial$Qtd_Registada[k-1]),3) #Excess
of material, when comparing with the originally requested amount (up to 3%, because of the condition)
                    if(EncomendasMaterial$Qtd_Excedente[k]<0){
                      EncomendasMaterial$Qtd_Pendente[k] <- abs(EncomendasMaterial$Qtd_Excedente[k])
                      EncomendasMaterial$Qtd_Excedente[k] <- 0
                    }
                    EncomendasMaterial$Qtd_Compensada[k] <- - EncomendasMaterial$Qtd_Pendente[k-1]
                  }
```

Figure 78: Code used to Combine ME3L and MB51 Transactions – Part IX

```
                }else{
                  if(round((filtro_mb51$Qtd_Total_Registada[j+1] + filtro_mb51$Qtd_Total_Registada[j]),3) <
filtro_me3l$Qtd.divisão[i]){
                    EncomendasMaterial$Qtd_Pendente[k] <-
EncomendasMaterial$Qtd_Divisão[k]-EncomendasMaterial$Qtd_Registada[k-1]-EncomendasMaterial$Qtd_Registada[k]
                    EncomendasMaterial$Qtd_Excedente[k] <- 0
                    EncomendasMaterial$Qtd_Compensada[k] <-
round(EncomendasMaterial$Qtd_Pendente[k-1]-EncomendasMaterial$Qtd_Registada[k],3)
                  }else{
                    EncomendasMaterial$Qtd_Pendente[k] <- 0
                    EncomendasMaterial$Qtd_Excedente[k] <-
round(EncomendasMaterial$Qtd_Registada[k]-(EncomendasMaterial$Qtd_Divisão[k]-EncomendasMaterial$Qtd_Registada[k-1]),3) #Excess
of material, when comparing with the originally requested amount (up to 3%, because of the condition)
                    EncomendasMaterial$Qtd_Compensada[k] <- - EncomendasMaterial$Qtd_Pendente[k-1]
                  }
                }

                #Assigning possible delays or anticipation of deliveries

                if(filtro_mb51$Ano.Semana.Entrega[j+1] != filtro_me3l$Ano.Semana.Entrega[i]){
                  if(filtro_mb51$Ano.Semana.Entrega[j+1] > filtro_me3l$Ano.Semana.Entrega[i]){
                    EncomendasMaterial$Atraso[k] <- 1
                    EncomendasMaterial$Atraso_Semanas[k] <- as.numeric(difftime(EncomendasMaterial$Data_Lançamento[k],
EncomendasMaterial$Data_Remessa[k], units = "weeks"))
                    EncomendasMaterial$Avanço[k] <- 0
                    EncomendasMaterial$Avanço_Semanas[k] <- 0

                  } else if (filtro_mb51$Ano.Semana.Entrega[j+1] < filtro_me3l$Ano.Semana.Entrega[i]){
                    EncomendasMaterial$Avanço[k] <- 1
                    EncomendasMaterial$Avanço_Semanas[k] <- as.numeric(difftime(EncomendasMaterial$Data_Remessa[k],
EncomendasMaterial$Data_Lançamento[k], units = "weeks"))
                    EncomendasMaterial$Atraso[k] <- 0
                    EncomendasMaterial$Atraso_Semanas[k] <- 0
                  }
                }else{
                  EncomendasMaterial$Atraso[k] <- 0
                  EncomendasMaterial$Atraso_Semanas[k] <- 0
                  EncomendasMaterial$Avanço[k] <- 0
                  EncomendasMaterial$Avanço_Semanas[k] <- 0
                }
                if(k==kk){
                  EncomendasMaterial$Balanço[k] <-
round(EncomendasMaterial$Qtd_Excedente[k]-EncomendasMaterial$Qtd_Pendente[k]-EncomendasMaterial$Qtd_Compensada[k],3)
                }else{
                  EncomendasMaterial$Balanço[k] <-
round(EncomendasMaterial$Qtd_Excedente[k]-EncomendasMaterial$Qtd_Pendente[k]-EncomendasMaterial$Qtd_Compensada[k]+
EncomendasMaterial$Balanço[k-1],3)
                }
                filtro_mb51$Check[j+1] <- 1
                filtro_me3l$Check[i] <- 1
                k <- k+1
                break
              }else if( round((filtro_mb51$Qtd_Total_Registada[j+1] + filtro_mb51$Qtd_Total_Registada[j]),3) >
filtro_me3l$Qtd.divisão[i] & round((filtro_mb51$Qtd_Total_Registada[j+1] + filtro_mb51$Qtd_Total_Registada[j]) -
filtro_me3l$Qtd.divisão[i],3) == abs(round(filtro_mb51$Qtd_Total_Registada[j+2]-filtro_me3l$Qtd.divisão[i+1],3)) &
filtro_mb51$Check[j] == 0 & filtro_mb51$Check[j+1] == 0 & filtro_mb51$Check[j+2] == 0){

                EncomendasMaterial$Pedido_Compra[k] <- filtro_mb51$Pedido[j]
                EncomendasMaterial$Data_Doc_Compra[k] <- filtro_me3l$Data.do.documento[i]
                EncomendasMaterial$Material[k] <- filtro_me3l$Material[i]
                EncomendasMaterial$Descrição[k] <- filtro_me3l$Texto.breve[i]
                EncomendasMaterial$Grupo_Mercadorias[k] <- filtro_me3l$Grupo.de.mercadorias[i]
                EncomendasMaterial$Preço_Líquido[k] <- filtro_me3l$Preço.líquido[i]
                EncomendasMaterial$Moeda[k] <- filtro_me3l$Moeda[i]
                EncomendasMaterial$Unid_Preço[k] <- filtro_me3l$Unidade.de.preço[i]
                EncomendasMaterial$Data_Remessa[k] <- filtro_me3l$Data.de.remessa[i]
                EncomendasMaterial$Semana_Pedido_Entrega[k] <- filtro_me3l$Ano.Semana.Entrega[i]
                EncomendasMaterial$Cód_Fornecedor[k] <- filtro_me3l$Cód.fornecedor[i]
                EncomendasMaterial$Descrição_Fornecedor[k] <- filtro_me3l$Descr..Fornecedor[i]
                EncomendasMaterial$Qtd_Divisão[k] <- filtro_me3l$Qtd.divisão[i]
                EncomendasMaterial$Unid_Medida_Pedido[k] <- filtro_me3l$UM.pedido[i]
                EncomendasMaterial$Qtd_Anterior[k] <- filtro_me3l$Quantidade.anterior[i]
                EncomendasMaterial$Qtd_Entrada_Total[k] <- filtro_me3l$Qtd.entrada[i]
                EncomendasMaterial$Data_Doc_Receção[k] <- filtro_mb51$Data.do.documento[j]
                EncomendasMaterial$Data_Lançamento[k] <- filtro_mb51$Data.de.lançamento[j]
                EncomendasMaterial$Semana_Real_Entrega[k] <- filtro_mb51$Ano.Semana.Entrega[j]
                EncomendasMaterial$Qtd_Registada[k] <- filtro_mb51$Qtd_Total_Registada[j]
                EncomendasMaterial$Unid_Medida_Básica[k] <- filtro_mb51$Unid.medida.básica[j]
                EncomendasMaterial$Unid_Registo[k] <- filtro_mb51$UM.registro[j]
                EncomendasMaterial$Montante.MI.Total[k] <- filtro_mb51$Montante.MI.Total[j]
                EncomendasMaterial$Montante.MI.Total.Atual[k] <- filtro_mb51$Montante.MI.Total.Atual[j]
                EncomendasMaterial$Moeda[k] <- filtro_mb51$Moeda[j]
                EncomendasMaterial$Unid_Preço_Pedido[k] <- filtro_mb51$Unid.prç.pedido[j]
```

Figure 79: Code used to Combine ME3L and MB51 Transactions – Part X

```
                #It depends if it was delivered on the same week or not

                if(filtro_mb51$Ano.Semana.Entrega[j+1] == EncomendasMaterial$Semana_Pedido_Entrega[k]){

                  EncomendasMaterial$Qtd_Pendente[k] <- 0
                  EncomendasMaterial$Qtd_Excedente[k] <- 0

                  EncomendasMaterial$Qtd_Compensada[k] <- 0

                  #Assigning possible delays or anticipation of deliveries

                  if(filtro_mb51$Ano.Semana.Entrega[j] != filtro_me31$Ano.Semana.Entrega[i]){
                    if(filtro_mb51$Ano.Semana.Entrega[j] > filtro_me31$Ano.Semana.Entrega[i]){
                      EncomendasMaterial$Atraso[k] <- 1
                      EncomendasMaterial$Atraso_Semanas[k] <- as.numeric(difftime(EncomendasMaterial$Data_Lançamento[k],
EncomendasMaterial$Data_Remessa[k], units = "weeks"))
                      EncomendasMaterial$Avanço[k] <- 0
                      EncomendasMaterial$Avanço_Semanas[k] <- 0

                    } else if (filtro_mb51$Ano.Semana.Entrega[j] < filtro_me31$Ano.Semana.Entrega[i]){
                      EncomendasMaterial$Avanço[k] <- 1
                      EncomendasMaterial$Avanço_Semanas[k] <- as.numeric(difftime(EncomendasMaterial$Data_Remessa[k],
EncomendasMaterial$Data_Lançamento[k], units = "weeks"))
                      EncomendasMaterial$Atraso[k] <- 0
                      EncomendasMaterial$Atraso_Semanas[k] <- 0
                    }
                  }else{
                    EncomendasMaterial$Atraso[k] <- 0
                    EncomendasMaterial$Atraso_Semanas[k] <- 0
                    EncomendasMaterial$Avanço[k] <- 0
                    EncomendasMaterial$Avanço_Semanas[k] <- 0
                  }
                  if(k==kk){
                    EncomendasMaterial$Balanço[k] <-
round(EncomendasMaterial$Qtd_Excedente[k]-EncomendasMaterial$Qtd_Pendente[k]-EncomendasMaterial$Qtd_Compensada[k],3)
                  }else{
                    EncomendasMaterial$Balanço[k] <-
round(EncomendasMaterial$Qtd_Excedente[k]-EncomendasMaterial$Qtd_Pendente[k]-EncomendasMaterial$Qtd_Compensada[k]+
EncomendasMaterial$Balanço[k-1],3)
                  }
                  filtro_mb51$Check[j] <- 1
                  k <- k+1
                }else{
                  EncomendasMaterial$Qtd_Pendente[k] <- EncomendasMaterial$Qtd_Divisão[k] - EncomendasMaterial$Qtd_Registada[k]
                  EncomendasMaterial$Qtd_Excedente[k] <- 0
                  EncomendasMaterial$Qtd_Compensada[k] <- 0

                  #Assigning possible delays or anticipation of deliveries

                  if(filtro_mb51$Ano.Semana.Entrega[j] != filtro_me31$Ano.Semana.Entrega[i]){
                    if(filtro_mb51$Ano.Semana.Entrega[j] > filtro_me31$Ano.Semana.Entrega[i]){
                      EncomendasMaterial$Atraso[k] <- 1
                      EncomendasMaterial$Atraso_Semanas[k] <- as.numeric(difftime(EncomendasMaterial$Data_Lançamento[k],
EncomendasMaterial$Data_Remessa[k], units = "weeks"))
                      EncomendasMaterial$Avanço[k] <- 0
                      EncomendasMaterial$Avanço_Semanas[k] <- 0
                    } else if (filtro_mb51$Ano.Semana.Entrega[j] < filtro_me31$Ano.Semana.Entrega[i]){
                      EncomendasMaterial$Avanço[k] <- 1
                      EncomendasMaterial$Avanço_Semanas[k] <- as.numeric(difftime(EncomendasMaterial$Data_Remessa[k],
EncomendasMaterial$Data_Lançamento[k], units = "weeks"))
                      EncomendasMaterial$Atraso[k] <- 0
                      EncomendasMaterial$Atraso_Semanas[k] <- 0
                    }
                  }else{
                    EncomendasMaterial$Atraso[k] <- 0
                    EncomendasMaterial$Atraso_Semanas[k] <- 0
                    EncomendasMaterial$Avanço[k] <- 0
                    EncomendasMaterial$Avanço_Semanas[k] <- 0
                  }
                  if(k==kk){
                    EncomendasMaterial$Balanço[k] <-
round(EncomendasMaterial$Qtd_Excedente[k]-EncomendasMaterial$Qtd_Pendente[k]-EncomendasMaterial$Qtd_Compensada[k],3)
                  }else{
                    EncomendasMaterial$Balanço[k] <-
round(EncomendasMaterial$Qtd_Excedente[k]-EncomendasMaterial$Qtd_Pendente[k]-EncomendasMaterial$Qtd_Compensada[k]+
EncomendasMaterial$Balanço[k-1],3)
                  }
                  filtro_mb51$Check[j] <- 1
                  k <- k+1

                }
```

Figure 80: Code used to Combine ME3L and MB51 Transactions – Part XI

```
                #Assigning second MB51 entry

                EncomendasMaterial$Pedido_Compra[k] <- filtro_mb51$Pedido[j+1]
                EncomendasMaterial$Data_Doc_Compra[k] <- filtro_me3l$Data.do.documento[i]
                EncomendasMaterial$Material[k] <- filtro_me3l$Material[i]
                EncomendasMaterial$Descrição[k] <- filtro_me3l$Texto.breve[i]
                EncomendasMaterial$Grupo_Mercadorias[k] <- filtro_me3l$Grupo.de.mercadorias[i]
                EncomendasMaterial$Preço_Líquido[k] <- filtro_me3l$Preço.líquido[i]
                EncomendasMaterial$Moeda[k] <- filtro_me3l$Moeda[i]
                EncomendasMaterial$Unid_Preço[k] <- filtro_me3l$Unidade.de.preço[i]
                EncomendasMaterial$Data_Remessa[k] <- filtro_me3l$Data.de.remessa[i]
                EncomendasMaterial$Semana_Pedido_Entrega[k] <- filtro_me3l$Ano.Semana.Entrega[i]
                EncomendasMaterial$Cód_Fornecedor[k] <- filtro_me3l$Cód.fornecedor[i]
                EncomendasMaterial$Descrição_Fornecedor[k] <- filtro_me3l$Descr..Fornecedor[i]
                EncomendasMaterial$Qtd_Divisão[k] <- filtro_me3l$Qtd.divisão[i]
                EncomendasMaterial$Unid_Medida_Pedido[k] <- filtro_me3l$UM.pedido[i]
                EncomendasMaterial$Qtd_Anterior[k] <- filtro_me3l$Quantidade.anterior[i]
                EncomendasMaterial$Qtd_Entrada_Total[k] <- filtro_me3l$Qtd.entrada[i]
                EncomendasMaterial$Data_Doc_Receção[k] <- filtro_mb51$Data.do.documento[j+1]
                EncomendasMaterial$Data_Lançamento[k] <- filtro_mb51$Data.de.lançamento[j+1]
                EncomendasMaterial$Semana_Real_Entrega[k] <- filtro_mb51$Ano.Semana.Entrega[j+1]
                EncomendasMaterial$Qtd_Registada[k] <- filtro_mb51$Qtd_Total_Registada[j+1]
                EncomendasMaterial$Unid_Medida_Básica[k] <- filtro_mb51$Unid.medida.básica[j+1]
                EncomendasMaterial$Unid_Registo[k] <- filtro_mb51$UM.registro[j+1]
                EncomendasMaterial$Montante.MI.Total[k] <- filtro_mb51$Montante.MI.Total[j+1]
                EncomendasMaterial$Montante.MI.Total.Atual[k] <- filtro_mb51$Montante.MI.Total.Atual[j+1]
                EncomendasMaterial$Moeda[k] <- filtro_mb51$Moeda[j+1]
                EncomendasMaterial$Unid_Preço_Pedido[k] <- filtro_mb51$Unid.prç.pedido[j+1]

                EncomendasMaterial$Qtd_Pendente[k] <- 0
                EncomendasMaterial$Qtd_Excedente[k] <- round((filtro_mb51$Qtd_Total_Registada[j+1] +
filtro_mb51$Qtd_Total_Registada[j]),3) - filtro_me3l$Qtd.divisão[i]

                EncomendasMaterial$Qtd_Compensada[k] <- - EncomendasMaterial$Qtd_Pendente[k-1]

                #Assigning possible delays or anticipation of deliveries

                if(filtro_mb51$Ano.Semana.Entrega[j+1] != filtro_me3l$Ano.Semana.Entrega[i]){
                  if(filtro_mb51$Ano.Semana.Entrega[j+1] > filtro_me3l$Ano.Semana.Entrega[i]){
                    EncomendasMaterial$Atraso[k] <- 1
                    EncomendasMaterial$Atraso_Semanas[k] <- as.numeric(difftime(EncomendasMaterial$Data_Lançamento[k],
EncomendasMaterial$Data_Remessa[k], units = "weeks"))
                    EncomendasMaterial$Avanço[k] <- 0
                    EncomendasMaterial$Avanço_Semanas[k] <- 0

                  } else if (filtro_mb51$Ano.Semana.Entrega[j+1] < filtro_me3l$Ano.Semana.Entrega[i]){
                    EncomendasMaterial$Avanço[k] <- 1
                    EncomendasMaterial$Avanço_Semanas[k] <- as.numeric(difftime(EncomendasMaterial$Data_Remessa[k],
EncomendasMaterial$Data_Lançamento[k], units = "weeks"))
                    EncomendasMaterial$Atraso[k] <- 0
                    EncomendasMaterial$Atraso_Semanas[k] <- 0
                  }
                }else{
                  EncomendasMaterial$Atraso[k] <- 0
                  EncomendasMaterial$Atraso_Semanas[k] <- 0
                  EncomendasMaterial$Avanço[k] <- 0
                  EncomendasMaterial$Avanço_Semanas[k] <- 0
                }
                if(k==kk){
                  EncomendasMaterial$Balanço[k] <-
round(EncomendasMaterial$Qtd_Excedente[k]-EncomendasMaterial$Qtd_Pendente[k]-EncomendasMaterial$Qtd_Compensada[k],3)
                }else{
                  EncomendasMaterial$Balanço[k] <-
round(EncomendasMaterial$Qtd_Excedente[k]-EncomendasMaterial$Qtd_Pendente[k]-EncomendasMaterial$Qtd_Compensada[k]+
EncomendasMaterial$Balanço[k-1],3)
                }
                filtro_mb51$Check[j+1] <- 1
                filtro_me3l$Check[i] <- 1
                k <- k+1
                break
              }else if( round((filtro_mb51$Qtd_Total_Registada[j+1] + filtro_mb51$Qtd_Total_Registada[j]),3) <
filtro_me3l$Qtd.divisão[i] & abs(round((filtro_mb51$Qtd_Total_Registada[j+1] + filtro_mb51$Qtd_Total_Registada[j]) -
filtro_me3l$Qtd.divisão[i],3)) == abs(round(filtro_mb51$Qtd_Total_Registada[j+2]-filtro_me3l$Qtd.divisão[i+1],3)) &
filtro_mb51$Check[j] == 0 & filtro_mb51$Check[j+1] == 0 & filtro_mb51$Check[j+2] == 0){

                EncomendasMaterial$Pedido_Compra[k] <- filtro_mb51$Pedido[j]
                EncomendasMaterial$Data_Doc_Compra[k] <- filtro_me3l$Data.do.documento[i]
                EncomendasMaterial$Material[k] <- filtro_me3l$Material[i]
                EncomendasMaterial$Descrição[k] <- filtro_me3l$Texto.breve[i]
                EncomendasMaterial$Grupo_Mercadorias[k] <- filtro_me3l$Grupo.de.mercadorias[i]
                EncomendasMaterial$Preço_Líquido[k] <- filtro_me3l$Preço.líquido[i]
                EncomendasMaterial$Moeda[k] <- filtro_me3l$Moeda[i]
                EncomendasMaterial$Unid_Preço[k] <- filtro_me3l$Unidade.de.preço[i]
                EncomendasMaterial$Data_Remessa[k] <- filtro_me3l$Data.de.remessa[i]
                EncomendasMaterial$Semana_Pedido_Entrega[k] <- filtro_me3l$Ano.Semana.Entrega[i]
                EncomendasMaterial$Cód_Fornecedor[k] <- filtro_me3l$Cód.fornecedor[i]
                EncomendasMaterial$Descrição_Fornecedor[k] <- filtro_me3l$Descr..Fornecedor[i]
```

Figure 81: Code used to Combine ME3L and MB51 Transactions – Part XII

```
                EncomendasMaterial$Unid_Medida_Pedido[k] <- filtro_me3l$UM.pedido[i]
                EncomendasMaterial$Qtd_Anterior[k] <- filtro_me3l$Quantidade.anterior[i]
                EncomendasMaterial$Qtd_Entrada_Total[k] <- filtro_me3l$Qtd.entrada[i]
                EncomendasMaterial$Data_Doc_Receção[k] <- filtro_mb51$Data.do.documento[j]
                EncomendasMaterial$Data_Lançamento[k] <- filtro_mb51$Data.de.lançamento[j]
                EncomendasMaterial$Semana_Real_Entrega[k] <- filtro_mb51$Ano.Semana.Entrega[j]
                EncomendasMaterial$Qtd_Registada[k] <- filtro_mb51$Qtd_Total_Registada[j]
                EncomendasMaterial$Unid_Medida_Básica[k] <- filtro_mb51$Unid.medida.básica[j]
                EncomendasMaterial$Unid_Registo[k] <- filtro_mb51$UM.registro[j]
                EncomendasMaterial$Montante.MI.Total[k] <- filtro_mb51$Montante.MI.Total[j]
                EncomendasMaterial$Montante.MI.Total.Atual[k] <- filtro_mb51$Montante.MI.Total.Atual[j]
                EncomendasMaterial$Moeda[k] <- filtro_mb51$Moeda[j]
                EncomendasMaterial$Unid_Preço_Pedido[k] <- filtro_mb51$Unid.prç.pedido[j]

                #It depends if it was delivered on the same week or not

                if(filtro_mb51$Ano.Semana.Entrega[j+1] == EncomendasMaterial$Semana_Pedido_Entrega[k]){

                  EncomendasMaterial$Qtd_Pendente[k] <- 0
                  EncomendasMaterial$Qtd_Excedente[k] <- 0

                  EncomendasMaterial$Qtd_Compensada[k] <- 0
                  #Assigning possible delays or anticipation of deliveries

                  if(filtro_mb51$Ano.Semana.Entrega[j] != filtro_me3l$Ano.Semana.Entrega[i]){
                    if(filtro_mb51$Ano.Semana.Entrega[j] > filtro_me3l$Ano.Semana.Entrega[i]){
                      EncomendasMaterial$Atraso[k] <- 1
                      EncomendasMaterial$Atraso_Semanas[k] <- as.numeric(difftime(EncomendasMaterial$Data_Lançamento[k],
EncomendasMaterial$Data_Remessa[k], units = "weeks"))
                      EncomendasMaterial$Avanço[k] <- 0
                      EncomendasMaterial$Avanço_Semanas[k] <- 0

                    } else if (filtro_mb51$Ano.Semana.Entrega[j] < filtro_me3l$Ano.Semana.Entrega[i]){
                      EncomendasMaterial$Avanço[k] <- 1
                      EncomendasMaterial$Avanço_Semanas[k] <- as.numeric(difftime(EncomendasMaterial$Data_Remessa[k],
EncomendasMaterial$Data_Lançamento[k], units = "weeks"))
                      EncomendasMaterial$Atraso[k] <- 0
                      EncomendasMaterial$Atraso_Semanas[k] <- 0
                    }
                  }else{
                    EncomendasMaterial$Atraso[k] <- 0
                    EncomendasMaterial$Atraso_Semanas[k] <- 0
                    EncomendasMaterial$Avanço[k] <- 0
                    EncomendasMaterial$Avanço_Semanas[k] <- 0
                  }
                  if(k==kk){
                    EncomendasMaterial$Balanço[k] <-
round(EncomendasMaterial$Qtd_Excedente[k]-EncomendasMaterial$Qtd_Pendente[k]-EncomendasMaterial$Qtd_Compensada[k],3)
                  }else{
                    EncomendasMaterial$Balanço[k] <-
round(EncomendasMaterial$Qtd_Excedente[k]-EncomendasMaterial$Qtd_Pendente[k]-EncomendasMaterial$Qtd_Compensada[k]+
EncomendasMaterial$Balanço[k-1],3)
                  }
                  filtro_mb51$Check[j] <- 1
                  k <- k+1
                }else{
                  EncomendasMaterial$Qtd_Pendente[k] <- EncomendasMaterial$Qtd_Divisão[k] - EncomendasMaterial$Qtd_Registada[k]
                  EncomendasMaterial$Qtd_Excedente[k] <- 0
                  EncomendasMaterial$Qtd_Compensada[k] <- 0

                  if(filtro_mb51$Ano.Semana.Entrega[j] != filtro_me3l$Ano.Semana.Entrega[i]){
                    if(filtro_mb51$Ano.Semana.Entrega[j] > filtro_me3l$Ano.Semana.Entrega[i]){
                      EncomendasMaterial$Atraso[k] <- 1
                      EncomendasMaterial$Atraso_Semanas[k] <- as.numeric(difftime(EncomendasMaterial$Data_Lançamento[k],
EncomendasMaterial$Data_Remessa[k], units = "weeks"))
                      EncomendasMaterial$Avanço[k] <- 0
                      EncomendasMaterial$Avanço_Semanas[k] <- 0
                    } else if (filtro_mb51$Ano.Semana.Entrega[j] < filtro_me3l$Ano.Semana.Entrega[i]){
                      EncomendasMaterial$Avanço[k] <- 1
                      EncomendasMaterial$Avanço_Semanas[k] <- as.numeric(difftime(EncomendasMaterial$Data_Remessa[k],
EncomendasMaterial$Data_Lançamento[k], units = "weeks"))
                      EncomendasMaterial$Atraso[k] <- 0
                      EncomendasMaterial$Atraso_Semanas[k] <- 0
                    }
                  }else{
                    EncomendasMaterial$Atraso[k] <- 0
                    EncomendasMaterial$Atraso_Semanas[k] <- 0
                    EncomendasMaterial$Avanço[k] <- 0
                    EncomendasMaterial$Avanço_Semanas[k] <- 0
                  }
                  if(k==kk){
                    EncomendasMaterial$Balanço[k] <-
round(EncomendasMaterial$Qtd_Excedente[k]-EncomendasMaterial$Qtd_Pendente[k]-EncomendasMaterial$Qtd_Compensada[k],3)
                  }else{
                    EncomendasMaterial$Balanço[k] <-
round(EncomendasMaterial$Qtd_Excedente[k]-EncomendasMaterial$Qtd_Pendente[k]-EncomendasMaterial$Qtd_Compensada[k]+
EncomendasMaterial$Balanço[k-1],3)
                  }
                  filtro_mb51$Check[j] <- 1
                  k <- k+1

                }
```

Figure 82: Code used to Combine ME3L and MB51 Transactions – Part XIII

```
                #Assigning second MB51 entry

                EncomendasMaterial$Pedido_Compra[k] <- filtro_mb51$Pedido[j+1]
                EncomendasMaterial$Data_Doc_Compra[k] <- filtro_me3l$Data.do.documento[i]
                EncomendasMaterial$Material[k] <- filtro_me3l$Material[i]
                EncomendasMaterial$Descrição[k] <- filtro_me3l$Texto.breve[i]
                EncomendasMaterial$Grupo_Mercadorias[k] <- filtro_me3l$Grupo.de.mercadorias[i]
                EncomendasMaterial$Preço_Líquido[k] <- filtro_me3l$Preço.líquido[i]
                EncomendasMaterial$Moeda[k] <- filtro_me3l$Moeda[i]
                EncomendasMaterial$Unid_Preço[k] <- filtro_me3l$Unidade.de.preço[i]
                EncomendasMaterial$Data_Remessa[k] <- filtro_me3l$Data.de.remessa[i]
                EncomendasMaterial$Semana_Pedido_Entrega[k] <- filtro_me3l$Ano.Semana.Entrega[i]
                EncomendasMaterial$Cód_Fornecedor[k] <- filtro_me3l$Cód.fornecedor[i]
                EncomendasMaterial$Descrição_Fornecedor[k] <- filtro_me3l$Descr..Fornecedor[i]
                EncomendasMaterial$Qtd_Divisão[k] <- filtro_me3l$Qtd.divisão[i]
                EncomendasMaterial$Unid_Medida_Pedido[k] <- filtro_me3l$UM.pedido[i]
                EncomendasMaterial$Qtd_Anterior[k] <- filtro_me3l$Quantidade.anterior[i]
                EncomendasMaterial$Qtd_Entrada_Total[k] <- filtro_me3l$Qtd.entrada[i]
                EncomendasMaterial$Data_Doc_Receção[k] <- filtro_mb51$Data.do.documento[j+1]
                EncomendasMaterial$Data_Lançamento[k] <- filtro_mb51$Data.de.lançamento[j+1]
                EncomendasMaterial$Semana_Real_Entrega[k] <- filtro_mb51$Ano.Semana.Entrega[j+1]
                EncomendasMaterial$Qtd_Registada[k] <- filtro_mb51$Qtd_Total_Registada[j+1]
                EncomendasMaterial$Unid_Medida_Básica[k] <- filtro_mb51$Unid.medida.básica[j+1]
                EncomendasMaterial$Unid_Registo[k] <- filtro_mb51$UM.registro[j+1]
                EncomendasMaterial$Montante.MI.Total[k] <- filtro_mb51$Montante.MI.Total[j+1]
                EncomendasMaterial$Montante.MI.Total.Atual[k] <- filtro_mb51$Montante.MI.Total.Atual[j+1]
                EncomendasMaterial$Moeda[k] <- filtro_mb51$Moeda[j+1]
                EncomendasMaterial$Unid_Preço_Pedido[k] <- filtro_mb51$Unid.prç.pedido[j+1]

                EncomendasMaterial$Qtd_Pendente[k] <- abs(round((filtro_mb51$Qtd_Total_Registada[j+1] +
filtro_mb51$Qtd_Total_Registada[j]),3) - filtro_me3l$Qtd.divisão[i])
                EncomendasMaterial$Qtd_Excedente[k] <- 0

                EncomendasMaterial$Qtd_Compensada[k] <- - EncomendasMaterial$Qtd_Pendente[k-1]

                #Assigning possible delays or anticipation of deliveries

                if(filtro_mb51$Ano.Semana.Entrega[j+1] != filtro_me3l$Ano.Semana.Entrega[i]){
                  if(filtro_mb51$Ano.Semana.Entrega[j+1] > filtro_me3l$Ano.Semana.Entrega[i]){
                    EncomendasMaterial$Atraso[k] <- 1
                    EncomendasMaterial$Atraso_Semanas[k] <- as.numeric(difftime(EncomendasMaterial$Data_Lançamento[k],
EncomendasMaterial$Data_Remessa[k], units = "weeks"))
                    EncomendasMaterial$Avanço[k] <- 0
                    EncomendasMaterial$Avanço_Semanas[k] <- 0

                  } else if (filtro_mb51$Ano.Semana.Entrega[j+1] < filtro_me3l$Ano.Semana.Entrega[i]){
                    EncomendasMaterial$Avanço[k] <- 1
                    EncomendasMaterial$Avanço_Semanas[k] <- as.numeric(difftime(EncomendasMaterial$Data_Remessa[k],
EncomendasMaterial$Data_Lançamento[k], units = "weeks"))
                    EncomendasMaterial$Atraso[k] <- 0
                    EncomendasMaterial$Atraso_Semanas[k] <- 0
                  }
                }else{
                  EncomendasMaterial$Atraso[k] <- 0
                  EncomendasMaterial$Atraso_Semanas[k] <- 0
                  EncomendasMaterial$Avanço[k] <- 0
                  EncomendasMaterial$Avanço_Semanas[k] <- 0
                }
                if(k==kk){
                  EncomendasMaterial$Balanço[k] <-
round(EncomendasMaterial$Qtd_Excedente[k]-EncomendasMaterial$Qtd_Pendente[k]-EncomendasMaterial$Qtd_Compensada[k],3)
                }else{
                  EncomendasMaterial$Balanço[k] <-
round(EncomendasMaterial$Qtd_Excedente[k]-EncomendasMaterial$Qtd_Pendente[k]-EncomendasMaterial$Qtd_Compensada[k]+
EncomendasMaterial$Balanço[k-1],3)
                }

                filtro_mb51$Check[j+1] <- 1
                filtro_me3l$Check[i] <- 1
                k <- k+1
                break
              }else{
                #The amount of material delivered was, indeed, inferior to the amount requested

                EncomendasMaterial$Pedido_Compra[k] <- filtro_mb51$Pedido[j]
                EncomendasMaterial$Data_Doc_Compra[k] <- filtro_me3l$Data.do.documento[i]
                EncomendasMaterial$Material[k] <- filtro_me3l$Material[i]
                EncomendasMaterial$Descrição[k] <- filtro_me3l$Texto.breve[i]
                EncomendasMaterial$Grupo_Mercadorias[k] <- filtro_me3l$Grupo.de.mercadorias[i]
                EncomendasMaterial$Preço_Líquido[k] <- filtro_me3l$Preço.líquido[i]
                EncomendasMaterial$Moeda[k] <- filtro_me3l$Moeda[i]
                EncomendasMaterial$Unid_Preço[k] <- filtro_me3l$Unidade.de.preço[i]
                EncomendasMaterial$Data_Remessa[k] <- filtro_me3l$Data.de.remessa[i]
                EncomendasMaterial$Semana_Pedido_Entrega[k] <- filtro_me3l$Ano.Semana.Entrega[i]
                EncomendasMaterial$Cód_Fornecedor[k] <- filtro_me3l$Cód.fornecedor[i]
                EncomendasMaterial$Descrição_Fornecedor[k] <- filtro_me3l$Descr..Fornecedor[i]
                EncomendasMaterial$Qtd_Divisão[k] <- filtro_me3l$Qtd.divisão[i]
```

Figure 83: Code used to Combine ME3L and MB51 Transactions – Part XIV

```
                EncomendasMaterial$Unid_Medida_Pedido[k] <- filtro_me3l$UM.pedido[i]
                EncomendasMaterial$Qtd_Anterior[k] <- filtro_me3l$Quantidade.anterior[i]
                EncomendasMaterial$Qtd_Entrada_Total[k] <- filtro_me3l$Qtd.entrada[i]
                EncomendasMaterial$Data_Doc_Receção[k] <- filtro_mb51$Data.do.documento[j]
                EncomendasMaterial$Data_Lançamento[k] <- filtro_mb51$Data.de.lançamento[j]
                EncomendasMaterial$Semana_Real_Entrega[k] <- filtro_mb51$Ano.Semana.Entrega[j]
                EncomendasMaterial$Qtd_Registada[k] <- filtro_mb51$Qtd_Total_Registada[j]
                EncomendasMaterial$Unid_Medida_Básica[k] <- filtro_mb51$Unid.medida.básica[j]
                EncomendasMaterial$Unid_Registo[k] <- filtro_mb51$UM.registro[j]
                EncomendasMaterial$Montante.MI.Total[k] <- filtro_mb51$Montante.MI.Total[j]
                EncomendasMaterial$Montante.MI.Total.Atual[k] <- filtro_mb51$Montante.MI.Total.Atual[j]
                EncomendasMaterial$Moeda[k] <- filtro_mb51$Moeda[j]
                EncomendasMaterial$Unid_Preço_Pedido[k] <- filtro_mb51$Unid.prç.pedido[j]

                #If the amount was inferior, there will never be excess of material

                EncomendasMaterial$Qtd_Pendente[k] <- (EncomendasMaterial$Qtd_Divisão[k] - EncomendasMaterial$Qtd_Registada[k])
                EncomendasMaterial$Qtd_Excedente[k] <- 0

                EncomendasMaterial$Qtd_Compensada[k] <- 0
                #Assigning possible delays or anticipation of deliveries

                if(filtro_mb51$Ano.Semana.Entrega[j] != filtro_me3l$Ano.Semana.Entrega[i]){
                  if(filtro_mb51$Ano.Semana.Entrega[j] > filtro_me3l$Ano.Semana.Entrega[i]){
                    EncomendasMaterial$Atraso[k] <- 1
                    EncomendasMaterial$Atraso_Semanas[k] <- as.numeric(difftime(EncomendasMaterial$Data_Lançamento[k],
EncomendasMaterial$Data_Remessa[k], units = "weeks"))
                    EncomendasMaterial$Avanço[k] <- 0
                    EncomendasMaterial$Avanço_Semanas[k] <- 0
                  } else if (filtro_mb51$Ano.Semana.Entrega[j] < filtro_me3l$Ano.Semana.Entrega[i]){
                    EncomendasMaterial$Avanço[k] <- 1
                    EncomendasMaterial$Avanço_Semanas[k] <- as.numeric(difftime(EncomendasMaterial$Data_Remessa[k],
EncomendasMaterial$Data_Lançamento[k], units = "weeks"))
                    EncomendasMaterial$Atraso[k] <- 0
                    EncomendasMaterial$Atraso_Semanas[k] <- 0
                  }
                }else{
                  EncomendasMaterial$Atraso[k] <- 0
                  EncomendasMaterial$Atraso_Semanas[k] <- 0
                  EncomendasMaterial$Avanço[k] <- 0
                  EncomendasMaterial$Avanço_Semanas[k] <- 0
                }
                if(k==kk){
                  EncomendasMaterial$Balanço[k] <-
round(EncomendasMaterial$Qtd_Excedente[k]-EncomendasMaterial$Qtd_Pendente[k]-EncomendasMaterial$Qtd_Compensada[k],3)
                }else{
                  EncomendasMaterial$Balanço[k] <-
round(EncomendasMaterial$Qtd_Excedente[k]-EncomendasMaterial$Qtd_Pendente[k]-EncomendasMaterial$Qtd_Compensada[k]+
EncomendasMaterial$Balanço[k-1],3)
                }
                filtro_mb51$Check[j] <- 1
                filtro_me3l$Check[i] <- 1
                k <- k+1
                break
                #}
              }
          }else{
            #In case the last line is being checked

              EncomendasMaterial$Pedido_Compra[k] <- filtro_mb51$Pedido[j]
              EncomendasMaterial$Data_Doc_Compra[k] <- filtro_me3l$Data.do.documento[i]
              EncomendasMaterial$Material[k] <- filtro_me3l$Material[i]
              EncomendasMaterial$Descrição[k] <- filtro_me3l$Texto.breve[i]
              EncomendasMaterial$Grupo_Mercadorias[k] <- filtro_me3l$Grupo.de.mercadorias[i]
              EncomendasMaterial$Preço_Líquido[k] <- filtro_me3l$Preço.líquido[i]
              EncomendasMaterial$Moeda[k] <- filtro_me3l$Moeda[i]
              EncomendasMaterial$Unid_Preço[k] <- filtro_me3l$Unidade.de.preço[i]
              EncomendasMaterial$Data_Remessa[k] <- filtro_me3l$Data.de.remessa[i]
              EncomendasMaterial$Semana_Pedido_Entrega[k] <- filtro_me3l$Ano.Semana.Entrega[i]
              EncomendasMaterial$Cód_Fornecedor[k] <- filtro_me3l$Cód.fornecedor[i]
              EncomendasMaterial$Descrição_Fornecedor[k] <- filtro_me3l$Descr..Fornecedor[i]
              EncomendasMaterial$Qtd_Divisão[k] <- filtro_me3l$Qtd.divisão[i]
              EncomendasMaterial$Unid_Medida_Pedido[k] <- filtro_me3l$UM.pedido[i]
              EncomendasMaterial$Qtd_Anterior[k] <- filtro_me3l$Quantidade.anterior[i]
              EncomendasMaterial$Qtd_Entrada_Total[k] <- filtro_me3l$Qtd.entrada[i]
              EncomendasMaterial$Data_Doc_Receção[k] <- filtro_mb51$Data.do.documento[j]
              EncomendasMaterial$Data_Lançamento[k] <- filtro_mb51$Data.de.lançamento[j]
              EncomendasMaterial$Semana_Real_Entrega[k] <- filtro_mb51$Ano.Semana.Entrega[j]
              EncomendasMaterial$Qtd_Registada[k] <- filtro_mb51$Qtd_Total_Registada[j]
              EncomendasMaterial$Unid_Medida_Básica[k] <- filtro_mb51$Unid.medida.básica[j]
              EncomendasMaterial$Unid_Registo[k] <- filtro_mb51$UM.registro[j]
              EncomendasMaterial$Montante.MI.Total[k] <- filtro_mb51$Montante.MI.Total[j]
              EncomendasMaterial$Montante.MI.Total.Atual[k] <- filtro_mb51$Montante.MI.Total.Atual[j]
              EncomendasMaterial$Moeda[k] <- filtro_mb51$Moeda[j]
              EncomendasMaterial$Unid_Preço_Pedido[k] <- filtro_mb51$Unid.prç.pedido[j]
```

Figure 84: Code used to Combine ME3L and MB51 Transactions – Part XV

```
            #If the amount was inferior, there will never be excess of material

            EncomendasMaterial$Qtd_Pendente[k] <- (EncomendasMaterial$Qtd_Divisão[k] - EncomendasMaterial$Qtd_Registada[k])
            EncomendasMaterial$Qtd_Excedente[k] <- 0

            EncomendasMaterial$Qtd_Compensada[k] <- 0

            #Assigning possible delays or anticipation of deliveries

            if(filtro_mb51$Ano.Semana.Entrega[j] != filtro_me31$Ano.Semana.Entrega[i]){
              if(filtro_mb51$Ano.Semana.Entrega[j] > filtro_me31$Ano.Semana.Entrega[i]){
                EncomendasMaterial$Atraso[k] <- 1
                EncomendasMaterial$Atraso_Semanas[k] <- as.numeric(difftime(EncomendasMaterial$Data_Lançamento[k],
EncomendasMaterial$Data_Remessa[k], units = "weeks"))
                EncomendasMaterial$Avanço[k] <- 0
                EncomendasMaterial$Avanço_Semanas[k] <- 0
              } else if (filtro_mb51$Ano.Semana.Entrega[j] < filtro_me31$Ano.Semana.Entrega[i]){
                EncomendasMaterial$Avanço[k] <- 1
                EncomendasMaterial$Avanço_Semanas[k] <- as.numeric(difftime(EncomendasMaterial$Data_Remessa[k],
EncomendasMaterial$Data_Lançamento[k], units = "weeks"))
                EncomendasMaterial$Atraso[k] <- 0
                EncomendasMaterial$Atraso_Semanas[k] <- 0
                  }
            }else{
              EncomendasMaterial$Atraso[k] <- 0
              EncomendasMaterial$Atraso_Semanas[k] <- 0
              EncomendasMaterial$Avanço[k] <- 0
              EncomendasMaterial$Avanço_Semanas[k] <- 0
            }
            if(k==kk){
              EncomendasMaterial$Balanço[k] <-
round(EncomendasMaterial$Qtd_Excedente[k]-EncomendasMaterial$Qtd_Pendente[k]-EncomendasMaterial$Qtd_Compensada[k],3)
            }else{
              EncomendasMaterial$Balanço[k] <-
round(EncomendasMaterial$Qtd_Excedente[k]-EncomendasMaterial$Qtd_Pendente[k]-EncomendasMaterial$Qtd_Compensada[k]+
EncomendasMaterial$Balanço[k-1],3)
            }
            filtro_mb51$Check[j] <- 1
            filtro_me31$Check[i] <- 1
            k <- k+1
            break

        }

        #When the amount delivered seems to be superior to the one requested

        }else if (filtro_mb51$Qtd_Total_Registada[j] > filtro_me31$Qtd.divisão[i] & filtro_mb51$Check[j] == 0 &
filtro_me31$Check[i] == 0){
          if(j != nrow(filtro_mb51)){
            if(filtro_mb51$Qtd_Total_Registada[j+1] == filtro_me31$Qtd.divisão[i] & filtro_mb51$Check[j] == 0 &
filtro_mb51$Check[j+1] == 0 & filtro_mb51$Data.de.lançamento[j] == filtro_mb51$Data.de.lançamento[j+1]){

              EncomendasMaterial$Pedido_Compra[k] <- filtro_mb51$Pedido[j+1]
              EncomendasMaterial$Data_Doc_Compra[k] <- filtro_me31$Data.do.documento[i]
              EncomendasMaterial$Material[k] <- filtro_me31$Material[i]
              EncomendasMaterial$Descrição[k] <- filtro_me31$Texto.breve[i]
              EncomendasMaterial$Grupo_Mercadorias[k] <- filtro_me31$Grupo.de.mercadorias[i]
              EncomendasMaterial$Preço_Líquido[k] <- filtro_me31$Preço.líquido[i]
              EncomendasMaterial$Moeda[k] <- filtro_me31$Moeda[i]
              EncomendasMaterial$Unid_Preço[k] <- filtro_me31$Unidade.de.preço[i]
              EncomendasMaterial$Data_Remessa[k] <- filtro_me31$Data.de.remessa[i]
              EncomendasMaterial$Semana_Pedido_Entrega[k] <- filtro_me31$Ano.Semana.Entrega[i]
              EncomendasMaterial$Cód_Fornecedor[k] <- filtro_me31$Cód.fornecedor[i]
              EncomendasMaterial$Descrição_Fornecedor[k] <- filtro_me31$Descr..Fornecedor[i]
              EncomendasMaterial$Qtd_Divisão[k] <- filtro_me31$Qtd.divisão[i]
              EncomendasMaterial$Unid_Medida_Pedido[k] <- filtro_me31$UM.pedido[i]
              EncomendasMaterial$Qtd_Anterior[k] <- filtro_me31$Quantidade.anterior[i]
              EncomendasMaterial$Qtd_Entrada_Total[k] <- filtro_me31$Qtd.entrada[i]
              EncomendasMaterial$Data_Doc_Receção[k] <- filtro_mb51$Data.do.documento[j+1]
              EncomendasMaterial$Data_Lançamento[k] <- filtro_mb51$Data.de.lançamento[j+1]
              EncomendasMaterial$Semana_Real_Entrega[k] <- filtro_mb51$Ano.Semana.Entrega[j+1]
              EncomendasMaterial$Qtd_Registada[k] <- filtro_mb51$Qtd_Total_Registada[j+1]
              EncomendasMaterial$Unid_Medida_Básica[k] <- filtro_mb51$Unid.medida.básica[j+1]
              EncomendasMaterial$Unid_Registo[k] <- filtro_mb51$UM.registro[j+1]
              EncomendasMaterial$Montante.MI.Total[k] <- filtro_mb51$Montante.MI.Total[j+1]
              EncomendasMaterial$Montante.MI.Total.Atual[k] <- filtro_mb51$Montante.MI.Total.Atual[j+1]
              EncomendasMaterial$Moeda[k] <- filtro_mb51$Moeda[j+1]
              EncomendasMaterial$Unid_Preço_Pedido[k] <- filtro_mb51$Unid.prç.pedido[j+1]

              #The amount of material requested was the exact amount delivered

              EncomendasMaterial$Qtd_Pendente[k] <- 0
              EncomendasMaterial$Qtd_Excedente[k] <- 0

              EncomendasMaterial$Qtd_Compensada[k] <- 0
```

Figure 85: Code used to Combine ME3L and MB51 Transactions – Part XVI

```
        #Assigning possible delays or anticipation of deliveries

        if(filtro_mb51$Ano.Semana.Entrega[j] != filtro_me3l$Ano.Semana.Entrega[i]){
          if(filtro_mb51$Ano.Semana.Entrega[j] > filtro_me3l$Ano.Semana.Entrega[i]){
            EncomendasMaterial$Atraso[k] <- 1
            EncomendasMaterial$Atraso_Semanas[k] <- as.numeric(difftime(EncomendasMaterial$Data_Lançamento[k],
EncomendasMaterial$Data_Remessa[k], units = "weeks"))
            EncomendasMaterial$Avanço[k] <- 0
            EncomendasMaterial$Avanço_Semanas[k] <- 0
          } else if (filtro_mb51$Ano.Semana.Entrega[j] < filtro_me3l$Ano.Semana.Entrega[i]){
            EncomendasMaterial$Avanço[k] <- 1
            EncomendasMaterial$Avanço_Semanas[k] <- as.numeric(difftime(EncomendasMaterial$Data_Remessa[k],
EncomendasMaterial$Data_Lançamento[k], units = "weeks"))
            EncomendasMaterial$Atraso[k] <- 0
            EncomendasMaterial$Atraso_Semanas[k] <- 0
          }
        }else{
          EncomendasMaterial$Atraso[k] <- 0
          EncomendasMaterial$Atraso_Semanas[k] <- 0
          EncomendasMaterial$Avanço[k] <- 0
          EncomendasMaterial$Avanço_Semanas[k] <- 0
        }
        if(k==kk){
          EncomendasMaterial$Balanço[k] <-
round(EncomendasMaterial$Qtd_Excedente[k]-EncomendasMaterial$Qtd_Pendente[k]-EncomendasMaterial$Qtd_Compensada[k],3)
        }else{
          EncomendasMaterial$Balanço[k] <-
round(EncomendasMaterial$Qtd_Excedente[k]-EncomendasMaterial$Qtd_Pendente[k]-EncomendasMaterial$Qtd_Compensada[k]+
EncomendasMaterial$Balanço[k-1],3)
        }
        filtro_mb51$Check[j+1] <- 1
        filtro_me3l$Check[i] <- 1
        k <- k+1
        break
      }else if(i != nrow(filtro_me3l)){

        if(filtro_mb51$Qtd_Total_Registada[j] == filtro_me3l$Qtd.divisão[i] + filtro_me3l$Qtd.divisão[i+1]){

          #One delivery in MB51 transaction covers two requests of ME3L transaction

          EncomendasMaterial$Pedido_Compra[k] <- filtro_mb51$Pedido[j]
          EncomendasMaterial$Data_Doc_Compra[k] <- filtro_me3l$Data.do.documento[i]
          EncomendasMaterial$Material[k] <- filtro_me3l$Material[i]
          EncomendasMaterial$Descrição[k] <- filtro_me3l$Texto.breve[i]
          EncomendasMaterial$Grupo_Mercadorias[k] <- filtro_me3l$Grupo.de.mercadorias[i]
          EncomendasMaterial$Preço_Líquido[k] <- filtro_me3l$Preço.líquido[i]
          EncomendasMaterial$Moeda[k] <- filtro_me3l$Moeda[i]
          EncomendasMaterial$Unid_Preço[k] <- filtro_me3l$Unidade.de.preço[i]
          EncomendasMaterial$Data_Remessa[k] <- filtro_me3l$Data.de.remessa[i]
          EncomendasMaterial$Semana_Pedido_Entrega[k] <- filtro_me3l$Ano.Semana.Entrega[i]
          EncomendasMaterial$Cód_Fornecedor[k] <- filtro_me3l$Cód.fornecedor[i]
          EncomendasMaterial$Descrição_Fornecedor[k] <- filtro_me3l$Descr..Fornecedor[i]
          EncomendasMaterial$Qtd_Divisão[k] <- filtro_me3l$Qtd.divisão[i]
          EncomendasMaterial$Unid_Medida_Pedido[k] <- filtro_me3l$UM.pedido[i]
          EncomendasMaterial$Qtd_Anterior[k] <- filtro_me3l$Quantidade.anterior[i]
          EncomendasMaterial$Qtd_Entrada_Total[k] <- filtro_me3l$Qtd.entrada[i]
          EncomendasMaterial$Data_Doc_Receção[k] <- filtro_mb51$Data.do.documento[j]
          EncomendasMaterial$Data_Lançamento[k] <- filtro_mb51$Data.de.lançamento[j]
          EncomendasMaterial$Semana_Real_Entrega[k] <- filtro_mb51$Ano.Semana.Entrega[j]

          #In the first entry, it is assigned the requested amount of the first scheduled delivery
          EncomendasMaterial$Qtd_Registada[k] <- filtro_me3l$Qtd.divisão[i]

          EncomendasMaterial$Unid_Medida_Básica[k] <- filtro_mb51$Unid.medida.básica[j]
          EncomendasMaterial$Unid_Registo[k] <- filtro_mb51$UM.registro[j]

          EncomendasMaterial$Montante.MI.Total[k] <-
(filtro_mb51$Montante.MI.Total[j]/filtro_mb51$Qtd_Total_Registada[j]) * filtro_me3l$Qtd.divisão[i]
          EncomendasMaterial$Montante.MI.Total.Atual[k] <-
(filtro_mb51$Montante.MI.Total.Atual[j]/filtro_mb51$Qtd_Total_Registada[j]) * filtro_me3l$Qtd.divisão[i]
          EncomendasMaterial$Moeda[k] <- filtro_mb51$Moeda[j]
          EncomendasMaterial$Unid_Preço_Pedido[k] <- filtro_mb51$Unid.prç.pedido[j]
          #The assumption is that the amount of material requested was the exact amount delivered

          EncomendasMaterial$Qtd_Pendente[k] <- 0
          EncomendasMaterial$Qtd_Excedente[k] <- 0

          EncomendasMaterial$Qtd_Compensada[k] <- 0
```

Figure 86: Code used to Combine ME3L and MB51 Transactions – Part XVII

```
                  #Assigning possible delays or anticipation of deliveries

                  if(filtro_mb51$Ano.Semana.Entrega[j] != filtro_me3l$Ano.Semana.Entrega[i]){
                    if(filtro_mb51$Ano.Semana.Entrega[j] > filtro_me3l$Ano.Semana.Entrega[i]){
                      EncomendasMaterial$Atraso[k] <- 1
                      EncomendasMaterial$Atraso_Semanas[k] <- as.numeric(difftime(EncomendasMaterial$Data_Lançamento[k],
EncomendasMaterial$Data_Remessa[k], units = "weeks"))
                      EncomendasMaterial$Avanço[k] <- 0
                      EncomendasMaterial$Avanço_Semanas[k] <- 0
                  } else if (filtro_mb51$Ano.Semana.Entrega[j] < filtro_me3l$Ano.Semana.Entrega[i]){
                      EncomendasMaterial$Avanço[k] <- 1
                      EncomendasMaterial$Avanço_Semanas[k] <- as.numeric(difftime(EncomendasMaterial$Data_Remessa[k],
EncomendasMaterial$Data_Lançamento[k], units = "weeks"))
                      EncomendasMaterial$Atraso[k] <- 0
                      EncomendasMaterial$Atraso_Semanas[k] <- 0
                  }
                  }else{
                    EncomendasMaterial$Atraso[k] <- 0
                    EncomendasMaterial$Atraso_Semanas[k] <- 0
                    EncomendasMaterial$Avanço[k] <- 0
                    EncomendasMaterial$Avanço_Semanas[k] <- 0
                  }
                  if(k==kk){
                    EncomendasMaterial$Balanço[k] <-
round(EncomendasMaterial$Qtd_Excedente[k]-EncomendasMaterial$Qtd_Pendente[k]-EncomendasMaterial$Qtd_Compensada[k],3)
                  }else{
                    EncomendasMaterial$Balanço[k] <-
round(EncomendasMaterial$Qtd_Excedente[k]-EncomendasMaterial$Qtd_Pendente[k]-EncomendasMaterial$Qtd_Compensada[k]+
EncomendasMaterial$Balanço[k-1],3)
                  }
                  k <- k+1
                  #Assigning second ME3L entry

                  EncomendasMaterial$Pedido_Compra[k] <- filtro_mb51$Pedido[j]
                  EncomendasMaterial$Data_Doc_Compra[k] <- filtro_me3l$Data.do.documento[i+1]
                  EncomendasMaterial$Material[k] <- filtro_me3l$Material[i+1]
                  EncomendasMaterial$Descrição[k] <- filtro_me3l$Texto.breve[i+1]
                  EncomendasMaterial$Grupo_Mercadorias[k] <- filtro_me3l$Grupo.de.mercadorias[i+1]
                  EncomendasMaterial$Preço_Líquido[k] <- filtro_me3l$Preço.líquido[i+1]
                  EncomendasMaterial$Moeda[k] <- filtro_me3l$Moeda[i+1]
                  EncomendasMaterial$Unid_Preço[k] <- filtro_me3l$Unidade.de.preço[i+1]
                  EncomendasMaterial$Data_Remessa[k] <- filtro_me3l$Data.de.remessa[i+1]
                  EncomendasMaterial$Semana_Pedido_Entrega[k] <- filtro_me3l$Ano.Semana.Entrega[i+1]
                  EncomendasMaterial$Cód_Fornecedor[k] <- filtro_me3l$Cód.fornecedor[i+1]
                  EncomendasMaterial$Descrição_Fornecedor[k] <- filtro_me3l$Descr..Fornecedor[i+1]
                  EncomendasMaterial$Qtd_Divisão[k] <- filtro_me3l$Qtd.divisão[i+1]
                  EncomendasMaterial$Unid_Medida_Pedido[k] <- filtro_me3l$UM.pedido[i+1]
                  EncomendasMaterial$Qtd_Anterior[k] <- filtro_me3l$Quantidade.anterior[i+1]
                  EncomendasMaterial$Qtd_Entrada_Total[k] <- filtro_me3l$Qtd.entrada[i+1]
                  EncomendasMaterial$Data_Doc_Receção[k] <- filtro_mb51$Data.do.documento[j]
                  EncomendasMaterial$Data_Lançamento[k] <- filtro_mb51$Data.de.lançamento[j]
                  EncomendasMaterial$Semana_Real_Entrega[k] <- filtro_mb51$Ano.Semana.Entrega[j]

                  #In the second entry, it is assigned the requested amount of the second scheduled delivery
                  EncomendasMaterial$Qtd_Registada[k] <- filtro_me3l$Qtd.divisão[i+1]

                  EncomendasMaterial$Unid_Medida_Básica[k] <- filtro_mb51$Unid.medida.básica[j]
                  EncomendasMaterial$Unid_Registo[k] <- filtro_mb51$UM.registro[j]

                  EncomendasMaterial$Montante.MI.Total[k] <-
(filtro_mb51$Montante.MI.Total[j]/filtro_mb51$Qtd_Total_Registada[j]) * filtro_me3l$Qtd.divisão[i+1]
                  EncomendasMaterial$Montante.MI.Total.Atual[k] <-
(filtro_mb51$Montante.MI.Total.Atual[j]/filtro_mb51$Qtd_Total_Registada[j]) * filtro_me3l$Qtd.divisão[i+1]
                  EncomendasMaterial$Moeda[k] <- filtro_mb51$Moeda[j]
                  EncomendasMaterial$Unid_Preço_Pedido[k] <- filtro_mb51$Unid.prç.pedido[j]
                  #The assumption is that the amount of material requested was the exact amount delivered

                  EncomendasMaterial$Qtd_Pendente[k] <- 0
                  EncomendasMaterial$Qtd_Excedente[k] <- 0

                  EncomendasMaterial$Qtd_Compensada[k] <- 0

                  #Assigning possible delays or anticipation of deliveries

                  if(filtro_mb51$Ano.Semana.Entrega[j] != filtro_me3l$Ano.Semana.Entrega[i+1]){
                    if(filtro_mb51$Ano.Semana.Entrega[j] > filtro_me3l$Ano.Semana.Entrega[i+1]){
                      EncomendasMaterial$Atraso[k] <- 1
                      EncomendasMaterial$Atraso_Semanas[k] <- as.numeric(difftime(EncomendasMaterial$Data_Lançamento[k],
EncomendasMaterial$Data_Remessa[k], units = "weeks"))
                      EncomendasMaterial$Avanço[k] <- 0
                      EncomendasMaterial$Avanço_Semanas[k] <- 0
                    } else if (filtro_mb51$Ano.Semana.Entrega[j] < filtro_me3l$Ano.Semana.Entrega[i+1]){
                      EncomendasMaterial$Avanço[k] <- 1
                      EncomendasMaterial$Avanço_Semanas[k] <- as.numeric(difftime(EncomendasMaterial$Data_Remessa[k],
EncomendasMaterial$Data_Lançamento[k], units = "weeks"))
                      EncomendasMaterial$Atraso[k] <- 0
                      EncomendasMaterial$Atraso_Semanas[k] <- 0
                    }
                  }else{
                    EncomendasMaterial$Atraso[k] <- 0
                    EncomendasMaterial$Atraso_Semanas[k] <- 0
                    EncomendasMaterial$Avanço[k] <- 0
                    EncomendasMaterial$Avanço_Semanas[k] <- 0
                  }
```

Figure 87: Code used to Combine ME3L and MB51 Transactions – Part XVIII

```
                  if(k==kk){
                    EncomendasMaterial$Balanço[k] <-
round(EncomendasMaterial$Qtd_Excedente[k]-EncomendasMaterial$Qtd_Pendente[k]-EncomendasMaterial$Qtd_Compensada[k],3)
                  }else{
                    EncomendasMaterial$Balanço[k] <-
round(EncomendasMaterial$Qtd_Excedente[k]-EncomendasMaterial$Qtd_Pendente[k]-EncomendasMaterial$Qtd_Compensada[k]+
EncomendasMaterial$Balanço[k-1],3)
                  }

                  filtro_mb51$Check[j] <- 1
                  filtro_me3l$Check[i+1] <- 1
                  filtro_me3l$Check[i] <- 1
                  k <- k+1
                  break
                }else{
                  #The amount of material delivered was, indeed, superior to the amount requested

                  EncomendasMaterial$Pedido_Compra[k] <- filtro_mb51$Pedido[j]
                  EncomendasMaterial$Data_Doc_Compra[k] <- filtro_me3l$Data.do.documento[i]
                  EncomendasMaterial$Material[k] <- filtro_me3l$Material[i]
                  EncomendasMaterial$Descrição[k] <- filtro_me3l$Texto.breve[i]
                  EncomendasMaterial$Grupo_Mercadorias[k] <- filtro_me3l$Grupo.de.mercadorias[i]
                  EncomendasMaterial$Preço_Liquido[k] <- filtro_me3l$Preço.líquido[i]
                  EncomendasMaterial$Moeda[k] <- filtro_me3l$Moeda[i]
                  EncomendasMaterial$Unid_Preço[k] <- filtro_me3l$Unidade.de.preço[i]
                  EncomendasMaterial$Data_Remessa[k] <- filtro_me3l$Data.de.remessa[i]
                  EncomendasMaterial$Semana_Pedido_Entrega[k] <- filtro_me3l$Ano.Semana.Entrega[i]
                  EncomendasMaterial$Cód_Fornecedor[k] <- filtro_me3l$Cód.fornecedor[i]
                  EncomendasMaterial$Descrição_Fornecedor[k] <- filtro_me3l$Descr..Fornecedor[i]
                  EncomendasMaterial$Qtd_Divisão[k] <- filtro_me3l$Qtd.divisão[i]
                  EncomendasMaterial$Unid_Medida_Pedido[k] <- filtro_me3l$UM.pedido[i]
                  EncomendasMaterial$Qtd_Anterior[k] <- filtro_me3l$Quantidade.anterior[i]
                  EncomendasMaterial$Qtd_Entrada_Total[k] <- filtro_me3l$Qtd.entrada[i]
                  EncomendasMaterial$Data_Doc_Receção[k] <- filtro_mb51$Data.do.documento[j]
                  EncomendasMaterial$Data_Lançamento[k] <- filtro_mb51$Data.de.lançamento[j]
                  EncomendasMaterial$Semana_Real_Entrega[k] <- filtro_mb51$Ano.Semana.Entrega[j]
                  EncomendasMaterial$Qtd_Registada[k] <- filtro_mb51$Qtd_Total_Registada[j]
                  EncomendasMaterial$Unid_Medida_Básica[k] <- filtro_mb51$Unid.medida.básica[j]
                  EncomendasMaterial$Unid_Registo[k] <- filtro_mb51$UM.registro[j]
                  EncomendasMaterial$Montante.MI.Total[k] <- filtro_mb51$Montante.MI.Total[j]
                  EncomendasMaterial$Montante.MI.Total.Atual[k] <- filtro_mb51$Montante.MI.Total.Atual[j]
                  EncomendasMaterial$Moeda[k] <- filtro_mb51$Moeda[j]
                  EncomendasMaterial$Unid_Preço_Pedido[k] <- filtro_mb51$Unid.prç.pedido[j]

                  #If the amount was superior, there will never be material missing

                  EncomendasMaterial$Qtd_Pendente[k] <- 0
                  EncomendasMaterial$Qtd_Excedente[k] <- EncomendasMaterial$Qtd_Registada[k] - EncomendasMaterial$Qtd_Divisão[k]

                  EncomendasMaterial$Qtd_Compensada[k] <- 0
                  #Assigning possible delays or anticipation of deliveries

                  if(filtro_mb51$Ano.Semana.Entrega[j] != filtro_me3l$Ano.Semana.Entrega[i]){
                    if(filtro_mb51$Ano.Semana.Entrega[j] > filtro_me3l$Ano.Semana.Entrega[i]){
                      EncomendasMaterial$Atraso[k] <- 1
                      EncomendasMaterial$Atraso_Semanas[k] <- as.numeric(difftime(EncomendasMaterial$Data_Lançamento[k],
EncomendasMaterial$Data_Remessa[k], units = "weeks"))
                      EncomendasMaterial$Avanço[k] <- 0
                      EncomendasMaterial$Avanço_Semanas[k] <- 0
                    } else if (filtro_mb51$Ano.Semana.Entrega[j] < filtro_me3l$Ano.Semana.Entrega[i]){
                      EncomendasMaterial$Avanço[k] <- 1
                      EncomendasMaterial$Avanço_Semanas[k] <- as.numeric(difftime(EncomendasMaterial$Data_Remessa[k],
EncomendasMaterial$Data_Lançamento[k], units = "weeks"))
                      EncomendasMaterial$Atraso[k] <- 0
                      EncomendasMaterial$Atraso_Semanas[k] <- 0
                    }
                  }else{
                    EncomendasMaterial$Atraso[k] <- 0
                    EncomendasMaterial$Atraso_Semanas[k] <- 0
                    EncomendasMaterial$Avanço[k] <- 0
                    EncomendasMaterial$Avanço_Semanas[k] <- 0
                  }

                  if(k==kk){
                    EncomendasMaterial$Balanço[k] <-
round(EncomendasMaterial$Qtd_Excedente[k]-EncomendasMaterial$Qtd_Pendente[k]-EncomendasMaterial$Qtd_Compensada[k],3)
                  }else{
                    EncomendasMaterial$Balanço[k] <-
round(EncomendasMaterial$Qtd_Excedente[k]-EncomendasMaterial$Qtd_Pendente[k]-EncomendasMaterial$Qtd_Compensada[k]+
EncomendasMaterial$Balanço[k-1],3)
                  }

                  filtro_mb51$Check[j] <- 1
                  filtro_me3l$Check[i] <- 1
                  k <- k+1
                  break
                }
```

Figure 88: Code used to Combine ME3L and MB51 Transactions – Part XIX

```
            }else{
              #In case the last line of the ME3L transaction is being checked

            EncomendasMaterial$Pedido_Compra[k] <- filtro_mb51$Pedido[j]
            EncomendasMaterial$Data_Doc_Compra[k] <- filtro_me3l$Data.do.documento[i]
            EncomendasMaterial$Material[k] <- filtro_me3l$Material[i]
            EncomendasMaterial$Descrição[k] <- filtro_me3l$Texto.breve[i]
            EncomendasMaterial$Grupo_Mercadorias[k] <- filtro_me3l$Grupo.de.mercadorias[i]
            EncomendasMaterial$Preço_Líquido[k] <- filtro_me3l$Preço.líquido[i]
            EncomendasMaterial$Moeda[k] <- filtro_me3l$Moeda[i]
            EncomendasMaterial$Unid_Preço[k] <- filtro_me3l$Unidade.de.preço[i]
            EncomendasMaterial$Data_Remessa[k] <- filtro_me3l$Data.de.remessa[i]
            EncomendasMaterial$Semana_Pedido_Entrega[k] <- filtro_me3l$Ano.Semana.Entrega[i]
            EncomendasMaterial$Cód_Fornecedor[k] <- filtro_me3l$Cód.fornecedor[i]
            EncomendasMaterial$Descrição_Fornecedor[k] <- filtro_me3l$Descr..Fornecedor[i]
            EncomendasMaterial$Qtd_Divisão[k] <- filtro_me3l$Qtd.divisão[i]
            EncomendasMaterial$Unid_Medida_Pedido[k] <- filtro_me3l$UM.pedido[i]
            EncomendasMaterial$Qtd_Anterior[k] <- filtro_me3l$Quantidade.anterior[i]
            EncomendasMaterial$Qtd_Entrada_Total[k] <- filtro_me3l$Qtd.entrada[i]
            EncomendasMaterial$Data_Doc_Receção[k] <- filtro_mb51$Data.do.documento[j]
            EncomendasMaterial$Data_Lançamento[k] <- filtro_mb51$Data.de.lançamento[j]
            EncomendasMaterial$Semana_Real_Entrega[k] <- filtro_mb51$Ano.Semana.Entrega[j]
            EncomendasMaterial$Qtd_Registada[k] <- filtro_mb51$Qtd_Total_Registada[j]
            EncomendasMaterial$Unid_Medida_Básica[k] <- filtro_mb51$Unid.medida.básica[j]
            EncomendasMaterial$Unid_Registo[k] <- filtro_mb51$UM.registro[j]
            EncomendasMaterial$Montante.MI.Total[k] <- filtro_mb51$Montante.MI.Total[j]
            EncomendasMaterial$Montante.MI.Total.Atual[k] <- filtro_mb51$Montante.MI.Total.Atual[j]
            EncomendasMaterial$Moeda[k] <- filtro_mb51$Moeda[j]
            EncomendasMaterial$Unid_Preço_Pedido[k] <- filtro_mb51$Unid.prç.pedido[j]

            #If the amount was superior, there will never be material missing

            EncomendasMaterial$Qtd_Pendente[k] <- 0
            EncomendasMaterial$Qtd_Excedente[k] <- EncomendasMaterial$Qtd_Registada[k] - EncomendasMaterial$Qtd_Divisão[k]

            EncomendasMaterial$Qtd_Compensada[k] <- 0
             #Assigning possible delays or anticipation of deliveries

             if(filtro_mb51$Ano.Semana.Entrega[j] != filtro_me3l$Ano.Semana.Entrega[i]){
               if(filtro_mb51$Ano.Semana.Entrega[j] > filtro_me3l$Ano.Semana.Entrega[i]){
                 EncomendasMaterial$Atraso[k] <- 1
                 EncomendasMaterial$Atraso_Semanas[k] <- as.numeric(difftime(EncomendasMaterial$Data_Lançamento[k],
EncomendasMaterial$Data_Remessa[k], units = "weeks"))
                 EncomendasMaterial$Avanço[k] <- 0
                 EncomendasMaterial$Avanço_Semanas[k] <- 0
               } else if (filtro_mb51$Ano.Semana.Entrega[j] < filtro_me3l$Ano.Semana.Entrega[i]){
                 EncomendasMaterial$Avanço[k] <- 1
                 EncomendasMaterial$Avanço_Semanas[k] <- as.numeric(difftime(EncomendasMaterial$Data_Remessa[k],
EncomendasMaterial$Data_Lançamento[k], units = "weeks"))
                 EncomendasMaterial$Atraso[k] <- 0
                 EncomendasMaterial$Atraso_Semanas[k] <- 0
               }
             }else{
               EncomendasMaterial$Atraso[k] <- 0
               EncomendasMaterial$Atraso_Semanas[k] <- 0
               EncomendasMaterial$Avanço[k] <- 0
               EncomendasMaterial$Avanço_Semanas[k] <- 0
             }

             if(k==kk){
               EncomendasMaterial$Balanço[k] <-
round(EncomendasMaterial$Qtd_Excedente[k]-EncomendasMaterial$Qtd_Pendente[k]-EncomendasMaterial$Qtd_Compensada[k],3)
             }else{
               EncomendasMaterial$Balanço[k] <-
round(EncomendasMaterial$Qtd_Excedente[k]-EncomendasMaterial$Qtd_Pendente[k]-EncomendasMaterial$Qtd_Compensada[k]+
EncomendasMaterial$Balanço[k-1],3)
             }

             filtro_mb51$Check[j] <- 1
             filtro_me3l$Check[i] <- 1
             k <- k+1
             break
           }
         }else{
            #In case the last line of the MB51 transaction is being checked

            EncomendasMaterial$Pedido_Compra[k] <- filtro_mb51$Pedido[j]
            EncomendasMaterial$Data_Doc_Compra[k] <- filtro_me3l$Data.do.documento[i]
            EncomendasMaterial$Material[k] <- filtro_me3l$Material[i]
            EncomendasMaterial$Descrição[k] <- filtro_me3l$Texto.breve[i]
            EncomendasMaterial$Grupo_Mercadorias[k] <- filtro_me3l$Grupo.de.mercadorias[i]
            EncomendasMaterial$Preço_Líquido[k] <- filtro_me3l$Preço.líquido[i]
            EncomendasMaterial$Moeda[k] <- filtro_me3l$Moeda[i]
            EncomendasMaterial$Unid_Preço[k] <- filtro_me3l$Unidade.de.preço[i]
            EncomendasMaterial$Data_Remessa[k] <- filtro_me3l$Data.de.remessa[i]
            EncomendasMaterial$Semana_Pedido_Entrega[k] <- filtro_me3l$Ano.Semana.Entrega[i]
            EncomendasMaterial$Cód_Fornecedor[k] <- filtro_me3l$Cód.fornecedor[i]
            EncomendasMaterial$Descrição_Fornecedor[k] <- filtro_me3l$Descr..Fornecedor[i]
```

Figure 89: Code used to Combine ME3L and MB51 Transactions – Part XX

```
                EncomendasMaterial$Qtd_Divisão[k] <- filtro_me3l$Qtd.divisão[i]
                EncomendasMaterial$Unid_Medida_Pedido[k] <- filtro_me3l$UM.pedido[i]
                EncomendasMaterial$Qtd_Anterior[k] <- filtro_me3l$Quantidade.anterior[i]
                EncomendasMaterial$Qtd_Entrada_Total[k] <- filtro_me3l$Qtd.entrada[i]
                EncomendasMaterial$Data_Doc_Receção[k] <- filtro_mb51$Data.do.documento[j]
                EncomendasMaterial$Data_Lançamento[k] <- filtro_mb51$Data.de.lançamento[j]
                EncomendasMaterial$Semana_Real_Entrega[k] <- filtro_mb51$Ano.Semana.Entrega[j]
                EncomendasMaterial$Qtd_Registada[k] <- filtro_mb51$Qtd_Total_Registada[j]
                EncomendasMaterial$Unid_Medida_Básica[k] <- filtro_mb51$Unid.medida.básica[j]
                EncomendasMaterial$Unid_Registo[k] <- filtro_mb51$UM.registro[j]
                EncomendasMaterial$Montante.MI.Total[k] <- filtro_mb51$Montante.MI.Total[j]
                EncomendasMaterial$Montante.MI.Total.Atual[k] <- filtro_mb51$Montante.MI.Total.Atual[j]
                EncomendasMaterial$Moeda[k] <- filtro_mb51$Moeda[j]
                EncomendasMaterial$Unid_Preço_Pedido[k] <- filtro_mb51$Unid.prç.pedido[j]

                #If the amount was superior, there will never be material missing

                EncomendasMaterial$Qtd_Pendente[k] <- 0
                EncomendasMaterial$Qtd_Excedente[k] <- EncomendasMaterial$Qtd_Registada[k] - EncomendasMaterial$Qtd_Divisão[k]

                EncomendasMaterial$Qtd_Compensada[k] <- 0

                #Assigning possible delays or anticipation of deliveries

                if(filtro_mb51$Ano.Semana.Entrega[j] != filtro_me3l$Ano.Semana.Entrega[i]){
                  if(filtro_mb51$Ano.Semana.Entrega[j] > filtro_me3l$Ano.Semana.Entrega[i]){
                    EncomendasMaterial$Atraso[k] <- 1
                    EncomendasMaterial$Atraso_Semanas[k] <- as.numeric(difftime(EncomendasMaterial$Data_Lançamento[k],
 EncomendasMaterial$Data_Remessa[k], units = "weeks"))
                    EncomendasMaterial$Avanço[k] <- 0
                    EncomendasMaterial$Avanço_Semanas[k] <- 0
                  } else if (filtro_mb51$Ano.Semana.Entrega[j] < filtro_me3l$Ano.Semana.Entrega[i]){
                    EncomendasMaterial$Avanço[k] <- 1
                    EncomendasMaterial$Avanço_Semanas[k] <- as.numeric(difftime(EncomendasMaterial$Data_Remessa[k],
 EncomendasMaterial$Data_Lançamento[k], units = "weeks"))
                    EncomendasMaterial$Atraso[k] <- 0
                    EncomendasMaterial$Atraso_Semanas[k] <- 0
                  }
                }else{
                  EncomendasMaterial$Atraso[k] <- 0
                  EncomendasMaterial$Atraso_Semanas[k] <- 0
                  EncomendasMaterial$Avanço[k] <- 0
                  EncomendasMaterial$Avanço_Semanas[k] <- 0
                }

                if(k==kk){
                  EncomendasMaterial$Balanço[k] <-
round(EncomendasMaterial$Qtd_Excedente[k]-EncomendasMaterial$Qtd_Pendente[k]-EncomendasMaterial$Qtd_Compensada[k],3)
                }else{
                  EncomendasMaterial$Balanço[k] <-
round(EncomendasMaterial$Qtd_Excedente[k]-EncomendasMaterial$Qtd_Pendente[k]-EncomendasMaterial$Qtd_Compensada[k]+
EncomendasMaterial$Balanço[k-1],3)
                }

                filtro_mb51$Check[j] <- 1
                filtro_me3l$Check[i] <- 1
                k <- k+1
                break
              }
            }
          }
        }
      }
    #}
#}

EncomendasMaterial <- EncomendasMaterial[-c(k:nrow(EncomendasMaterial)),] #in the end, it always adds an extra line in position
k

write.xlsx(EncomendasMaterial, "Mat_1.xlsx")
```

Figure 90: Code used to Combine ME3L and MB51 Transactions – Part XXI

APPENDIX IX – EXAMPLE OF DATA TABLE COMBINING ME3L AND MB51 TRANSACTIONS

Table 35 shows a sample of the combined dataset for material '101I0000001565'.

Table 35: Example of a Combined ME3L and MB51 Dataset

Pedido_Compra	Data_Doc_Compra	Material	Grupo_Merca	Preço_Líquido	Moeda	Unid_Preço	Data_Remess	Semana_Pedi	Cód_Fornece	Qtd_Divisão	Unid_Medida	Qtd_Anterior	Qtd_Entrada_	Data_Doc_Re	Data_Lançam	Semana_Real	Qtd_Registad	Unid_Medida	Unid_Registo	Montante.MI	Montante.MI	Unid_Preço_F	Qtd_Pendente	Qtd_Excedent	Balanço	Atraso	Atraso_Sema	Avanço	Avanço_Sema	Qtd_Compens
5500039331	09/08/2020	101I00000015	100	39,75	EUR	1	09/18/2020	202038	70077	1200	M2	1200	1200	09/18/2020	09/18/2020	202038	1199,17	M2	M2	46629,74	47464,4677	M2	0,83	0	-0,83	0	0	0	0	0
5500039331	09/08/2020	101I00000015	100	39,75	EUR	1	09/25/2020	202039	70077	900	M2	900	900	09/22/2020	09/22/2020	202039	909,95	M2	M2	35383,41	36016,8219	M2	0	9,95	9,12	0	0	0	0	0
5500039331	09/08/2020	101I00000015	100	39,75	EUR	1	10/02/2020	202040	70077	809,12	M2	809,12	809,12	10/02/2020	10/02/2020	202040	804,91	M2	M2	31298,94	31859,2232	M2	4,21	0	4,91	0	0	0	0	0
5500039331	09/08/2020	101I00000015	100	39,75	EUR	1	10/09/2020	202041	70077	704,91	M2	704,91	704,91	10/07/2020	10/07/2020	202041	703,01	M2	M2	27336,55	27825,9091	M2	1,9	0	3,01	0	0	0	0	0
5500039331	09/08/2020	101I00000015	100	39,75	EUR	1	10/16/2020	202042	70077	803,01	M2	803,01	803,01	10/14/2020	10/14/2020	202042	805,29	M2	M2	31313,7	31874,264	M2	0	2,28	5,29	0	0	0	0	0
5500039331	09/08/2020	101I00000015	100	39,75	EUR	1	10/23/2020	202043	70077	900	M2	900	900	10/20/2020	10/20/2020	202043	1556,04	M2	M2	60506,6	61589,7748	M2	0	656,04	661,33	0	0	0	0	0
5500039331	09/08/2020	101I00000015	100	39,75	EUR	1	10/30/2020	202044	70077	1661,33	M2	1661,33	1661,33	10/27/2020	10/27/2020	202044	1046,48	M2	M2	40692,37	41420,8295	M2	614,85	0	46,48	0	0	0	0	0
5500039331	09/08/2020	101I00000015	100	39,75	EUR	1	11/06/2020	202045	70077	1046,48	M2	1046,48	1046,48	11/06/2020	11/06/2020	202045	1004,35	M2	M2	39054,15	39753,2778	M2	42,13	0	4,35	0	0	0	0	0
5500039331	09/08/2020	101I00000015	100	39,75	EUR	1	11/13/2020	202046	70077	500	M2	500	500	11/12/2020	11/12/2020	202046	503,19	M2	M2	19566,54	19916,8137	M2	0	3,19	7,54	0	0	0	0	0
5500039331	09/08/2020	101I00000015	100	39,75	EUR	1	11/20/2020	202047	70077	507,54	M2	507,54	507,54	11/17/2020	11/17/2020	202047	500,69	M2	M2	19469,33	19817,861	M2	6,85	0	0,69	0	0	0	0	0
5500039331	09/08/2020	101I00000015	100	39,75	EUR	1	11/27/2020	202048	70077	500,69	M2	500,69	500,69	11/26/2020	11/26/2020	202048	504,24	M2	M2	19607,37	19958,3739	M2	0	3,55	4,24	0	0	0	0	0
5500039331	09/11/2020	101I00000015	100	39,75	EUR	1	12/04/2020	202049	70077	804,24	M2	804,24	804,24	12/07/2020	12/07/2020	202050	825,04	M2	M2	32081,69	32655,9907	M2	0	20,8	25,04	1	0,42857143	0	0	0
5500039331	09/18/2020	101I00000015	100	39,75	EUR	1	12/11/2020	202050	70077	1000	M2	1000	1000	12/15/2020	12/15/2020	202051	1005,31	M2	M2	39091,48	39791,2756	M2	0	5,31	30,35	1	0,57142857	0	0	0
5500039331	10/02/2020	101I00000015	100	39,75	EUR	1	01/11/2021	202102	70077	1030,35	M2	1030,35	1030,35	01/07/2021	01/07/2021	202101	1000,63	M2	M2	38909,5	39606,0361	M2	29,72	0	0,63	0	0	1	0,57142857	0
5500039331	10/16/2020	101I00000015	100	39,75	EUR	1	01/15/2021	202102	70077	900,63	M2	900,63	900,63	01/14/2021	01/14/2021	202102	905,48	M2	M2	35209,58	35839,8944	M2	0	4,85	5,48	0	0	0	0	0
5500039331	10/16/2020	101I00000015	100	39,75	EUR	1	01/22/2021	202103	70077	1005,48	M2	1005,48	1005,48	01/19/2021	01/19/2021	202103	1000,68	M2	M2	38911,44	39608,0151	M2	4,8	0	0,68	0	0	0	0	0
5500039331	10/23/2020	101I00000015	100	39,75	EUR	1	01/29/2021	202104	70077	500,68	M2	500,68	500,68	01/29/2021	01/29/2021	202104	501,79	M2	M2	19512,1	19861,4002	M2	0	1,11	1,79	0	0	0	0	0
5500039331	10/30/2020	101I00000015	100	39,75	EUR	1	02/05/2021	202105	70077	800	M2	800	800	02/02/2021	02/02/2021	202105	829,95	M2	M2	32272,61	32850,3339	M2	0	29,95	31,74	0	0	0	0	0
5500039331	11/20/2020	101I00000015	100	39,75	EUR	1	02/12/2021	202106	70077	531,74	M2	531,74	531,74	02/11/2021	02/11/2021	202106	500,08	M2	M2	18334,43	19793,7165	M2	31,66	0	0,08	0	0	0	0	0
5500039331	11/27/2020	101I00000015	100	39,75	EUR	1	02/18/2021	202107	70077	800	M2	800	800	02/18/2021	02/18/2021	202107	802,76	M2	M2	29431,58	31774,1238	M2	0	2,76	2,84	0	0	0	0	0
5500039331	12/04/2020	101I00000015	100	39,75	EUR	1	02/25/2021	202108	70077	800	M2	800	800	02/23/2021	02/23/2021	202108	802,61	M2	M2	29426,09	31768,1867	M2	0	2,61	5,45	0	0	0	0	0
5500039331	12/11/2020	101I00000015	100	39,75	EUR	1	03/04/2021	202109	70077	500	M2	500	500	03/01/2021	03/03/2021	202109	502,32	M2	M2	18416,55	19882,3782	M2	0	2,32	7,77	0	0	0	0	0
5500039331	12/18/2020	101I00000015	100	39,75	EUR	1	03/11/2021	202110	70077	500	M2	500	500	03/09/2021	03/09/2021	202110	504,32	M2	M2	18489,88	19961,5404	M2	0	4,32	12,09	0	0	0	0	0
5500039331	12/18/2020	101I00000015	100	39,75	EUR	1	03/18/2021	202111	70077	500	M2	500	500	03/17/2021	03/17/2021	202111	504,21	M2	M2	18485,85	19957,1864	M2	0	4,21	16,3	0	0	0	0	0
5500039331	01/08/2021	101I00000015	100	39,75	EUR	1	03/25/2021	202112	70077	500	M2	500	500	03/23/2021	03/23/2021	202112	505,05	M2	M2	18516,65	19990,4346	M2	0	5,05	21,35	0	0	0	0	0
5500039331	01/08/2021	101I00000015	100	39,75	EUR	1	04/01/2021	202113	70077	900	M2	900	900	03/31/2021	03/31/2021	202113	935,56	M2	M2	34300,44	37030,4939	M2	0	35,56	56,91	0	0	0	0	0
5500039331	01/15/2021	101I00000015	100	39,75	EUR	1	04/08/2021	202114	70077	900	M2	900	900	04/06/2021	04/06/2021	202114	901,73	M2	M2	33060,13	35691,4653	M2	0	1,73	58,64	0	0	0	0	0
5500039331	01/22/2021	101I00000015	100	39,75	EUR	1	04/15/2021	202115	70077	1000	M2	1000	1000	04/12/2021	04/12/2021	202115	504,82	M2	M2	18508,21	19981,3309	M2	495,18	0	-436,54	0	0	0	0	0
5500039331	01/22/2021	101I00000015	100	39,75	EUR	1	04/22/2021	202116	70077	500	M2	500	500	04/13/2021	04/13/2021	202115	1005,09	M2	M2	36849,61	39782,5678	M2	0	505,09	68,55	0	0	1	1,28571429	0
5500039331	01/29/2021	101I00000015	100	39,75	EUR	1	04/29/2021	202117	70077	800	M2	800	800	04/19/2021	04/22/2021	202116	501,2	M2	M2	18375,49	19838,0473	M2	298,8	0	-230,25	0	0	1	1	0
5500039331	02/05/2021	101I00000015	100	39,75	EUR	1	05/06/2021	202118	70077	700	M2	700	700	04/26/2021	04/27/2021	202117	801,93	M2	M2	29401,16	31741,2715	M2	0	101,93	-128,32	0	0	1	1,28571429	0
5500039331	02/12/2021	101I00000015	100	39,75	EUR	1	05/07/2021	202118	70077	579,68	M2	579,68	579,68	04/29/2021	05/03/2021	202118	708	M2	M2	25957,4	28023,4188	M2	0	128,32	0	0	0	0	0	0
5500039331	02/19/2021	101I00000015	100	39,75	EUR	1	05/14/2021	202119	70077	4,55	M2	4,55	4,55	05/10/2021	05/12/2021	202119	4,55	M2	M2	166,816612	180,094005	M2	0	0	0	0	0	0	0	0
5500039331	02/12/2021	101I00000015	100	39,75	EUR	1	05/20/2021	202120	70077	800	M2	800	800	05/10/2021	05/12/2021	202119	800	M2	M2	29330,3934	31664,88	M2	0	0	0	0	0	1	1,14285714	0
5500039331	05/14/2021	101I00000015	100	39,75	EUR	1	05/20/2021	202120	70077	800	M2	800	800	05/18/2021	05/19/2021	202120	800	M2	M2	29330,401	31664,88	M2	0	0	0	0	0	0	0	0
5500039331	02/19/2021	101I00000015	100	39,75	EUR	1	05/27/2021	202121	70077	1,19	M2	1,19	1,19	05/18/2021	05/19/2021	202120	1,19	M2	M2	43,6289715	47,101509	M2	0	0	0	0	0	1	1,14285714	0
5500039331	05/21/2021	101I00000015	100	39,75	EUR	1	05/27/2021	202121	70077	900	M2	900	900	05/31/2021	06/01/2021	202122	908,42	M2	M2	33305,4	35956,2629	M2	0	8,42	8,42	1	0,71428571	0	0	0
5500039331	02/19/2021	101I00000015	100	39,75	EUR	1	06/03/2021	202122	70077	700	M2	700	700	06/01/2021	06/04/2021	202122	701,49	M2	M2	25718,72	27765,7458	M2	0	1,49	9,91	0	0	0	0	0
5500039331	02/26/2021	101I00000015	100	39,75	EUR	1	06/10/2021	202123	70077	500	M2	500	500	06/08/2021	06/09/2021	202123	504,32	M2	M2	18489,89	19961,5404	M2	0	4,32	14,23	0	0	0	0	0
5500039331	02/26/2021	101I00000015	100	39,75	EUR	1	06/17/2021	202124	70077	500	M2	500	500	06/14/2021	06/15/2021	202124	502,34	M2	M2	18417,3	19883,1698	M2	0	2,34	16,57	0	0	0	0	0
5500039331	02/26/2021	101I00000015	100	39,75	EUR	1	06/24/2021	202125	70077	900	M2	900	900	06/21/2021	06/23/2021	202125	904,4	M2	M2	33158,02	35797,1468	M2	0	4,4	20,97	0	0	0	0	0
5500039331	03/04/2021	101I00000015	100	39,75	EUR	1	07/01/2021	202126	70077	900	M2	900	900	06/29/2021	07/01/2021	202126	906,96	M2	M2	33251,86	35898,4745	M2	0	6,96	27,93	0	0	0	0	0
5500039331	03/04/2021	101I00000015	100	39,75	EUR	1	07/08/2021	202127	70077	800	M2	800	800	07/05/2021	07/07/2021	202127	801,91	M2	M2	29400,43	31740,4799	M2	0	1,91	29,84	0	0	0	0	0
5500039331	03/18/2021	101I00000015	100	39,75	EUR	1	07/15/2021	202128	70077	728,49	M2	728,49	728,49	07/12/2021	07/13/2021	202128	698,65	M2	M2	25614,61	27653,3355	M2	29,84	0	0	0	0	0	0	0
5500039331	04/29/2021	101I00000015	100	39,75	EUR	1	07/22/2021	202129	70077	500	M2	500	500	07/19/2021	07/20/2021	202129	512,2	M2	M2	18778,79	20273,4394	M2	0	12,2	12,2	0	0	0	0	0
5500039331	04/29/2021	101I00000015	100	39,75	EUR	1	07/29/2021	202130	70077	1400	M2	1400	1400	07/27/2021	07/30/2021	202130	1396,89	M2	M2	51214,16	55290,4428	M2	3,11	0	9,09	0	0	0	0	0
5500039331	04/29/2021	101I00000015	100	39,75	EUR	1	08/05/2021	202131	70077	900	M2	900	900	08/05/2021	08/05/2021	202131	910,68	M2	M2	33388,27	36045,7161	M2	0	10,68	19,77	0	0	0	0	0
5500039331	05/07/2021	101I00000015	100	39,75	EUR	1	09/02/2021	202135	70077	800	M2	800	800	09/02/2021	09/02/2021	202135	842,49	M2	M2	30888,21	33346,6809	M2	0	42,49	62,26	0	0	0	0	0
5500039331	05/14/2021	101I00000015	100	39,75	EUR	1	09/09/2021	202136	70077	800	M2	800	800	09/06/2021	09/07/2021	202136	802,19	M2	M2	29410,68	31751,5626	M2	0	2,19	64,45	0	0	0	0	0
5500039331	07/16/2021	101I00000015	100	39,75	EUR	1	09/30/2021	202139	70077	500	M2	500	500	09/28/2021	09/28/2021	202139	502,47	M2	M2	18422,06	19888,3153	M2	0	2,47	66,92	0	0	0	0	0
5500039331	07/23/2021	101I00000015	100	39,75	EUR	1	10/07/2021	202140	70077	500	M2	500	500	10/06/2021	10/06/2021	202140	500,37	M2	M2	18345,07	19805,195	M2	0	0,37	67,29	0	0	0	0	0
5500039331	07/23/2021	101I00000015	100	39,75	EUR	1	10/14/2021	202141	70077	600	M2	600	600	10/12/2021	10/12/2021	202141	604,44	M2	M2	22160,58	23924,4001	M2	0	4,44	71,73	0	0	0	0	0
5500039331	07/23/2021	101I00000015	100	39,75	EUR	1	10/21/2021	202142	70077	700	M2	700	700	10/20/2021	10/20/2021	202142	805,7	M2	M2	29539,38	31890,4923	M2	0	105,7	177,43	0	0	0	0	0
5500039331	07/23/2021	101I00000015	100	39,75	EUR	1	10/28/2021	202143	70077	700	M2	700	700	10/26/2021	10/26/2021	202143	704,07	M2	M2	25813,32	27867,8651	M2	0	4,07	181,5	0	0	0	0	0
5500039331	07/30/2021	101I00000015	100	39,75	EUR	1	11/04/2021	202144	70077	800	M2	800	800	11/05/2021	11/05/2021	202144	802,66	M2	M2	29427,92	31770,1657	M2	0	2,66	184,16	0	0	0	0	0
5500039331	07/30/2021	101I00000015	100	39,75	EUR	1	11/11/2021	202145	70077	700	M2	700	700	11/09/2021	11/09/2021	202145	706,32	M2	M2	25895,81	27956,9226	M2	0	6,32	190,48	0	0	0	0	0
5500039331	09/01/2021	101I00000015	100	39,75	EUR	1	11/25/2021	202147	70077	500	M2	500	500	11/19/2021	11/23/2021	202147	500,32	M2	M2	18343,23	19803,216	M2	0	0,32	190,8	0	0	0	0	0

APPENDIX X – LOGIC USED TO CREATE SUPPLY STOCK OUTS LIST

With the help of auxiliary variables that compare the combined ME3L and MB51 dataset with its summarised version, comprising only the entries with negative values in variable 'Balanço', for each entry of this second data frame, a list of their subsequent requests is compiled. The first entry of this new list presenting variable 'Balanço' equal to or superior to zero is the delivery that would have ensured the replenishment of the missing amount of material and its respective **'Data.de.lançamento'** is then stored in variable **'Data_ReposiçãoBalanço'** of the new dataset.

Notwithstanding, this method alone did not guarantee that the obtained list of stock outs represented unique occurrences. Table 36 helps to explain the reason why.

Table 36: Preliminary List of Stock Outs

Material	Data_Remessa	Cód_Fornecedor	Data_Lançamento	Qtd_Pendente	Balanço	Data_ReposiçãoBalanço	eliminado
101I0000001509	2022-02-03	70428	2022-02-07	3462.90	-1985.81	2022-04-12	0
101I0000001509	2022-02-03	70428	2022-02-15	2161.12	-684.03	2022-04-12	1
101I0000001509	2022-02-17	70428	2022-02-21	409.42	-1093.45	2022-04-12	0
101I0000001509	2022-02-24	70428	2022-02-24	0.00	-1050.21	2022-04-12	1
101I0000001509	2022-03-03	70428	2022-02-25	0.00	-567.47	2022-04-12	1
101I0000001509	2022-03-10	70428	2022-03-01	0.00	-567.47	2022-04-12	1
101I0000001509	2022-03-10	70428	2022-03-10	385.89	-953.36	2022-04-12	0
101I0000001509	2022-03-17	70428	2022-03-15	1462.62	-2415.98	2022-04-12	0
101I0000001509	2022-03-24	70428	2022-03-21	0.00	-1496.24	2022-04-12	1
101I0000001509	2022-03-31	70428	2022-03-28	0.00	-1496.24	2022-04-12	1
101I0000001509	2022-03-31	70428	2022-03-29	0.00	-1434.88	2022-04-12	1
101I0000001509	2022-04-07	70428	2022-04-04	3150.99	-4585.87	2022-04-12	0
101I0000001509	2022-04-07	70428	2022-04-05	0.00	-573.95	2022-04-12	1
101I0000001509	2022-08-18	70428	2022-08-19	549.81	-549.81	2022-08-22	0
101I0000001509	2022-11-10	70428	2022-11-15	481.20	-481.20	2022-11-18	0
101I0000001509	2023-01-19	70428	2023-01-20	38.83	-38.83	2023-01-23	0
101I0000001509	2023-02-02	70428	2023-01-31	135.37	-135.37	2023-02-10	0
101I0000001509	2023-03-23	70428	2023-03-22	515.10	-515.10	2023-03-28	0
101I0000001509	2023-04-20	70428	2023-04-18	819.85	-132.78	2023-04-26	0

The first of the highlighted entries in Table 36 shows that the delivery of material '101I0000001509' on February 7th, 2022 arrived with less 3.462,90 square metres than requested. However, because there was some extra material in stock, the total amount of missing material was only of 1.985,81 square metres (the real stock out value).

On the other hand, in the second of the highlighted lines, one can find another negative balance that was restocked in the same **'Data_ReposiçãoBalanço'** as the first, meaning that these are consecutive entries in the combined dataset. Although still negative, in this second entry fewer square metres of material were missing, which indicates that this delivery was fulfilled with some extra amount of material that compensated part of the previous stock out. Because of this, one can conclude that this entry should not be considered as a new stock out and that, therefore, should not be included on this list.

The same cannot be said about the third delivery registered with the same **'Data_ReposiçãoBalanço'**. From the second to the third entries, the inventory balance decreases a bit more, meaning that more square metres of material were missing and there was a new stock out of 409,42 square metres (**'Qtd_Pendente'**).

Consequently, in order to help decide which entries should be kept in the final list of stock outs, the developed algorithm assesses these situations and assigns value 1 to binary variable **'eliminado'**, in case an entry should be excluded from the final dataset. Note that the described logic only applies if the stock outs share the same **'Data_ReposiçãoBalanço'**.

APPENDIX XI – CREATION OF SUPPLY STOCK OUTS LIST

Figure 91 shows the code used to obtain the list of supply stock outs.

```
#List of Stock Outs
```{r}
EncomendasMaterial <- data.frame(read_excel("EncomendasMaterial.xlsx"))
```

```{r}
negativos <- subset(EncomendasMaterial, Balanço < 0)

negativos <- negativos[,c(3,9,11,18,26,28)]

negativos$Data_ReposiçãoBalanço <- as.Date(as.character("2000-01-01"))

for (i in 1:nrow(negativos)) {
  filtro <- subset(EncomendasMaterial, Data_Remessa >= negativos$Data_Remessa[i] & Data_Lançamento >=
negativos$Data_Lançamento[i] & Material == negativos$Material[i])
  if(length(filtro) != 0){ #a material can have its last line with a negative balance
    filtro2 <- filtro
    filtro2 <- filtro2[,c(3,9,11,18,26,28)]

    for (j in 1:nrow(filtro2)) {
      if(filtro2$Balanço[j] >= 0){
        negativos$Data_ReposiçãoBalanço[i] <- as.Date(as.character(filtro2$Data_Lançamento[j]))
        break

      }
    }
  }
}

negativos$eliminado <- 0

#Dealing with consecutive entries with negative balance

for (i in 1:(nrow(negativos)-1)) {
  if(negativos$Material[i] == negativos$Material[i+1] & negativos$Balanço[i] <= negativos$Balanço[i+1] &
negativos$Data_ReposiçãoBalanço[i] == negativos$Data_ReposiçãoBalanço[i+1] ){
    negativos$eliminado[i+1] <- 1
  }
}

negativos2 <- subset(negativos, eliminado == 0)

#Real amount of material missing

reposições <- unique(negativos2$Data_ReposiçãoBalanço)
materiais <- unique(negativos2$Material)

negativos2$QuebraReal <- NA
negativos2$index <- NA

for (i in 1:nrow(negativos2)) {
  negativos2$index[i] <- i
}

for (material in materiais) {
  for (n in reposições) {
    filtro3 <- subset(negativos2, Material == material & Data_ReposiçãoBalanço == n)

    if(nrow(filtro3) == 1){
      negativos2$QuebraReal[filtro3$index[1]] <- abs(negativos2$Balanço[filtro3$index[1]])

    }else if(nrow(filtro3) > 1){
      negativos2$QuebraReal[filtro3$index[1]] <- abs(negativos2$Balanço[filtro3$index[1]])

      for (j in 2:nrow(filtro3)) {
        negativos2$QuebraReal[filtro3$index[j]] <- negativos2$Qtd_Pendente[filtro3$index[j]]
      }

    }

  }

}
```

```{r}
write.xlsx(negativos2, "AtéAnularBalanço.xlsx")
```
```

Figure 91: Code used to Obtain the List of Supply Stock Outs

APPENDIX XII – CREATION OF RAW MATERIALS' WEEKLY DEMAND DATASET

Figure 92 details the code used to create raw materials' weekly demand dataset.

```
```{r}
data <- read.table("D:/Análise_Stock_compilações/Tabela_Real/MateriaisA_TabelaReal_compilado.csv",header = TRUE, sep=";", dec = ",")
```

```{r}
#Selecting the ten materials studied in depth

data <- subset(data, Material == "105I0000000403" | Material == "101I0000001565" | Material == "105I0000000405" | Material ==
"104I0000000003" | Material == "102B0000000001" | Material == "102B0000000002" | Material == "102I0000000083" | Material ==
"101I0000001509" | Material == "102I0000000124" | Material == "101I0000001443")

data <- data[, c(2,6,7,8,10,12)] #choosing the variables to be kept from the original dataset

data$ProcuraSemanalReal <- 0

data <- data[order(data$Material,data$Semana),]
```

```{r}
for (i in 2:nrow(data)) {
  if(data$Material[i] == data$Material[i-1]){
    data$ProcuraSemanalReal[i] <- round(data$ResOrd.Semana_i[i] - data$ResOrd.Transitadas[i-1] + data$ResOrd.Novas_Semana_i1[i] +
data$NecDep.Semana_i1[i],3)
  }
}
```

```{r}
write.xlsx(data, "ProcuraReal.xlsx", rowNames = FALSE)
```
```

Figure 92: Code used to Create Raw Materials' Weekly Demand Dataset

APPENDIX XIII – CREATION OF AUXILIARY WEEK TO MONTH DATASET

The code used to assign a month to each year week number employs the date table created on Power BI and shown in Table 37 as input. After running the code of Figure 93, the dataset of Table 38 is obtained. This last table is the one used in the creation of raw materials' monthly demand dataset.

Table 37: Sample of the Date Table used as Input

Date	DateAsInteger	Year	Monthnumber	YearMonthnumber	YearMonthShort	MonthNameShort	MonthNameLong	DayOfWeekNumber	DayOfWeek	DayOfWeekShort	Quarter	YearQuarter	YearWeeknumber	QuarterSort
01/07/2020 00:00	20200701	2020	07	2020/07	2020/jul	jul	julho	4	quarta-feira	qua	Q3	2020/Q3	202027	20203
02/07/2020 00:00	20200702	2020	07	2020/07	2020/jul	jul	julho	5	quinta-feira	qui	Q3	2020/Q3	202027	20203
03/07/2020 00:00	20200703	2020	07	2020/07	2020/jul	jul	julho	6	sexta-feira	sex	Q3	2020/Q3	202027	20203
04/07/2020 00:00	20200704	2020	07	2020/07	2020/jul	jul	julho	7	sábado	sáb	Q3	2020/Q3	202027	20203
05/07/2020 00:00	20200705	2020	07	2020/07	2020/jul	jul	julho	1	domingo	dom	Q3	2020/Q3	202027	20203
06/07/2020 00:00	20200706	2020	07	2020/07	2020/jul	jul	julho	2	segunda-feira	seg	Q3	2020/Q3	202028	20203
07/07/2020 00:00	20200707	2020	07	2020/07	2020/jul	jul	julho	3	terça-feira	ter	Q3	2020/Q3	202028	20203
08/07/2020 00:00	20200708	2020	07	2020/07	2020/jul	jul	julho	4	quarta-feira	qua	Q3	2020/Q3	202028	20203
09/07/2020 00:00	20200709	2020	07	2020/07	2020/jul	jul	julho	5	quinta-feira	qui	Q3	2020/Q3	202028	20203
10/07/2020 00:00	20200710	2020	07	2020/07	2020/jul	jul	julho	6	sexta-feira	sex	Q3	2020/Q3	202028	20203
11/07/2020 00:00	20200711	2020	07	2020/07	2020/jul	jul	julho	7	sábado	sáb	Q3	2020/Q3	202028	20203
12/07/2020 00:00	20200712	2020	07	2020/07	2020/jul	jul	julho	1	domingo	dom	Q3	2020/Q3	202028	20203
13/07/2020 00:00	20200713	2020	07	2020/07	2020/jul	jul	julho	2	segunda-feira	seg	Q3	2020/Q3	202029	20203
14/07/2020 00:00	20200714	2020	07	2020/07	2020/jul	jul	julho	3	terça-feira	ter	Q3	2020/Q3	202029	20203
15/07/2020 00:00	20200715	2020	07	2020/07	2020/jul	jul	julho	4	quarta-feira	qua	Q3	2020/Q3	202029	20203
16/07/2020 00:00	20200716	2020	07	2020/07	2020/jul	jul	julho	5	quinta-feira	qui	Q3	2020/Q3	202029	20203
17/07/2020 00:00	20200717	2020	07	2020/07	2020/jul	jul	julho	6	sexta-feira	sex	Q3	2020/Q3	202029	20203
18/07/2020 00:00	20200718	2020	07	2020/07	2020/jul	jul	julho	7	sábado	sáb	Q3	2020/Q3	202029	20203

```
#Auxiliary Week to Month Dataset
```{r}
datas <- read_excel("datas.xlsx") #Power BI date table

str(datas)

datas$Date <- as.Date(as.character(datas$Date))
str(datas)
```

```{r}
semanas <- data.frame(unique(datas$YearWeeknumber))

semanas$lastDate <- as.Date(as.character("2000-01-01"))

colnames(semanas) <- c("weeknumber","lastDate")

for (semana in semanas$weeknumber) {
  filtro_semanas <- subset(datas, YearWeeknumber == semana)
  controlo <- subset(filtro_semanas, DayOfWeekNumber == "5") #number 5 represents Thursdays
  j <- which(semanas$weeknumber == semana)
  semanas$lastDate[j] <- controlo$Date[1]

}
```

```{r}
write.xlsx(semanas, "weeks_final.xlsx")
```
```

Figure 93: Code used to Create the Auxiliary Week to Month Dataset

Table 38: Sample of the Auxiliary Week to Month Dataset

weeknumber	lastDate
202027	07/02/2020
202028	07/09/2020
202029	07/16/2020
202030	07/23/2020
202031	07/30/2020
202032	08/06/2020
202033	08/13/2020
202034	08/20/2020
202035	08/27/2020
202036	09/03/2020
202037	09/10/2020
202038	09/17/2020
202039	09/24/2020
202040	10/01/2020
202001	01/02/2020

APPENDIX XIV – CREATION OF RAW MATERIALS' MONTHLY DEMAND DATASET

Figure 94 details the code used to create raw materials' monthly demand dataset.

```
```{r}

procuraReal <- data.frame(read_excel("ProcuraReal.xlsx"))
semanas <- read.table("D:/Power BI_ClasseA/weeks_final.csv", header = TRUE, sep = ";") #auxiliary week to month dataset

semanas <- separate(semanas, col = lastDate, into = c('Dia','Mês', 'Ano'), sep = '/')

semanas <- semanas[,-2]

for (i in 1:nrow(semanas)) {
  if(semanas$Mês[i] == '01'){
    semanas$Mês[i] <- 'jan'
  }else if(semanas$Mês[i] == '02'){
    semanas$Mês[i] <- 'fev'
  }else if(semanas$Mês[i] == '03'){
    semanas$Mês[i] <- 'mar'
  }else if(semanas$Mês[i] == '04'){
    semanas$Mês[i] <- 'abr'
  }else if(semanas$Mês[i] == '05'){
    semanas$Mês[i] <- 'mai'
  }else if(semanas$Mês[i] == '06'){
    semanas$Mês[i] <- 'jun'
  }else if(semanas$Mês[i] == '07'){
    semanas$Mês[i] <- 'jul'
  }else if(semanas$Mês[i] == '08'){
    semanas$Mês[i] <- 'ago'
  }else if(semanas$Mês[i] == '09'){
    semanas$Mês[i] <- 'set'
  }else if(semanas$Mês[i] == '10'){
    semanas$Mês[i] <- 'out'
  }else if(semanas$Mês[i] == '11'){
    semanas$Mês[i] <- 'nov'
  }else if(semanas$Mês[i] == '12'){
    semanas$Mês[i] <- 'dez'
  }
}
procuraReal$Mês <- NA
procuraReal$Ano <- NA

for (i in 1:nrow(procuraReal)) {
  filtro_semana <- subset(semanas, weeknumber == procuraReal$Semana[i])
  procuraReal$Mês[i] <- filtro_semana$Mês[1]
  procuraReal$Ano[i] <- filtro_semana$Ano[1]
}

procuraReal$Descrição <- 0

procuraReal <- procuraReal[,c(1,10,2,8,9, c(3:7))]
```

```{r}

procuraReal_mensal <- procuraReal

procuraReal_mensal <- unique(procuraReal_mensal[,c(1,2,4,5)])

procuraReal_mensal$ProcuraRealMensal <- 0

for (i in 1:nrow(procuraReal)) {

  for (j in 1:nrow(procuraReal_mensal)) {

    if(procuraReal$Material[i] == procuraReal_mensal$Material[j] & procuraReal$Mês[i] == procuraReal_mensal$Mês[j] & procuraReal$Ano[i]
== procuraReal_mensal$Ano[j]){

      procuraReal_mensal$ProcuraRealMensal[j] <- procuraReal_mensal$ProcuraRealMensal[j] + procuraReal$ProcuraSemanalReal[i]

    }

  }

}

```

```{r}

write.xlsx(procuraReal_mensal, file = "ProcuraReal.Mensal_Compilada.xlsx")
```
```

Figure 94: Code used to Create Raw Materials' Monthly Demand Dataset

Appendix XV – Time Series Analysis and Normality Tests

Figures 95 and 96 show the R code used to perform time series and seasonality analyses to each material's demand data, as well as normality tests.

````
```{r}

library(openxlsx)
library(readxl)
library(tidyverse)
library(naniar)
library(dplyr)
library(ggplot2)
library(scales)
library(lubridate)
library(fpp2)
library(rstatix)
library(ggpubr)
library(fitdistrplus)

```

```{r}

procura <- data.frame(read_excel("ProcuraReal.Mensal_Compilada.xlsx"))

```

```{r}

#Split the information by material

materials <- unique(procura$Material)

for (material in materials){
  nam <- paste("mat", material, sep = "")
  assign(nam, subset(procura, Material == material ))

}

#Not including the months for which materials '105I0000000403', '105I0000000405', '102I0000000124' e '102I0000000083' were not used in production

mat105I0000000403 <- mat105I0000000403[-1,]
mat105I0000000405 <- mat105I0000000405[-1,]
mat102I0000000124 <- mat102I0000000124[-1,]
mat102I0000000083 <- mat102I0000000083[-c(1:3),]



```

```{r}

#Declaring as Time Series

df <- c(list(mat101I0000001443), list(mat101I0000001509), list(mat101I0000001565), list(mat102B0000000001), list(mat102B0000000002),
list(mat102I0000000083), list(mat102I0000000124), list(mat104I0000000003), list(mat105I0000000403), list(mat105I0000000405))

for (i in 1:length(df)) {

  nam2 <- paste("y", df[[i]][[1]][[1]], sep = "")

  if(df[[i]][[1]][[1]] == "101I0000001443" | df[[i]][[1]][[1]] == "101I0000001565" | df[[i]][[1]][[1]] == "104I0000000003" |
df[[i]][[1]][[1]] == "101I0000001509"){

    assign(nam2, ts(df[[i]][[5]], start = c(2020,1), frequency = 12))

  }else if(df[[i]][[1]][[1]] == "102I0000000083"){
    assign(nam2, ts(df[[i]][[5]], start = c(2021,4), frequency = 12))
  }else if(df[[i]][[1]][[1]] == "102I0000000124" | df[[i]][[1]][[1]] == "105I0000000403" | df[[i]][[1]][[1]] == "105I0000000405"){
    assign(nam2, ts(df[[i]][[5]], start = c(2022,4), frequency = 12))
  }else if(df[[i]][[1]][[1]] == "102B0000000001" | df[[i]][[1]][[1]] == "102B0000000002"){
    assign(nam2, ts(df[[i]][[5]], start = c(2022,2), frequency = 12))
  }

}
```
````

Figure 95: Code used for Demand Time Series Analysis and Normality Tests – Part I

```{r}
#Time plots

data <- list(y101I0000001443, y101I0000001509, y101I0000001565, y102B0000000001, y102B0000000002, y102I0000000083, y102I0000000124,
y104I0000000003, y105I0000000403, y105I0000000405)

for (j in 1:length(data)) {
  aux_variable <- data[[j]]

  print(autoplot(aux_variable) + ggtitle("Monthly Demand Evolution", materials[j]) + ylab("Monthly Demand") + xlab("Month"))

}
```

```{r}
#Seasonal Plots

for (j in 1:length(data)) {
  aux_variable <- data[[j]]

  #Seasonal Plot
  print(ggseasonplot(aux_variable) + ggtitle("Monthly Demand Evolution", materials[j]) + ylab("Monthly Demand") + xlab("Month"))

  #Polar Seasonal Plot
  print(ggseasonplot(aux_variable, polar = TRUE) + ggtitle("Monthly Demand Evolution", materials[j]) + ylab("Monthly Demand") +
xlab("Month"))

  #Excluding material with not enough observations for the Seasonal Subseries Plot

  if(materials[j] != "105I0000000403" & materials[j] != "105I0000000405" & materials[j] != "102B0000000001" & materials[j] !=
"102B0000000002" & materials[j] != "102I0000000124"){
    print(ggsubseriesplot(aux_variable) + ggtitle("Monthly Demand Evolution", materials[j]) + ylab("Monthly Demand") + xlab("Month"))
  }

}

```

```{r}
#Normality Tests - Shapiro-Wilk and Q-Q Plots

for (j in 1:length(data)) {
  aux_variable <- data[[j]]

  #Shapiro-Wilk Test
  cat("Shapiro-Wilk Test Material:", materials[j], "\n")
  print(shapiro.test(aux_variable))


  ##Visual Methods - Q-Q plot

  print(ggqqplot(aux_variable) + ggtitle("QQ Plot", materials[j]))

}
```

```{r}
#Fitting normal distributions

data3 <- c(list(mat105I0000000403), list(mat105I0000000405), list(mat104I0000000003), list(mat101I0000001443), list(mat101I0000001509),
list(mat101I0000001565), list(mat102I0000000124))

for (k in 1:length(data3)){
  nam3 <- paste("FIT", data3[[k]][[1]][[1]], sep = "")
  assign(nam3, fitdist(data3[[k]][[5]], "norm"))

}

fit_norm <- c(list(FIT105I0000000403), list(FIT105I0000000405), list(FIT104I0000000003), list(FIT101I0000001443),
list(FIT101I0000001509), list(FIT101I0000001565), list(FIT102I0000000124))


for (k in 1:length(fit_norm)) {
  print(plot(fit_norm[[k]]))

}
```

Figure 96: Code used for Demand Time Series Analysis and Normality Tests – Part II

Appendix XVI – Normality Tests

In order to evaluate if demand is normally distributed for any of the ten raw materials under study, statistical and graphical tests were conducted. Since, all materials' samples had less than 50 observations each, Shapiro-Wilk's normality test was applied.

This test's null hypothesis (H0) considers data to be normally distributed, but on the contrary, if the null hypothesis is rejected, demand data cannot be considered to follow a normal distribution. Rejecting or not rejecting the null hypothesis depends on the p-value returned by the normality test. Considering the standard significance level of 95%, the null hypothesis is rejected if the returned p-value is equal or inferior to 5%. Table 39 summarises the obtained Shapiro-Wilk test results for each material.

Table 39: Shapiro-Wilk Test Results

Material	p-value Shapiro-Wilk Normality Test	Normality Test Result
105I0000000403	0,3094	Cannot Reject H0
101I0000001565	0,05423	Cannot Reject H0
105I0000000405	0,3559	Cannot Reject H0
104I0000000003	0,385	Cannot Reject H0
102B0000000001	0,0001671	Reject H0
102B0000000002	0,000219	Reject H0
102I0000000083	0,00003708	Reject H0
101I0000001509	0,2518	Cannot Reject H0
102I0000000124	0,8523	Cannot Reject H0
101I0000001443	0,09784	Cannot Reject H0

As shown in Table 39, the Shapiro-Wilk test rejected the null hypothesis for materials '102B0000000001', '102B0000000002' and '102I0000000083' (hereafter named materials E, F and G), while, for the others, it allowed the possibility of demand being normally distributed.

This analysis was complemented by the use of Q-Q Plots (quantile-quantile plots) on the demand data, as a graphical method to test their normality. In these graphics, data is considered to be normally distributed when all points fall approximately along the reference line. The Q-Q plots of each raw material under study are presented in Figure 97.

After carefully analysing each materials' results some conclusions were reached. Primarily, the Q-Q plots confirmed the Shapiro-Wilk test results for materials E, F and G, as well as materials A, H and I (the last two being materials '105I0000000403' and '105I0000000405', respectively), or to put it in another words the first group of raw materials could not be considered to have a normally distributed demand, whereas the second group could.

However, the Q-Q plots returned unclear results for materials B and D, while completely contradicting the Shapiro-Wilk test results for materials C and J (the latter being material '102I0000000124').

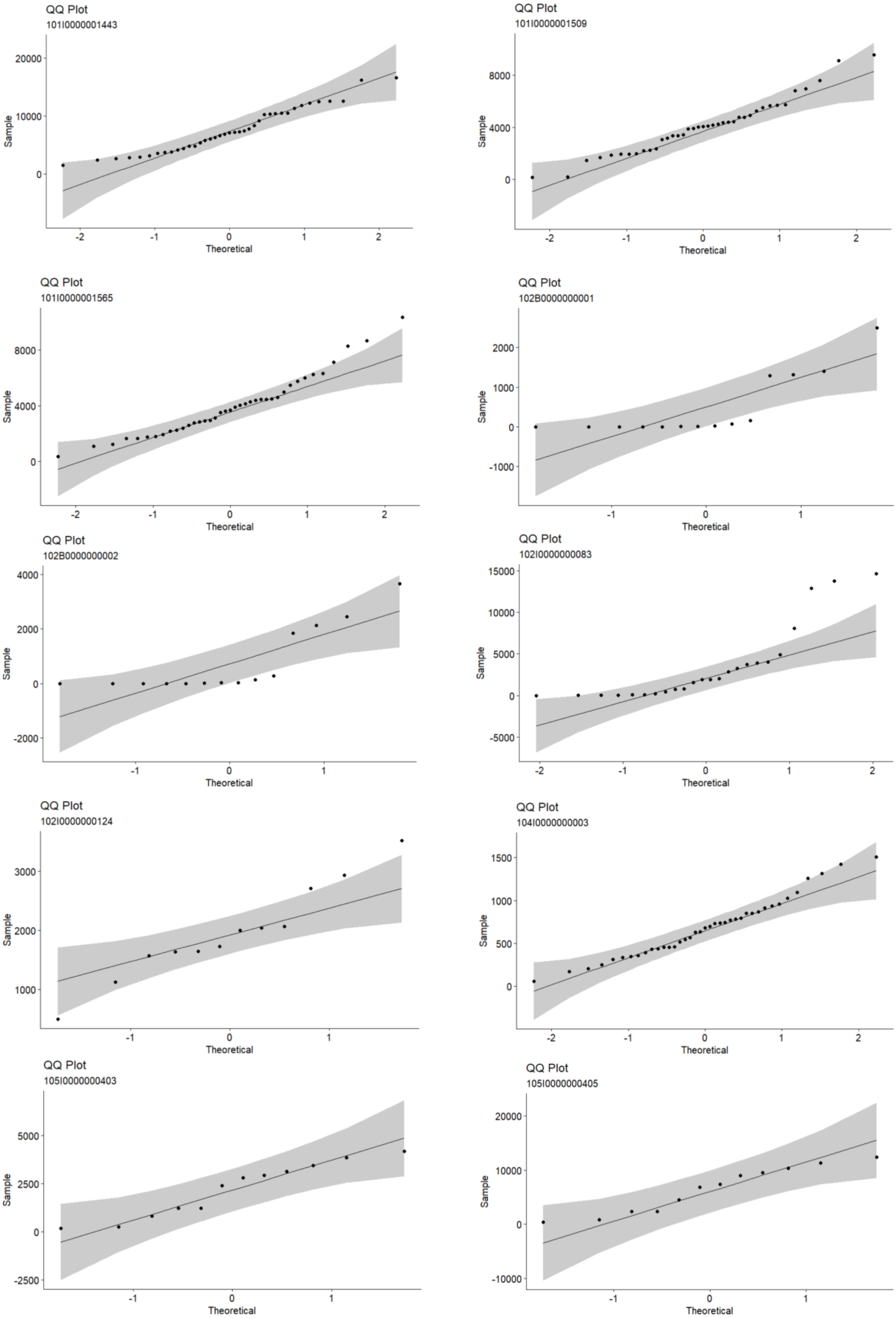


Figure 97: Q-Q Plots

As a result, for all materials, with the exception of those whose demand was considered not to be normally distributed by both tests (materials E, F and G), *fitdist* function from R's fitdistrplus library was used to find the theoretical normal distribution that best fitted demand data. This analysis intended to verify which materials could, in fact, be considered as having a normally distributed demand by assessing the quality of the approximation reached with the suggested normal distribution. The results obtained for each material are presented in Figures 98 to 104.

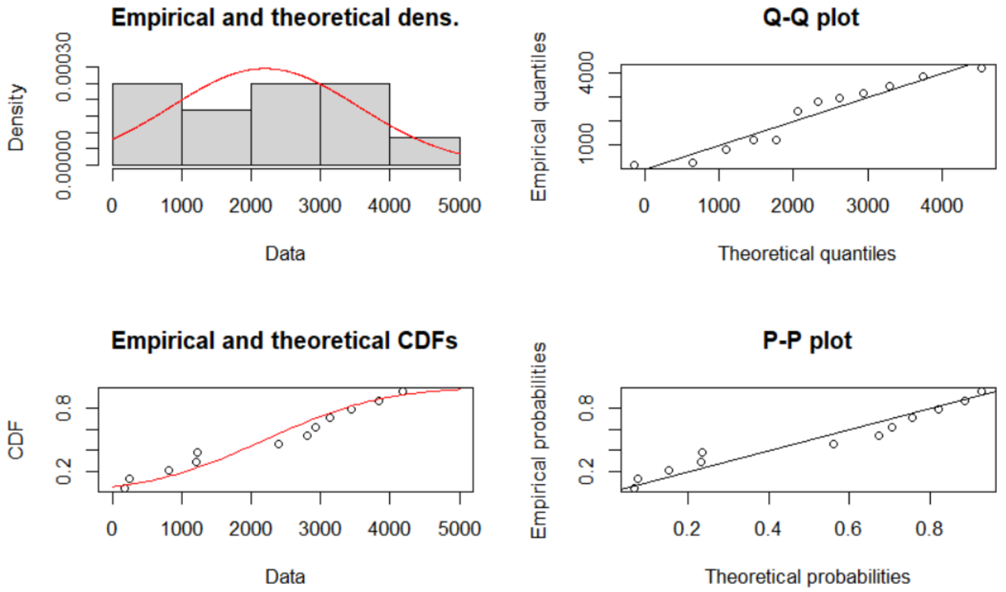


Figure 98: Theoretical Normal Distribution Results – Material H

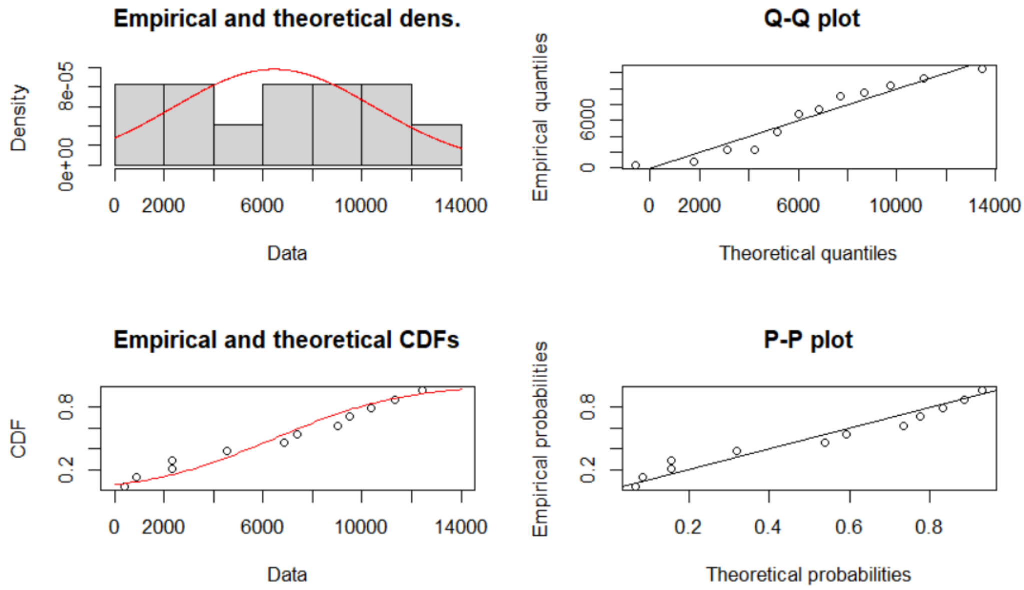


Figure 99: Theoretical Normal Distribution Results – Material I

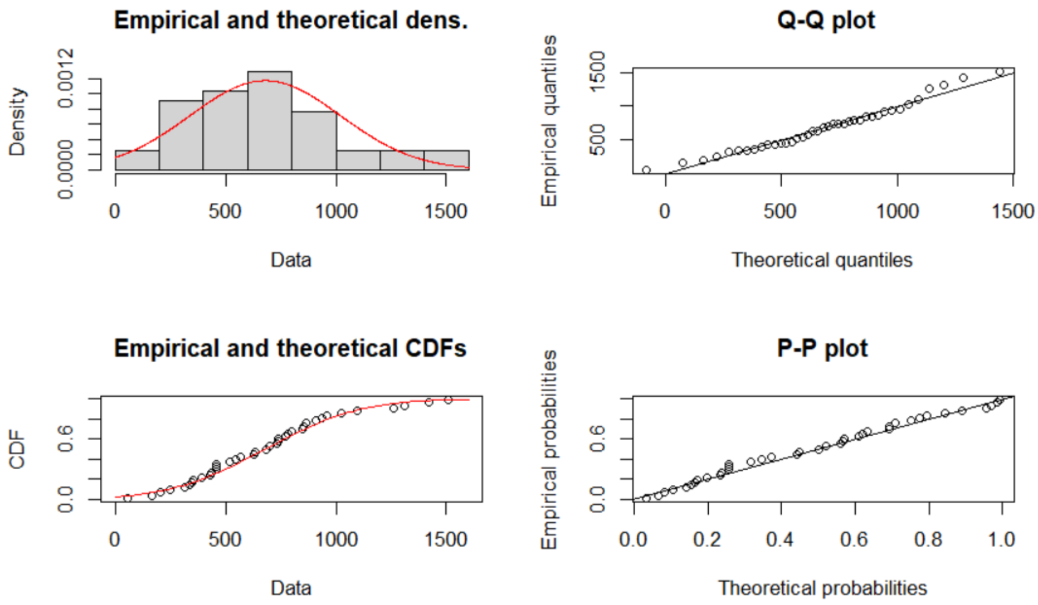


Figure 100: Theoretical Normal Distribution Results – Material D

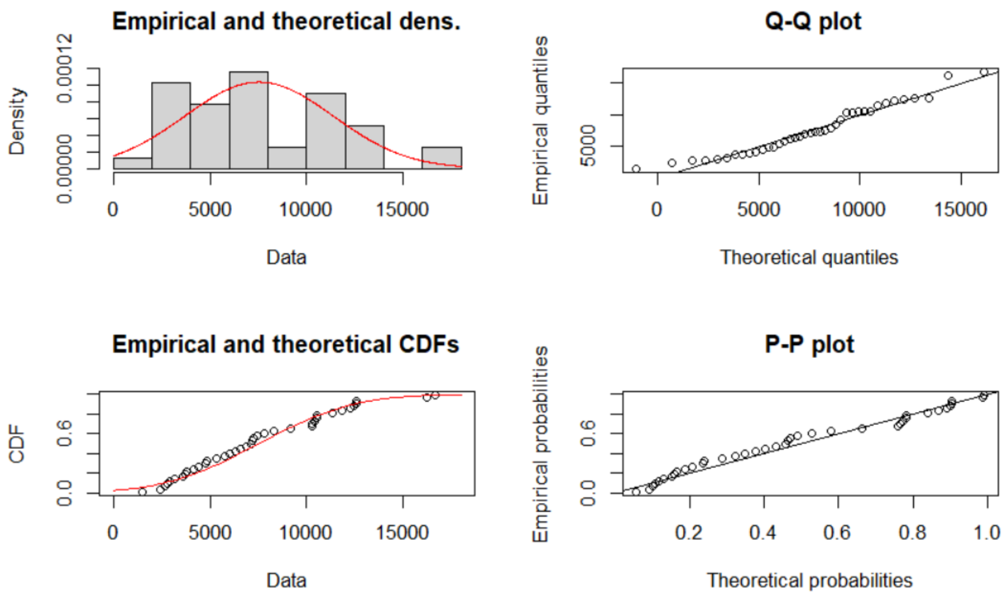


Figure 101: Theoretical Normal Distribution Results – Material A

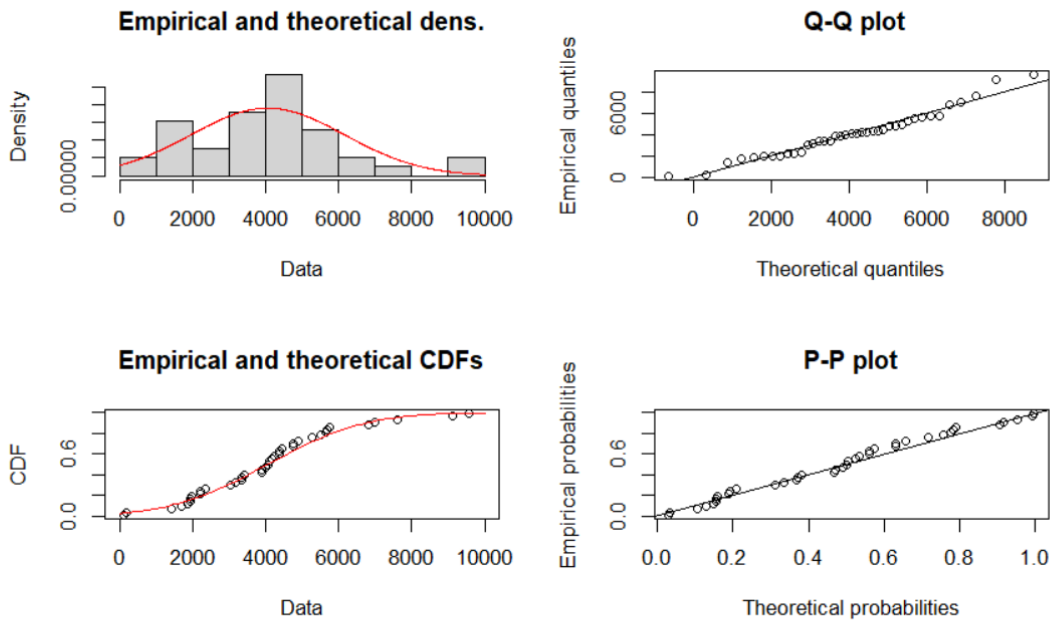


Figure 102: Theoretical Normal Distribution Results – Material B

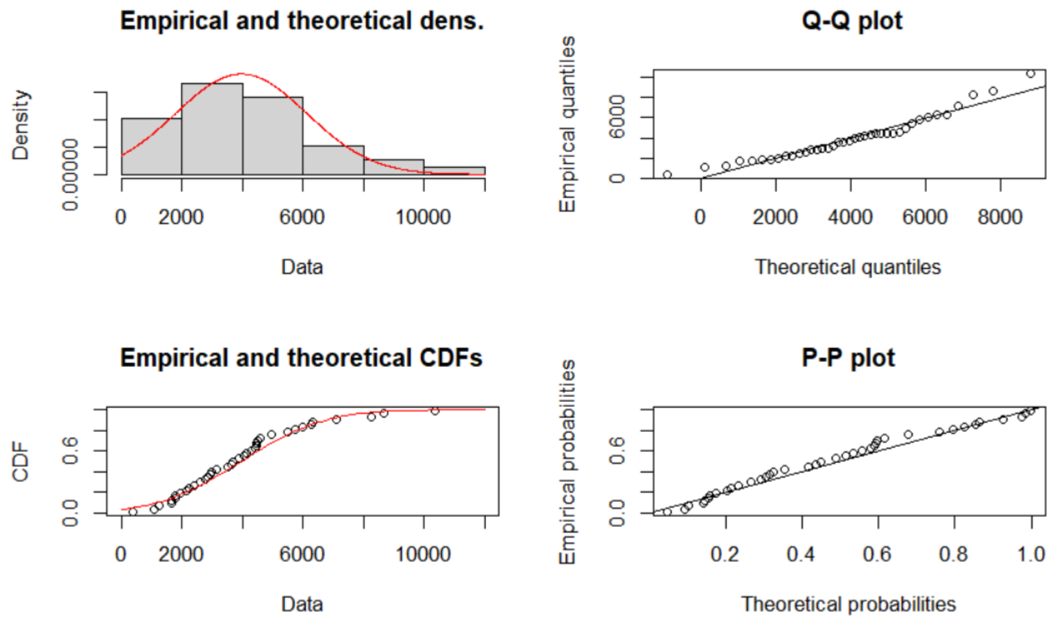


Figure 103: Theoretical Normal Distribution Results – Material C

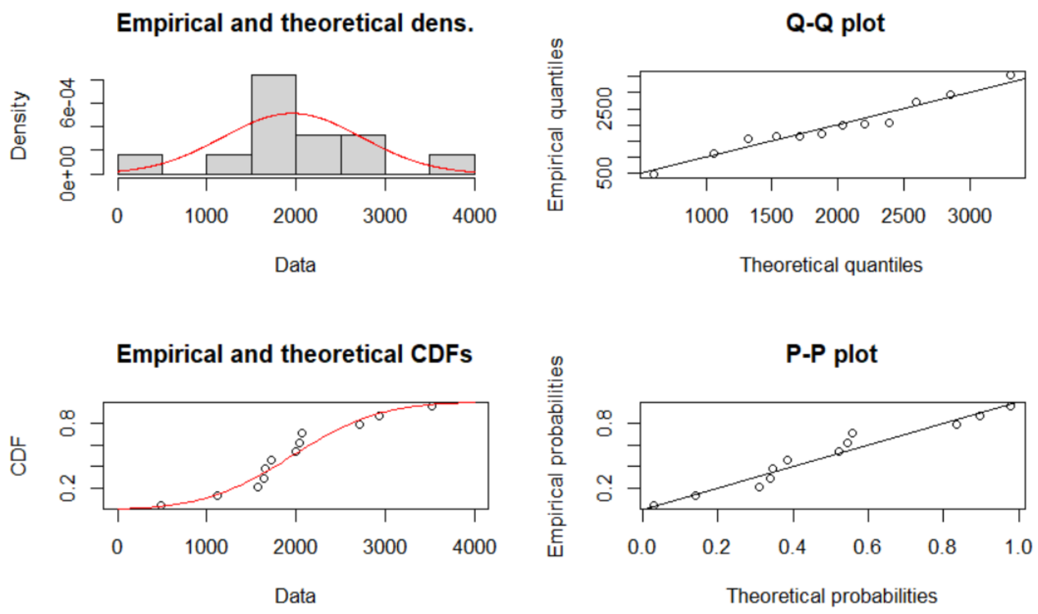


Figure 104: Theoretical Normal Distribution Results – Material J

Unlike what could be expected, demand data related to materials H and I fitted very poorly to the suggested normal distributions, and the same happened with material J, supporting and reinforcing the results found in the Q-Q Plot.

On the contrary, the theoretical normal distributions reached for materials D, A, B and C proved to be quite interesting approximations to each of these materials' historical demand data.

Since the inventory management policies studied in this dissertation rely on the fact that each material's demand is normally distributed over time, the choice was made to only include, for the rest of the analysis, materials that comply with this assumption. Therefore, and following the results obtained by the normality tests conducted, the materials chosen for further assessment were D, A, B and C, interestingly enough the ones associated with projects that have been in production longer. Appendix XV presents the code used to conduct this analysis.

APPENDIX XVII – REAL VARIATION RATE OF MATERIALS' NEEDS: TIME SERIES ANALYSIS

Figure 105 displays the time series results obtained for the real variation rate of materials' needs, before (left) and after (right) applying the logarithmic transformation to the data.

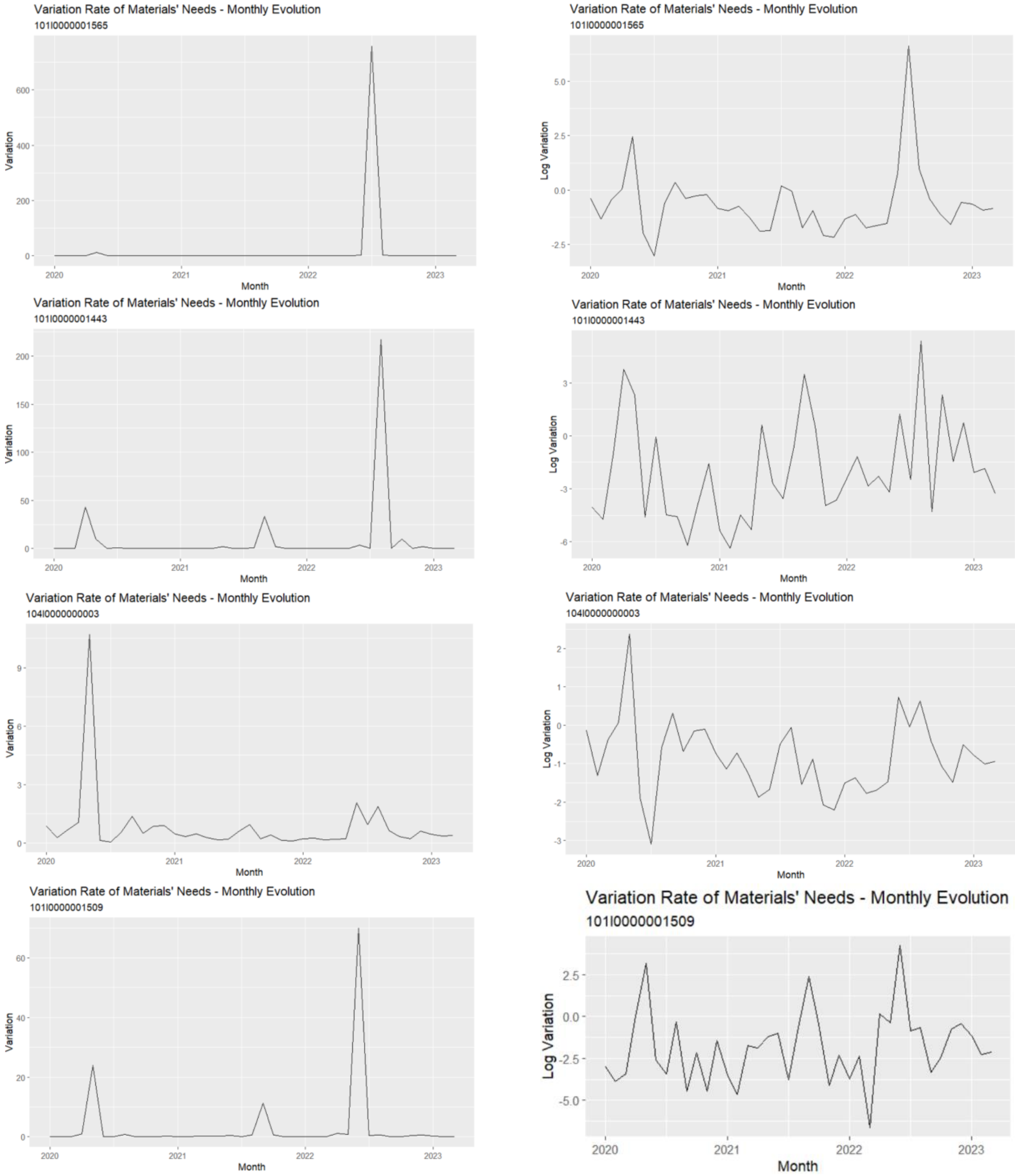


Figure 105: Evolution of the Real Variation Rate of Materials' Needs over Time

APPENDIX XVIII – SAFETY TIME ESTIMATION

Figures 106 and 107 detail the R code used to estimate each materials' safety time.

```
```{r}
atraso <- data.frame(read_excel("Evolução.Esperança.Média.AtrasoMenosZeros_Compilado.xlsx"))
```

```{r}
#Split the information by material
materials <- unique(atraso$Material)
for (material in materials){
  nam <- paste("mat", material, sep = "")
  assign(nam, subset(atraso, Material == material ))
}
```

```{r}
#Declaring as Time Series
df <- c(list(mat101I0000001443), list(mat101I0000001509), list(mat101I0000001565), list(mat102B0000000001), list(mat102B0000000002),
list(mat102I0000000083), list(mat102I0000000124), list(mat104I0000000003), list(mat105I0000000403), list(mat105I0000000405))
for (i in 1:length(df)) {
  nam2 <- paste("y", df[[i]][[1]][[1]], sep = "")
  if(df[[i]][[1]][[1]] == "101I0000001443" | df[[i]][[1]][[1]] == "101I0000001565" | df[[i]][[1]][[1]] == "104I0000000003" |
df[[i]][[1]][[1]] == "101I0000001509"){
    assign(nam2, ts(df[[i]][[9]], start = c(2020,9), frequency = 12))
  }else if(df[[i]][[1]][[1]] == "102I0000000083"){
    assign(nam2, ts(df[[i]][[9]], start = c(2021,11), frequency = 12))
  }else if(df[[i]][[1]][[1]] == "102I0000000124" | df[[i]][[1]][[1]] == "105I0000000405"){
    assign(nam2, ts(df[[i]][[9]], start = c(2022,4), frequency = 12))
  }else if(df[[i]][[1]][[1]] == "105I0000000403"){
    assign(nam2, ts(df[[i]][[9]], start = c(2022,5), frequency = 12))
  }else if(df[[i]][[1]][[1]] == "102B0000000001" | df[[i]][[1]][[1]] == "102B0000000002"){
    assign(nam2, ts(df[[i]][[9]], start = c(2022,9), frequency = 12))
  }
}
```

```{r}
#Fitting a Normal Distribution for the materials under study
data3 <- c(list(mat101I0000001565), list(mat101I0000001443), list(mat104I0000000003), list(mat101I0000001509))
for (k in 1:length(data3)) {
  nam3 <- paste("FIT", data3[[k]][[1]][[1]], sep = "")
  assign(nam3, fitdist(data3[[k]][[9]], "norm"))
}
```

```{r}
#ST table used as output
tabelaST <- data.frame(atraso[,c(1)])
tabelaST <- unique(tabelaST)
tabelaST <- data.frame(tabelaST[c(1, 3, 7, 10),])
colnames(tabelaST) <- "Material"
tabelaST$Original.LT <- c(27, 49, 56, 56)
tabelaST$SignificanceLevel <- 0
tabelaST$Estimated.LT.Days <- 0
tabelaST$Estimated.LT.Weeks <- 0
tabelaST$ST.Days <- 0
tabelaST$ST.Weeks <- 0
```
```

Figure 106: Code used to Determine Safety Time Values – Part I

```{r}
#Defining significance level

prob <- 0.95

fit_norm <- c(list(FIT101I0000001565), list(FIT101I0000001443), list(FIT104I0000000003), list(FIT101I0000001509))

for (k in 1:length(fit_norm)) {
  tabelaST$SignificanceLevel[k] <- prob

  #Estimating Total LT based on the desired significance level
  tabelaST$Estimated.LT.Days[k] <- round(qnorm(p = prob, mean = fit_norm[[k]][[1]][[1]], sd = fit_norm[[k]][[1]][[2]]),3)

  tabelaST$Estimated.LT.Weeks[k] <- ceiling(tabelaST$Estimated.LT.Days[k]/7)
  tabelaST$ST.Days[k] <-  tabelaST$Estimated.LT.Days[k] - tabelaST$Original.LT[k]
  tabelaST$ST.Weeks[k] <- ceiling(tabelaST$ST.Days[k]/7)
}

write.xlsx(tabelaST, file = "Resultados_para_ST_final.xlsx")
```

Figure 107: Code used to Determine Safety Time Values – Part II

APPENDIX XIX – V2 CURRENT STATUS ALGORITHM

Figures 108 to 111 show the R code used to simulate current system performance when considering the possibility of suppliers not complying with the ordered amount of material.

```
# Import da data
```{r}

# read previously saved files

data <- data.frame(read_excel("dataGestãoStocks95_n1_Dist.Teórica.xlsx"))#for current status algorithms does not matter the
data file its reading, since the information it is using are common to all new approaches algorithms

data <- data[c(4, 3, 1, 2),]

data2 <- data.frame(read_excel("data2_Procura_GestãoStocks.xlsx"))

data2 <- subset(data2, Material == "101I0000001565" | Material == "104I0000000003" | Material == "101I0000001509" | Material
== "101I0000001443")
```
```

```
```{r}
#Variable and Table Creation

data$lead_time_semanas <- ceiling(data$lead_time_semanas)

data2$Chegada.Material.Real <- 0

 j <- 1

 for (i in 1:nrow(data)) {
   for (n in j:(j+20-1)) {
     data2$Chegada.Material.Real[n] <- round(data2$Chegada.Material[n]*(1-data$Percent.QtdQuebra_Fornec[i]),2)
   }
   j <- j+20
 }

tabelaPrint <- data2
tabelaPrint <- tabelaPrint[,c(1,3,6,7,8)]

dataCustos <- data.frame(data[,-(2:26)])
colnames(dataCustos) <- c("Material")

tabelaPrint$StockInicial<- 0
tabelaPrint$StockFinal <- 0

tabelaPrint$StockTransito <- 0
tabelaPrint$StockTotal <- 0
tabelaPrint$Quebras <- 0
tabelaPrint$StockMedio <- 0
tabelaPrint$QuebrasReais <- 0
tabelaPrint$C1semanal <- 0
tabelaPrint$C2 <- 0
tabelaPrint$C3 <- 0
tabelaPrint$CustoGestaoStock <- 0

tabelaPrint$NivelServico <- 0


dataCustos$CustosPosse <- 0
dataCustos$CustosQuebra <- 0
dataCustos$CustosEnc <- 0
dataCustos$CustosTotal <- 0
dataCustos$NivelServico <- 0
dataCustos$Avg.StockMedio <- 0
dataCustos$Avg.StockTransito <- 0
dataCustos$Avg.StockTotal <- 0
dataCustos$Avg.Quebras <- 0
dataCustos$Avg.QuebrasReais <- 0
```
```

Figure 108: V2 Current Status Algorithm – Part I

```{r}
#Determining initial and final stocks in week 202240 for each material
j <- 1

for( i in 1:nrow(data) ){
  tabelaPrint$StockInicial[j] <- data$initial_stock[i]
  if(tabelaPrint$StockInicial[j] + tabelaPrint$Chegada.Material.Real[j] + data$initial_lotesQm[i] -
tabelaPrint$ProcuraSemanalReal[j] >= 0){
    tabelaPrint$StockFinal[j] <- tabelaPrint$StockInicial[j] + tabelaPrint$Chegada.Material.Real[j] + data$initial_lotesQm[i]
- tabelaPrint$ProcuraSemanalReal[j]
  } else {
    tabelaPrint$StockFinal[j] <- 0
  }

  #Since information about each material's deliveries is available for the entire simulation period, StockTransito for all 20
weeks can already be calculated

  materials <- unique(tabelaPrint$Material)

  filtro <- subset(tabelaPrint, Material == tabelaPrint$Material[j])

  rec_programadas <- sum(filtro$Chegada.Material)

  for (n in j:(j+20-1)) {
    tabelaPrint$StockTransito[n] <- rec_programadas - sum(tabelaPrint$Chegada.Material.Real[j:n])
  }

  tabelaPrint$StockTotal[j] = tabelaPrint$StockFinal[j] + tabelaPrint$StockTransito[j]

  if(tabelaPrint$StockInicial[j] + tabelaPrint$Chegada.Material[j] + data$initial_lotesQm[i] -
tabelaPrint$ProcuraSemanalReal[j]>=0) {
    tabelaPrint$Quebras[j] <- 0
  }else {
      tabelaPrint$Quebras[j] <- abs(tabelaPrint$StockInicial[j] + tabelaPrint$Chegada.Material.Real[j] +
data$initial_lotesQm[i] - tabelaPrint$ProcuraSemanalReal[j])
  }
  j <- j+20
}
```

```{r}
#Simulating stock evolution during the other 19 weeks

k <- 1
l <- 20

for (i in 1:nrow(data)){
  for (j in k:l) {

    if(j!=k){
      tabelaPrint$StockInicial[j]=tabelaPrint$StockFinal[j-1]
    }

    if(j!=k){
     if(tabelaPrint$StockInicial[j] + tabelaPrint$Chegada.Material.Real[j]
-tabelaPrint$ProcuraSemanalReal[j]-tabelaPrint$Quebras[j-1] >= 0){
       tabelaPrint$StockFinal[j] <- tabelaPrint$StockFinal[j] + (tabelaPrint$StockInicial[j] +
tabelaPrint$Chegada.Material.Real[j] - tabelaPrint$ProcuraSemanalReal[j] - tabelaPrint$Quebras[j-1])
     }

    }

   if(j!=k){

     tabelaPrint$StockTotal[j] = tabelaPrint$StockFinal[j] + tabelaPrint$StockTransito[j]

   }
   if(j!=k){
       if((tabelaPrint$StockInicial[j] + tabelaPrint$Chegada.Material.Real[j])
-(tabelaPrint$ProcuraSemanalReal[j]+tabelaPrint$Quebras[j-1])>=0) {
         tabelaPrint$Quebras[j] <- 0
       }else {
         if(tabelaPrint$StockInicial[j] + tabelaPrint$Chegada.Material.Real[j]>tabelaPrint$ProcuraSemanalReal[j]){
           tabelaPrint$Quebras[j] <- tabelaPrint$Quebras[j-1]-(tabelaPrint$StockInicial[j] +
tabelaPrint$Chegada.Material.Real[j] - tabelaPrint$ProcuraSemanalReal[j])
         }else {
         tabelaPrint$Quebras[j] <- abs(tabelaPrint$StockInicial[j]+
tabelaPrint$Chegada.Material.Real[j]-tabelaPrint$ProcuraSemanalReal[j])+tabelaPrint$Quebras[j-1]
         }
       }
   }

  }

 k <- k+20
 l <- l+20

}

```

Figure 109: V2 Current Status Algorithm – Part II

```
```{r}
#Calculating performance measurements

k <- 1
l <- 20

for (i in 1:nrow(data)){
  for (j in k:l) {
    tabelaPrint$StockMedio[j] <- (tabelaPrint$StockInicial[j] + tabelaPrint$StockFinal[j])/2
    tabelaPrint$C1semanal[j] <- round(tabelaPrint$StockMedio[j] * data$C1[i], digits = 2)

    tabelaPrint$C2[j] <- round(tabelaPrint$Quebras[j] * data$C2[i], digits = 2)

    if(j != k){
      if(tabelaPrint$Quebras[j] > tabelaPrint$Quebras[j-1]){
        tabelaPrint$QuebrasReais[j] <- tabelaPrint$Quebras[j] - tabelaPrint$Quebras[j-1]
      }
    }else{
      if(tabelaPrint$Quebras[j] != 0){
        tabelaPrint$QuebrasReais[j] <- tabelaPrint$Quebras[j]
      }
    }

    if(tabelaPrint$Chegada.Material.Real[j] > 0){
      tabelaPrint$C3[j] <- round(data$Inbound[i]*tabelaPrint$Chegada.Material.Real[j],2)
    }
    if(j==l){

      tabelaPrint$CustoGestaoStock[j] <- round(sum(tabelaPrint$C1semanal[(j-19):j]) + sum(tabelaPrint$C2[(j-19):j]) +
sum(tabelaPrint$C3[(j-19):j]), digits = 2)

      tabelaPrint$NivelServico[j] <-
(1-(sum(tabelaPrint$QuebrasReais[(j-19):j])/sum(tabelaPrint$ProcuraSemanalReal[j:(j-19)])))

      dataCustos$CustosPosse[i] <- sum(tabelaPrint$C1semanal[(j-19):j])
      dataCustos$CustosQuebra[i] <- sum(tabelaPrint$C2[(j-19):j])
      dataCustos$CustosEnc[i] <- sum(tabelaPrint$C3[(j-19):j])
      dataCustos$NivelServico[i] <- tabelaPrint$NivelServico[j]
      dataCustos$CustosTotal[i] <- tabelaPrint$CustoGestaoStock[j]

      dataCustos$Avg.StockMedio[i] <- mean(tabelaPrint$StockMedio[(j-19):j])
      dataCustos$Avg.StockTransito[i] <- mean(tabelaPrint$StockTransito[(j-19):j])
      dataCustos$Avg.StockTotal[i] <- mean(tabelaPrint$StockTotal[(j-19):j])
      dataCustos$Avg.Quebras[i] <- mean(tabelaPrint$Quebras[(j-19):j])
      dataCustos$Avg.QuebrasReais[i] <- mean(tabelaPrint$QuebrasReais[(j-19):j])
    }
  }
  k <- k+20
  l <- l+20
}
dataCustos[nrow(dataCustos) + 1,] <- c("Total", sum(dataCustos$CustosPosse[1:nrow(dataCustos)]),
sum(dataCustos$CustosQuebra[1:nrow(dataCustos)]), sum(dataCustos$CustosEnc[1:nrow(dataCustos)]),
sum(dataCustos$CustosTotal[1:nrow(dataCustos)]), mean(na.omit(dataCustos$NivelServico[1:nrow(dataCustos)])), NA, NA, NA, NA,
NA)

dataCustos$CustosPosse <- as.numeric(dataCustos$CustosPosse)
dataCustos$CustosQuebra <- as.numeric(dataCustos$CustosQuebra)
dataCustos$CustosEnc <- as.numeric(dataCustos$CustosEnc)
dataCustos$CustosTotal <- as.numeric(dataCustos$CustosTotal)
dataCustos$NivelServico <- as.numeric(dataCustos$NivelServico)

dataCustos$Avg.StockMedio <- as.numeric(dataCustos$Avg.StockMedio)
dataCustos$Avg.StockTransito <- as.numeric(dataCustos$Avg.StockTransito)
dataCustos$Avg.StockTotal <- as.numeric(dataCustos$Avg.StockTotal)
dataCustos$Avg.Quebras <- as.numeric(dataCustos$Avg.Quebras)
dataCustos$Avg.QuebrasReais <- as.numeric(dataCustos$Avg.QuebrasReais)

```
```

Figure 110: V2 Current Status Algorithm – Part III

```{r}
#Exporting Files

wb <- loadWorkbook("Simulador_GestãoStocks.xlsx")
addWorksheet(wb,"Simulador_CStatus_v2")
DF <- tabelaPrint
writeData(wb,"Simulador_CStatus_v2",DF)
saveWorkbook(wb,"Simulador_GestãoStocks.xlsx",overwrite = TRUE)

wb <- loadWorkbook("Simulador_GestãoStocks.xlsx")
addWorksheet(wb,"Simulador_CStatus_v2_Custos")
DF <- dataCustos
writeData(wb,"Simulador_CStatus_v2_Custos",DF)
saveWorkbook(wb,"Simulador_GestãoStocks.xlsx",overwrite = TRUE)



write.xlsx(tabelaPrint, "Simulador_CStatus_v2.xlsx", rowNames = FALSE)
write.xlsx(dataCustos, "Simulador_CStatus_v2_Custos.xlsx", rowNames = FALSE)
```

Figure 111: V2 Current Status Algorithm – Part IV

APPENDIX XX – SIMULATOR OF ALL NEW APPROACHES' SCENARIOS

Figures 112 to 116 show the code that allowed to test all the scenarios under the new approaches category.

```
# Import da data
```{r}

# read previously saved file

data <- data.frame(read_excel("dataGestãoStocks99_n_recalculado_Tx.Variação_ST.xlsx"))
data <- data[c(4, 3, 1, 2),]

data2 <- data.frame(read_excel("data2_Procura_GestãoStocks.xlsx"))
data2 <- subset(data2, Material == "101I0000001565" | Material == "104I0000000003" | Material == "101I0000001509" | Material ==
"101I0000001443")

```
```

```
```{r}

#Variable and Table Creation

 data$lead_time_semanas <- ceiling(data$lead_time_semanas)

  data2$Chegada.Material.Real <- 0

  j <- 1

  for (i in 1:nrow(data)) {
    for (n in j:(j+20-1)) {
      data2$Chegada.Material.Real[n] <- round(data2$Chegada.Material[n]*(1-data$Percent.QtdQuebra_Fornec[i]),2)
    }
    j <- j+20
  }

 tabelaPrint <- data2
 tabelaPrint <- tabelaPrint[,c(1,3,6,7,8,9)]
 tabelaPrint <- tabelaPrint[,c(1:3,5,4,6)]

#Preparing the transition between new and old inventory management policies

 for (x in c(0:3)) {

   mat <- tabelaPrint$Material[1+20*x]

   linha_aux <- subset(data, Material == mat)

   LT <- linha_aux$lead_time_semanas

   tabelaPrint$Chegada.Material[((1+20*x)+LT+1):((1+20*x)+20-1)] <- 0
   tabelaPrint$Chegada.Material.Real[((1+20*x)+LT+1):((1+20*x)+20-1)] <- 0

 }
 dataCustos <- data.frame(data[,-(2:26)])
 colnames(dataCustos) <- c("Material")

 tabelaPrint$StockInicial<- 0
 tabelaPrint$StockFinal <- 0
 tabelaPrint$StockFinal_Antecipado <- 0
 tabelaPrint$QuantEnc <- 0
 tabelaPrint$StockTransito <- 0
 tabelaPrint$StockTotal <- 0
 tabelaPrint$Quebras <- 0
 tabelaPrint$StockMedio <- 0
 tabelaPrint$QuebrasReais <- 0
 tabelaPrint$C1semanal <- 0
 tabelaPrint$C2 <- 0
 tabelaPrint$C3 <- 0
 tabelaPrint$CustoGestaoStock <- 0

 tabelaPrint$NivelServico <- 0

 dataCustos$CustosPosse <- 0
 dataCustos$CustosQuebra <- 0
 dataCustos$CustosEnc <- 0
 dataCustos$CustosTotal <- 0
 dataCustos$NivelServico <- 0

```
```

Figure 112: Code used to Test All New Approaches' Scenarios – Part I

```{r}

#Determining initial and final stocks in week 202240 for each material
j <- 1


for( i in 1:nrow(data) ){
  tabelaPrint$StockInicial[j] <- data$initial_stock[i]
  if(tabelaPrint$StockInicial[j] + tabelaPrint$Chegada.Material.Real[j] + data$initial_lotesQm[i] -
tabelaPrint$ProcuraSemanalReal[j] >= 0){
    tabelaPrint$StockFinal[j] <- tabelaPrint$StockInicial[j] + tabelaPrint$Chegada.Material.Real[j] + data$initial_lotesQm[i] -
tabelaPrint$ProcuraSemanalReal[j]
  } else {
    tabelaPrint$StockFinal[j] <- 0
  }


  if(tabelaPrint$StockInicial[j] + tabelaPrint$Chegada.Material.Real[j] + data$initial_lotesQm[i] -
tabelaPrint$ProcuraSemanalReal[j]>=0) {
    tabelaPrint$Quebras[j] <- 0
  }else {
      tabelaPrint$Quebras[j] <- abs(tabelaPrint$StockInicial[j] + tabelaPrint$Chegada.Material.Real[j] + data$initial_lotesQm[i] -
tabelaPrint$ProcuraSemanalReal[j])
  }

  if(data$ST[i] != 0){
    tabelaPrint$StockFinal_Antecipado[j] <- tabelaPrint$StockFinal[j] - sum(tabelaPrint$ResOrd[(j+1):(j+data$ST[i])])
  }else{
    tabelaPrint$StockFinal_Antecipado[j] <- tabelaPrint$StockFinal[j]
  }
  #Deciding the amount of material to order

    if(tabelaPrint$StockFinal_Antecipado[j]<= data$reorder_point[i]){
      if(data$order_up_to_level[i] - (tabelaPrint$StockFinal_Antecipado[j]-tabelaPrint$Quebras[j]) > data$moq[i]){
        if(data$order_multiple == -1 || (data$order_up_to_level[i] -
(tabelaPrint$StockFinal_Antecipado[j]-tabelaPrint$Quebras[j]))%%data$order_multiple[i] == 0){
          tabelaPrint$QuantEnc[j] <- data$order_up_to_level[i] - (tabelaPrint$StockFinal_Antecipado[j]-tabelaPrint$Quebras[j])
        } else {
          quociente <- ceiling((data$order_up_to_level[i] -
(tabelaPrint$StockFinal_Antecipado[j]-tabelaPrint$Quebras[j]))/data$order_multiple[i], 0)
          tabelaPrint$QuantEnc[j] <- abs(quociente * data$order_multiple[i])
        }
      } else {
        quociente <- ceiling(data$moq[i]/abs(data$order_multiple[i]))
        tabelaPrint$QuantEnc[j] <- abs(quociente * data$order_multiple[i])
      }
    } else {
      tabelaPrint$QuantEnc[j] <- 0
    }

  materials <- unique(tabelaPrint$Material)

  filtro <- subset(tabelaPrint, Material == tabelaPrint$Material[j])

  rec_programadas <- sum(filtro$Chegada.Material)

  for (n in j:(j+20-1)) {
    tabelaPrint$StockTransito[n] <- rec_programadas - sum(tabelaPrint$Chegada.Material.Real[j:n])
  }
  if(tabelaPrint$QuantEnc[j]>0){
      v_lt = data$lead_time_semanas[i]
      tabelaPrint$StockFinal[j+v_lt] <- round(tabelaPrint$QuantEnc[j]*(1-data$Percent.QtdQuebra_Fornec[i]),2)
      tabelaPrint$StockTransito[(j+1) : (j+v_lt-1)] <- tabelaPrint$StockTransito[(j+1) : (j+v_lt-1)] + tabelaPrint$QuantEnc[j]
      tabelaPrint$StockTransito[j+v_lt] <- tabelaPrint$StockTransito[j+v_lt-1]-tabelaPrint$StockFinal[j+v_lt]
      tabelaPrint$StockTransito[(j+v_lt+1):(j+20-1)] <- tabelaPrint$StockTransito[(j+v_lt+1):(j+20-1)] + (tabelaPrint$QuantEnc[j]-
tabelaPrint$StockFinal[j+v_lt])
  }


  tabelaPrint$StockTotal[j] = tabelaPrint$StockFinal[j] + tabelaPrint$StockTransito[j]

  j <- j+20
}

```
```

Figure 113: Code used to Test All New Approaches' Scenarios – Part II
```

```{r}
#Simulating stock evolution during the other 19 weeks

v_lt = 0

k <- 1
l <- 20

for (i in 1:nrow(data)){
  # Review Period
  n <- data$n[i]

  for (j in k:l) {
    if(j!=k){
      tabelaPrint$StockInicial[j]=tabelaPrint$StockFinal[j-1]
    }

    if(j!=k){
     if(tabelaPrint$StockInicial[j] + tabelaPrint$Chegada.Material.Real[j]
-tabelaPrint$ProcuraSemanalReal[j]-tabelaPrint$Quebras[j-1] >= 0){
       tabelaPrint$StockFinal[j] <- tabelaPrint$StockFinal[j] + (tabelaPrint$StockInicial[j] +
tabelaPrint$Chegada.Material.Real[j] - tabelaPrint$ProcuraSemanalReal[j] - tabelaPrint$Quebras[j-1])
     }

    }

    if((j+1) < l & (j+data$ST[i]) < l+1 & j!=k){
      if(data$ST[i] != 0){
        tabelaPrint$StockFinal_Antecipado[j] <- tabelaPrint$StockFinal[j] - sum(tabelaPrint$ResOrd[(j+1):(j+data$ST[i])])
      }else{
        tabelaPrint$StockFinal_Antecipado[j] <- tabelaPrint$StockFinal[j]
      }
    }else if(j!=k){
      tabelaPrint$StockFinal_Antecipado[j] <- tabelaPrint$StockFinal[j]
    }
   if(j!=k){
       if((tabelaPrint$StockInicial[j] + tabelaPrint$Chegada.Material.Real[j])
-(tabelaPrint$ProcuraSemanalReal[j]+tabelaPrint$Quebras[j-1])>=0) {
         tabelaPrint$Quebras[j] <- 0
       }else {
         if(tabelaPrint$StockInicial[j] + tabelaPrint$Chegada.Material.Real[j]>tabelaPrint$ProcuraSemanalReal[j]){
           tabelaPrint$Quebras[j] <- tabelaPrint$Quebras[j-1]-(tabelaPrint$StockInicial[j]+
tabelaPrint$Chegada.Material.Real[j]-tabelaPrint$ProcuraSemanalReal[j])
         }else {
         tabelaPrint$Quebras[j] <- abs(tabelaPrint$StockInicial[j]+
tabelaPrint$Chegada.Material.Real[j]-tabelaPrint$ProcuraSemanalReal[j])+tabelaPrint$Quebras[j-1]
         }
       }
   }

  #Deciding the amount of material to order
    ##Checking review period
      if( j == (k+n) || j == (k+n*2) || j == (k+n*3) || j == (k+n*4) || j == (k+n*5) || j == (k+n*6) || j == (k+n*7) || j ==
(k+n*8) || j == (k+n*9) || j == (k+n*10) || j == (k+n*11) || j == (k+n*12) || j == (k+n*13) || j == (k+n*14) || j == (k+n*15) || j
== (k+n*16) || j == (k+n*17) || j == (k+n*18) || j == (k+n*19)){ #no máx faz este ciclo 19 vezes, que é o que acontece qd o LT é
de 1 semana

        if (tabelaPrint$StockFinal_Antecipado[j]<= data$reorder_point[i]){

          if(data$order_up_to_level[i] - (tabelaPrint$StockFinal_Antecipado[j]-tabelaPrint$Quebras[j]) > data$moq[i]){
            if(data$order_multiple == -1 || (data$order_up_to_level[i] -
(tabelaPrint$StockFinal_Antecipado[j]-tabelaPrint$Quebras[j]))%%data$order_multiple[i] == 0){
              tabelaPrint$QuantEnc[j] <- data$order_up_to_level[i] - (tabelaPrint$StockFinal_Antecipado[j]-tabelaPrint$Quebras[j])
            } else {
              quociente <- ceiling((data$order_up_to_level[i] -
(tabelaPrint$StockFinal_Antecipado[j]-tabelaPrint$Quebras[j]))/data$order_multiple[i], 0)
              tabelaPrint$QuantEnc[j] <- quociente * data$order_multiple[i]
            }
          } else {
            quociente <- ceiling(data$moq[i]/data$order_multiple[i])
            tabelaPrint$QuantEnc[j] <- quociente * data$order_multiple[i]
          }
        } else {
          tabelaPrint$QuantEnc[j] <- 0
        }
      }
   if(j!=k){
    if(tabelaPrint$QuantEnc[j]>0){
      v_lt = data$lead_time_semanas[i]
      if (j+v_lt <= l){
        tabelaPrint$StockFinal[j+v_lt] <- round(tabelaPrint$QuantEnc[j]*(1-data$Percent.QtdQuebra_Fornec[i]),2)
        tabelaPrint$StockTransito[(j+1) : (j+v_lt-1)] <- tabelaPrint$StockTransito[(j+1) : (j+v_lt-1)] + tabelaPrint$QuantEnc[j]
        tabelaPrint$StockTransito[j+v_lt] <- tabelaPrint$StockTransito[j+v_lt-1]-tabelaPrint$StockFinal[j+v_lt]
        tabelaPrint$StockTransito[(j+v_lt+1):l] <- tabelaPrint$StockTransito[(j+v_lt+1):l] + (tabelaPrint$QuantEnc[j]-
tabelaPrint$StockFinal[j+v_lt])
      }else{
        tabelaPrint$StockTransito[(j+1) : l] <- tabelaPrint$StockTransito[(j+1) : l] + tabelaPrint$QuantEnc[j]
      }
    }
```

Figure 114: Code used to Test All New Approaches' Scenarios – Part III

```
  line <- j - data$lead_time_semanas[i]+1

  if(line >= 1){
    if(sum(tabelaPrint$QuantEnc[line:j]) == 0 & tabelaPrint$StockTransito[j] != 0){
      tabelaPrint$StockFinal[j+1] <- tabelaPrint$StockTransito[j]
      tabelaPrint$StockTransito[(j+1):l] <- 0
    }
  }

 }

  if(j!=k){

    tabelaPrint$StockTotal[j] = tabelaPrint$StockFinal[j] + tabelaPrint$StockTransito[j]

  }

 }

 k <- k+20
 l <- l+20

}

#Setting negative values of 'StockFinal_Antecipado' equal to 0

for (nn in 1:nrow(tabelaPrint)) {
  if(is.na(tabelaPrint$Material[nn]) == FALSE & tabelaPrint$StockFinal_Antecipado[nn] < 0){
    tabelaPrint$StockFinal_Antecipado[nn] <- 0
  }
}
```

```{r}
#Calculating performance measurements

k <- 1
l <- 20

for (i in 1:nrow(data)){
  for (j in k:l) {
    tabelaPrint$StockMedio[j] <- (tabelaPrint$StockInicial[j] + tabelaPrint$StockFinal[j])/2
    tabelaPrint$C1semanal[j] <- round(tabelaPrint$StockMedio[j] * data$C1[i], digits = 2)

    tabelaPrint$C2[j] <- round(tabelaPrint$Quebras[j] * data$C2[i], digits = 2)

    if(j != k){
      if(tabelaPrint$Quebras[j] > tabelaPrint$Quebras[j-1]){
        tabelaPrint$QuebrasReais[j] <- tabelaPrint$Quebras[j] - tabelaPrint$Quebras[j-1]
      }
    }else{
      if(tabelaPrint$Quebras[j] != 0){
        tabelaPrint$QuebrasReais[j] <- tabelaPrint$Quebras[j]
      }
    }

    if(tabelaPrint$QuantEnc[j] > 0){
      tabelaPrint$C3[j] <- round(data$Inbound[i]*(tabelaPrint$QuantEnc[j]+tabelaPrint$Chegada.Material[j]),2)
    }

    if(j==l){

      tabelaPrint$CustoGestaoStock[j] <- round(sum(tabelaPrint$C1semanal[(j-19):j]) + sum(tabelaPrint$C2[(j-19):j]) +
sum(tabelaPrint$C3[(j-19):j]), digits = 2)

      tabelaPrint$NivelServico[j] <- (1-(sum(tabelaPrint$QuebrasReais[(j-19):j])/sum(tabelaPrint$ProcuraSemanalReal[j:(j-19)])))


      dataCustos$CustosPosse[i] <- sum(tabelaPrint$C1semanal[(j-19):j])
      dataCustos$CustosQuebra[i] <- sum(tabelaPrint$C2[(j-19):j])
      dataCustos$CustosEnc[i] <- sum(tabelaPrint$C3[(j-19):j])
      dataCustos$NivelServico[i] <- tabelaPrint$NivelServico[j]
      dataCustos$CustosTotal[i] <- tabelaPrint$CustoGestaoStock[j]

      dataCustos$Avg.StockMedio[i] <- mean(tabelaPrint$StockMedio[(j-19):j])
      dataCustos$Avg.StockTransito[i] <- mean(tabelaPrint$StockTransito[(j-19):j])
      dataCustos$Avg.StockTotal[i] <- mean(tabelaPrint$StockTotal[(j-19):j])
      dataCustos$Avg.Quebras[i] <- mean(tabelaPrint$Quebras[(j-19):j])
      dataCustos$Avg.QuebrasReais[i] <- mean(tabelaPrint$QuebrasReais[(j-19):j])
    }
  }
  k <- k+20
  l <- l+20
}
```

Figure 115: Code used to Test All New Approaches' Scenarios – Part IV

```r
dataCustos[nrow(dataCustos) + 1,] <- c("Total", sum(dataCustos$CustosPosse[1:nrow(dataCustos)]),
sum(dataCustos$CustosQuebra[1:nrow(dataCustos)]), sum(dataCustos$CustosEnc[1:nrow(dataCustos)]),
sum(dataCustos$CustosTotal[1:nrow(dataCustos)]), mean(na.omit(dataCustos$NivelServico[1:nrow(dataCustos)])), NA, NA, NA, NA, NA)

dataCustos$CustosPosse <- as.numeric(dataCustos$CustosPosse)
dataCustos$CustosQuebra <- as.numeric(dataCustos$CustosQuebra)
dataCustos$CustosEnc <- as.numeric(dataCustos$CustosEnc)
dataCustos$CustosTotal <- as.numeric(dataCustos$CustosTotal)
dataCustos$NivelServico <- as.numeric(dataCustos$NivelServico)

dataCustos$Avg.StockMedio <- as.numeric(dataCustos$Avg.StockMedio)
dataCustos$Avg.StockTransito <- as.numeric(dataCustos$Avg.StockTransito)
dataCustos$Avg.StockTotal <- as.numeric(dataCustos$Avg.StockTotal)
dataCustos$Avg.Quebras <- as.numeric(dataCustos$Avg.Quebras)
dataCustos$Avg.QuebrasReais <- as.numeric(dataCustos$Avg.QuebrasReais)

```

```{r}

#Exporting Files


wb <- loadWorkbook("Simulador_GestãoStocks.xlsx")
addWorksheet(wb,"Simulador_V25")
DF <- tabelaPrint
writeData(wb,"Simulador_V25",DF)
saveWorkbook(wb,"Simulador_GestãoStocks.xlsx",overwrite = TRUE)

wb <- loadWorkbook("Simulador_GestãoStocks_Custos.xlsx")
addWorksheet(wb,"Simulador_V25")
DF <- dataCustos
writeData(wb,"Simulador_V25",DF)
saveWorkbook(wb,"Simulador_GestãoStocks_Custos.xlsx",overwrite = TRUE)



write.xlsx(tabelaPrint, "Simulador_V25.xlsx", rowNames = FALSE)
write.xlsx(dataCustos, "Simulador_V25_Custos.xlsx", rowNames = FALSE)
```
```

Figure 116: Code used to Test All New Approaches' Scenarios – Part V
```

APPENDIX XXI – EACH MATERIAL'S BEHAVIOUR DURING THE TWENTY WEEKS OF SIMULATION

Tables 40 to 44 detail each material's behaviour during the twenty weeks of simulation for the scenarios that achieved top performance. In the case of material '101I0000001443' both V2 and V7 scenarios are displayed.

Table 40: Behaviour of Material '101I0000001509' During the Twenty Weeks of Simulation – Scenario V13

Material	Seman	Procura Semanal Re	ResOr	Chegada Material	Chegada Material Rea	Stock Inici	Stock Fina	StockFinal Antecipado	QuantE	Stock Trans	Stock Tot	Quebr	Stock Medi	Quebras Reai	C1 seman	C2	C3	Custo Gestao Stock	Nivel Servi
101I0000001509	202244	560,06	299,85	0	0	2455,99	1895,93	1556,52	9290,48	1499,79	3395,72	0	2175,96	0	254,79 €	0,00 €	4 870,59 €	0,00 €	0
101I0000001509	202245	466,62	339,41	0	0	1895,93	1429,31	1409,65	0,00	10790,27	12219,58	0	1662,62	0	194,68 €	0,00 €	0,00 €	0,00 €	0
101I0000001509	202246	29,57	19,66	500,00	474,85	1429,31	1874,59	1537,13	0,00	10315,42	12190,02	0	1651,95	0	193,43 €	0,00 €	0,00 €	0,00 €	0
101I0000001509	202247	377,12	337,46	999,79	949,50	1874,59	2446,97	1834,96	0,00	9365,92	11812,90	0	2160,78	0	253,01 €	0,00 €	0,00 €	0,00 €	0
101I0000001509	202248	629,78	612,01	0	0	2446,97	1817,19	1681,91	9165,09	9365,92	11183,11	0	2132,08	0	249,65 €	0,00 €	4 804,85 €	0,00 €	0
101I0000001509	202249	295,51	135,28	0	0	1817,19	1521,69	1014,39	0,00	18531,01	20052,70	0	1669,44	0	195,48 €	0,00 €	0,00 €	0,00 €	0
101I0000001509	202250	515,01	507,30	0	0	1521,69	1006,68	1006,68	0,00	18531,01	19537,69	0	1264,18	0	148,03 €	0,00 €	0,00 €	0,00 €	0
101I0000001509	202251	7,71	0,00	0	0	1006,68	998,96	998,96	0,00	18531,01	19529,97	0	1002,82	0	117,42 €	0,00 €	0,00 €	0,00 €	0
101I0000001509	202252	233,88	0,00	0	0	998,96	9588,26	9096,83	1750,17	9707,84	19296,10	0	5293,61	0	619,84 €	0,00 €	917,54 €	0,00 €	0
101I0000001509	202301	503,95	491,43	0	0	9588,26	9084,31	8655,25	0,00	11458,01	20542,32	0	9336,28	0	1 093,21 €	0,00 €	0,00 €	0,00 €	0
101I0000001509	202302	928,22	429,06	0	0	9084,31	8156,09	7629,69	0,00	11458,01	19614,10	0	8620,20	0	1 009,36 €	0,00 €	0,00 €	0,00 €	0
101I0000001509	202303	535,22	526,40	0	0	8156,09	7620,87	6588,84	0,00	11458,01	19078,89	0	7888,48	0	923,68 €	0,00 €	0,00 €	0,00 €	0
101I0000001509	202304	1063,31	1032,04	0	0	7620,87	15261,64	14639,61	0,00	2753,93	18015,58	0	11441,26	0	1 339,68 €	0,00 €	0,00 €	0,00 €	0
101I0000001509	202305	760,02	622,04	0	0	15261,64	14501,62	13462,37	0,00	2753,93	17255,55	0	14881,63	0	1 742,52 €	0,00 €	0,00 €	0,00 €	0
101I0000001509	202306	1105,48	1039,25	0	0	14501,62	13396,15	12523,19	0,00	2753,93	16150,08	0	13948,88	0	1 633,31 €	0,00 €	0,00 €	0,00 €	0
101I0000001509	202307	932,82	872,95	0	0	13396,15	12463,32	11089,81	0,00	2753,93	15217,25	0	12929,73	0	1 513,97 €	0,00 €	0,00 €	0,00 €	0
101I0000001509	202308	1444,71	1373,51	0	0	12463,32	12680,75	11432,56	0,00	1091,79	13772,54	0	12572,04	0	1 472,09 €	0,00 €	0,00 €	0,00 €	0
101I0000001509	202309	1404,11	1248,19	0	0	12680,75	12368,43	11217,66	0,00	0,00	12368,43	0	12524,59	0	1 466,53 €	0,00 €	0,00 €	0,00 €	0
101I0000001509	202310	1216,28	1150,77	0	0	12368,43	11152,15	11152,15	0,00	0,00	11152,15	0	11760,29	0	1 377,04 €	0,00 €	0,00 €	0,00 €	0
101I0000001509	202311	1821,54	1538,61	0	0	11152,15	9330,61	9330,61	0,00	0,00	9330,61	0	10241,38	0	1 199,19 €	0,00 €	0,00 €	27 589,89 €	1

Table 41: Behaviour of Material ‘101I0000001565’ During the Twenty Weeks of Simulation – Scenario V7

Material	Semar	Procura Semanal Re	ResOrd	Chegada Materia	Chegada Material Re	Stock Inic	Stock Fin	StockFinal Antecipa	QuantE	Stock Transito	Stock Tot	Quebr	Stock Medi	Quebras Reais	C1 seman	C2	C3	Custo Gestao Stock	Nivel Serv
101I0000001565	202244	965,33	914,51	0	0	1828,79	863,46	0,00	7054,86	1499,79	2363,25	0,00	1346,13	0,00	151,78 €	0,00 €	4 178,41 €	0,00 €	0
101I0000001565	202245	961,12	923,32	0	0	863,46	0,00	0,00	0,00	8554,65	8554,65	97,65	431,73	97,65	48,68 €	3 881,75 €	0,00 €	0,00 €	0
101I0000001565	202246	1108,34	878,38	500,00	499,95	0,00	0,00	0,00	8283,33	8054,70	8054,70	706,04	0,00	608,39	0,00 €	28 065,21 €	5 202,15 €	0,00 €	0
101I0000001565	202247	860,28	582,29	999,79	999,69	0,00	0,00	0,00	0,00	15338,34	15338,34	566,64	0,00	0,00	0,00 €	22 523,82 €	0,00 €	0,00 €	0
101I0000001565	202248	1200,55	831,86	0	0	0,00	7054,15	5899,85	0,00	8284,19	15338,34	1767,18	3527,08	1200,55	397,69 €	70 245,56 €	0,00 €	0,00 €	0
101I0000001565	202249	1405,18	1154,30	0	0	7054,15	3881,79	2735,43	0,00	8284,19	12165,98	0,00	5467,97	0,00	616,53 €	0,00 €	0,00 €	0,00 €	0
101I0000001565	202250	1391,50	1146,36	0	0	3881,79	10772,79	10772,79	0,00	1,69	10774,48	0,00	7327,29	0,00	826,17 €	0,00 €	0,00 €	0,00 €	0
101I0000001565	202251	7,94	0,00	0	0	10772,79	10766,54	10766,54	0,00	0,00	10766,54	0,00	10769,67	0,00	1 214,31 €	0,00 €	0,00 €	0,00 €	0
101I0000001565	202252	1481,49	0,00	0	0	10766,54	9285,05	8648,93	0,00	0,00	9285,05	0,00	10025,80	0,00	1 130,43 €	0,00 €	0,00 €	0,00 €	0
101I0000001565	202301	1233,76	636,12	0	0	9285,05	8051,29	7198,38	0,00	0,00	8051,29	0,00	8668,17	0,00	977,36 €	0,00 €	0,00 €	0,00 €	0
101I0000001565	202302	1104,90	852,91	0	0	8051,29	6946,39	6029,58	0,00	0,00	6946,39	0,00	7498,84	0,00	845,51 €	0,00 €	0,00 €	0,00 €	0
101I0000001565	202303	1155,35	916,81	0	0	6946,39	5791,04	5185,91	0,00	0,00	5791,04	0,00	6368,71	0,00	718,09 €	0,00 €	0,00 €	0,00 €	0
101I0000001565	202304	992,50	605,13	0	0	5791,04	4798,54	3958,50	3036,50	0,00	4798,54	0,00	5294,79	0,00	597,00 €	0,00 €	1 798,44 €	0,00 €	0
101I0000001565	202305	1116,03	840,04	0	0	4798,54	3682,52	2859,25	0,00	3036,50	6719,02	0,00	4240,53	0,00	478,13 €	0,00 €	0,00 €	0,00 €	0
101I0000001565	202306	1263,06	823,27	0	0	3682,52	2419,45	1570,13	5424,87	3036,50	5455,95	0,00	3050,98	0,00	344,01 €	0,00 €	3 213,01 €	0,00 €	0
101I0000001565	202307	1170,77	849,32	0	0	2419,45	1248,69	464,65	0,00	8461,37	9710,05	0,00	1834,07	0,00	206,80 €	0,00 €	0,00 €	0,00 €	0
101I0000001565	202308	1052,85	784,04	0	0	1248,69	3232,03	2350,37	4644,63	5425,17	8657,20	0,00	2240,36	0,00	252,61 €	0,00 €	2 750,90 €	0,00 €	0
101I0000001565	202309	1116,74	881,66	0	0	3232,03	2115,29	1276,47	0,00	10069,79	12185,08	0,00	2673,66	0,00	301,46 €	0,00 €	0,00 €	0,00 €	0
101I0000001565	202310	1227,88	838,82	0	0	2115,29	6311,73	6311,73	0,00	4645,47	10957,21	0,00	4213,51	0,00	475,08 €	0,00 €	0,00 €	0,00 €	0
101I0000001565	202311	1162,50	747,02	0	0	6311,73	5149,23	5149,23	0,00	4645,47	9794,70	0,00	5730,48	0,00	646,13 €	0,00 €	0,00 €	152 087,02 €	0,9133

Table 42: Behaviour of Material ‘104I0000000003’ During the Twenty Weeks of Simulation – Scenario V7

Material	Semar	Procura Semanal Re	ResOrd	Chegada Materia	Chegada Material Re	Stock Inic	Stock Fin	StockFinal Antecipa	QuantE	Stock Transito	Stock Tot	Quebr	Stock Medi	Quebras Reais	C1 seman	C2	C3	Custo Gestao Stock	Nivel Serv
104I0000000003	202244	156,43	146,66	0	0	151,56	0,00	0,00	2194,79	0,00	0,00	4,87	75,78	4,87	11,42 €	258,54 €	2 646,53 €	0,00 €	0
104I0000000003	202245	160,87	154,65	0	0	0,00	0,00	0,00	0,00	2194,79	2194,79	165,74	0,00	160,87	0,00 €	8 804,06 €	0,00 €	0,00 €	0
104I0000000003	202246	184,11	140,27	0	0	0,00	0,00	0,00	2481,07	2194,79	2194,79	349,85	0,00	184,11	0,00 €	18 584,19 €	2 991,74 €	0,00 €	0
104I0000000003	202247	126,93	85,30	0	0	0,00	0,00	0,00	0,00	4675,86	4675,86	476,78	0,00	126,93	0,00 €	25 326,77 €	0,00 €	0,00 €	0
104I0000000003	202248	217,32	150,92	0	0	0,00	0,00	0,00	2953,17	4675,86	4675,86	694,11	0,00	217,32	0,00 €	36 870,91 €	3 561,00 €	0,00 €	0
104I0000000003	202249	249,54	182,84	0	0	0,00	0,00	0,00	0,00	7629,03	7629,03	943,65	0,00	249,54	0,00 €	50 126,63 €	0,00 €	0,00 €	0
104I0000000003	202250	220,03	181,23	0	0	0,00	0,00	0,00	3058,68	7629,03	7629,03	1163,68	0,00	220,03	0,00 €	61 814,47 €	3 688,22 €	0,00 €	0
104I0000000003	202251	1,31	0,00	0	0	0,00	0,00	0,00	0,00	10687,71	10687,71	1164,99	0,00	1,31	0,00 €	61 884,00 €	0,00 €	0,00 €	0
104I0000000003	202252	247,67	0,00	0	0	0,00	2175,25	1873,23	0,00	8512,46	10687,71	1412,66	1087,63	247,67	163,88 €	75 040,39 €	0,00 €	0,00 €	0
104I0000000003	202301	258,86	145,91	0	0	2175,25	503,73	173,03	0,00	8512,46	9016,19	0,00	1339,49	0,00	201,83 €	0,00 €	0,00 €	0,00 €	0
104I0000000003	202302	195,16	156,10	0	0	503,73	2767,56	2476,83	0,00	6053,47	8821,02	0,00	1635,64	0,00	246,45 €	0,00 €	0,00 €	0,00 €	0
104I0000000003	202303	213,87	174,59	0	0	2767,56	2553,69	2281,05	0,00	6053,47	8607,16	0,00	2660,62	0,00	400,89 €	0,00 €	0,00 €	0,00 €	0
104I0000000003	202304	183,10	116,13	0	0	2553,69	5297,48	4981,25	0,00	3126,58	8424,06	0,00	3925,59	0,00	591,50 €	0,00 €	0,00 €	0,00 €	0
104I0000000003	202305	203,94	156,51	0	0	5297,48	5093,55	4775,58	0,00	3126,58	8220,12	0,00	5195,51	0,00	782,84 €	0,00 €	0,00 €	0,00 €	0
104I0000000003	202306	235,87	159,72	0	0	5093,55	7889,13	7570,86	0,00	95,13	7984,25	0,00	6491,34	0,00	978,09 €	0,00 €	0,00 €	0,00 €	0
104I0000000003	202307	220,89	158,25	0	0	7889,13	7763,36	7443,10	0,00	0,00	7763,36	0,00	7826,24	0,00	1 179,23 €	0,00 €	0,00 €	0,00 €	0
104I0000000003	202308	205,64	160,02	0	0	7763,36	7557,72	7232,93	0,00	0,00	7557,72	0,00	7660,54	0,00	1 154,27 €	0,00 €	0,00 €	0,00 €	0
104I0000000003	202309	195,97	160,24	0	0	7557,72	7361,75	7063,89	0,00	0,00	7361,75	0,00	7459,74	0,00	1 124,01 €	0,00 €	0,00 €	0,00 €	0
104I0000000003	202310	239,72	164,56	0	0	7361,75	7122,03	7122,03	0,00	0,00	7122,03	0,00	7241,89	0,00	1 091,19 €	0,00 €	0,00 €	0,00 €	0
104I0000000003	202311	198,80	133,31	0	0	7122,03	6923,23	6923,23	0,00	0,00	6923,23	0,00	7022,63	0,00	1 058,15 €	0,00 €	0,00 €	360 581,20 €	0,6393

Table 43: Behaviour of Material ‘101I0000001443’ During the Twenty Weeks of Simulation – Scenario V2

Material	Seman	Procura Semanal Rea	Chegada Material	Chegada Material Re	Stock Inici	Stock Fina	Stock Transito	Stock Tota	Quebras	Stock Med	Quebras Reais	C1 seman	C2	C3	Custo Gestao Stock	Nivel Servi
101I0000001443	202244	1322,05	0,00	0,00	1207,83	0,00	41863,90	41863,90	114,22	603,92	114,22	67,72 €	4 515,00 €	0,00 €	0,00 €	0
101I0000001443	202245	431,18	451,33	402,00	0,00	0,00	41461,90	41461,90	143,39	0,00	29,18	0,00 €	5 668,36 €	233,60 €	0,00 €	0
101I0000001443	202246	1794,21	3519,11	3134,47	0,00	1196,86	38327,43	39524,29	0,00	598,43	0,00	67,10 €	0,00 €	1 821,41 €	0,00 €	0
101I0000001443	202247	47,19	2598,23	2314,24	1196,86	3463,92	36013,19	39477,11	0,00	2330,39	0,00	261,30 €	0,00 €	1 344,78 €	0,00 €	0
101I0000001443	202248	691,12	0,00	0,00	3463,92	2772,80	36013,19	38785,99	0,00	3118,36	0,00	349,66 €	0,00 €	0,00 €	0,00 €	0
101I0000001443	202249	622,93	0,00	0,00	2772,80	2149,86	36013,19	38163,05	0,00	2461,33	0,00	275,98 €	0,00 €	0,00 €	0,00 €	0
101I0000001443	202250	1056,18	4012,74	3574,15	2149,86	4667,84	32439,04	37106,88	0,00	3408,85	0,00	382,23 €	0,00 €	2 076,91 €	0,00 €	0
101I0000001443	202251	8,25	0,00	0,00	4667,84	4659,59	32439,04	37098,63	0,00	4663,71	0,00	522,93 €	0,00 €	0,00 €	0,00 €	0
101I0000001443	202252	423,27	0,00	0,00	4659,59	4236,32	32439,04	36675,36	0,00	4447,95	0,00	498,74 €	0,00 €	0,00 €	0,00 €	0
101I0000001443	202301	1215,90	0,00	0,00	4236,32	3020,42	32439,04	35459,46	0,00	3628,37	0,00	406,84 €	0,00 €	0,00 €	0,00 €	0
101I0000001443	202302	1146,74	4109,45	3660,29	3020,42	5533,97	28778,75	34312,72	0,00	4277,20	0,00	479,60 €	0,00 €	2 126,96 €	0,00 €	0
101I0000001443	202303	1304,77	2090,71	1862,20	5533,97	6091,41	26916,55	33007,96	0,00	5812,69	0,00	651,77 €	0,00 €	1 082,11 €	0,00 €	0
101I0000001443	202304	1118,35	2508,18	2234,04	6091,41	7207,10	24682,51	31889,61	0,00	6649,25	0,00	745,57 €	0,00 €	1 298,18 €	0,00 €	0
101I0000001443	202305	2746,07	3503,46	3120,53	7207,10	7581,55	21561,98	29143,53	0,00	7394,32	0,00	829,11 €	0,00 €	1 813,31 €	0,00 €	0
101I0000001443	202306	1689,36	3811,01	3394,47	7581,55	9286,66	18167,51	27454,17	0,00	8434,11	0,00	945,70 €	0,00 €	1 972,50 €	0,00 €	0
101I0000001443	202307	1854,63	2896,26	2579,70	9286,66	10011,73	15587,81	25599,54	0,00	9649,20	0,00	1 081,95 €	0,00 €	1 499,04 €	0,00 €	0
101I0000001443	202308	1521,58	2653,23	2363,23	10011,73	10853,38	13224,58	24077,96	0,00	10432,56	0,00	1 169,79 €	0,00 €	1 373,25 €	0,00 €	0
101I0000001443	202309	1481,48	3664,25	3263,75	10853,38	12635,65	9960,83	22596,48	0,00	11744,52	0,00	1 316,89 €	0,00 €	1 896,54 €	0,00 €	0
101I0000001443	202310	2708,91	2789,67	2484,76	12635,65	12411,50	7476,07	19887,57	0,00	12523,57	0,00	1 404,25 €	0,00 €	1 443,87 €	0,00 €	0
101I0000001443	202311	2681,40	3256,27	2900,36	12411,50	12630,46	4575,71	17206,17	0,00	12520,98	0,00	1 403,96 €	0,00 €	1 685,37 €	44 712,28 €	0,9945

Table 44: Behaviour of Material ‘101I0000001443’ During the Twenty Weeks of Simulation – Scenario V7

Material	Semar	Procura Semanal Re	ResOrd	Chegada Materia	Chegada Material Re	Stock Inic	Stock Fin	StockFinal Antecipa	QuantE	Stock Transito	Stock Tot	Quebr	Stock Medi	Quebras Reais	C1 seman	C2	C3	Custo Gestao Stock	Nivel Serv
101I0000001443	202244	1322,05	1222,48	0	0	1207,83	0,00	0,00	19497,95	10581,41	10581,41	114,22	603,92	114,22	67,72 €	4 515,00 €	11 330,08 €	0,00 €	0
101I0000001443	202245	431,18	413,73	451,33	402,00	0,00	0,00	0,00	0,00	29677,36	29677,36	143,39	0,00	29,18	0,00 €	5 668,36 €	0,00 €	0,00 €	0
101I0000001443	202246	1794,21	1744,72	3519,11	3134,47	0,00	1196,86	1170,25	17799,75	26542,89	27739,75	0,00	598,43	0,00	67,10 €	0,00 €	12 388,20 €	0,00 €	0
101I0000001443	202247	47,19	26,62	2598,23	2314,24	1196,86	3463,92	3395,69	0,00	42028,40	45492,32	0,00	2330,39	0,00	261,30 €	0,00 €	0,00 €	0,00 €	0
101I0000001443	202248	691,12	68,23	0	0	3463,92	2772,80	2151,07	16818,93	42028,40	44801,20	0,00	3118,36	0,00	349,66 €	0,00 €	9 773,33 €	0,00 €	0
101I0000001443	202249	622,93	621,72	0	0	2772,80	2149,86	1100,72	0,00	58847,33	60997,19	0,00	2461,33	0,00	275,98 €	0,00 €	0,00 €	0,00 €	0
101I0000001443	202250	1056,18	1049,14	4012,74	3574,15	2149,86	4667,84	4660,80	14309,20	55273,18	59941,01	0,00	3408,85	0,00	382,23 €	0,00 €	10 646,71 €	0,00 €	0
101I0000001443	202251	8,25	7,04	0	0	4667,84	22026,41	22026,41	0,00	52215,56	74241,97	0,00	13347,12	0,00	1 496,59 €	0,00 €	0,00 €	0,00 €	0
101I0000001443	202252	423,27	0,00	0	0	22026,41	21603,14	20553,17	0,00	52215,56	73818,69	0,00	21814,77	0,00	2 446,06 €	0,00 €	0,00 €	0,00 €	0
101I0000001443	202301	1215,90	1049,97	0	0	21603,14	36241,48	35195,02	0,00	36361,32	72602,80	0,00	28922,31	0,00	3 243,01 €	0,00 €	0,00 €	0,00 €	0
101I0000001443	202302	1146,74	1046,46	0	0	36241,48	35094,74	33842,34	0,00	36361,32	71456,06	0,00	35668,11	0,00	3 999,41 €	0,00 €	0,00 €	0,00 €	0
101I0000001443	202303	1304,77	1252,41	0	0	35094,74	48770,60	47848,47	0,00	21380,70	70151,29	0,00	41932,67	0,00	4 701,84 €	0,00 €	0,00 €	0,00 €	0
101I0000001443	202304	1118,35	922,13	0	0	48770,60	47652,25	44928,61	0,00	21380,70	69032,94	0,00	48211,42	0,00	5 405,87 €	0,00 €	0,00 €	0,00 €	0
101I0000001443	202305	2746,07	2723,63	0	0	47652,25	57651,37	56400,49	0,00	8635,50	66286,87	0,00	52651,81	0,00	5 903,76 €	0,00 €	0,00 €	0,00 €	0
101I0000001443	202306	1689,36	1250,89	0	0	57651,37	64597,51	62911,58	0,00	0,00	64597,51	0,00	61124,44	0,00	6 853,78 €	0,00 €	0,00 €	0,00 €	0
101I0000001443	202307	1854,63	1685,93	0	0	64597,51	62742,88	61440,88	0,00	0,00	62742,88	0,00	63670,19	0,00	7 139,23 €	0,00 €	0,00 €	0,00 €	0
101I0000001443	202308	1521,58	1302,00	0	0	62742,88	61221,30	59739,81	0,00	0,00	61221,30	0,00	61982,09	0,00	6 949,95 €	0,00 €	0,00 €	0,00 €	0
101I0000001443	202309	1481,48	1481,48	0	0	61221,30	59739,81	57231,06	0,00	0,00	59739,81	0,00	60480,56	0,00	6 781,59 €	0,00 €	0,00 €	0,00 €	0
101I0000001443	202310	2708,91	2508,75	0	0	59739,81	57030,90	57030,90	0,00	0,00	57030,90	0,00	58385,36	0,00	6 546,65 €	0,00 €	0,00 €	0,00 €	0
101I0000001443	202311	2681,40	2598,15	0	0	57030,90	54349,51	54349,51	0,00	0,00	54349,51	0,00	55690,20	0,00	6 244,45 €	0,00 €	0,00 €	123 437,86 €	0,9945

APPENDIX XXII – EACH MATERIAL'S BEHAVIOUR DURING THE TWENTY WEEKS OF SIMULATION (SENSITIVITY ANALYSIS)

Tables 45 to 48 detail each material's behaviour during the twenty weeks of simulation for the scenarios that achieved top performance in the sensitivity analysis. In the case of material '101I0000001443' only V7_C1_10_C3_dobro scenario is displayed since the V2 scenario behaves the same to the original analysis.

Table 45: Behaviour of Material '101I0000001509' During the Twenty Weeks of Simulation – Scenario V13_C1_20

Material	Semana	Procura Semanal Re	ResOrd	Chegada Materia	Chegada Material Re	StockInic	StockFin	StockFinal Antecipa	QuantEr	Stock Transito	Stock Tot	Quebra	Stock Me	Quebras Reais	C1 semar	C2	C3	Custo Gestao Stock	Nivel Servico
101I0000001509	202244	560,06	299,85	0	0	2455,99	1895,93	1556,52	8837,48	1499,79	3395,72	0	2175,96	0	345,48 €	0,00 €	4 633,10 €	0,00 €	0
101I0000001509	202245	466,62	339,41	0	0	1895,93	1429,31	1409,65	0,00	10337,27	11766,58	0	1662,62	0	263,97 €	0,00 €	0,00 €	0,00 €	0
101I0000001509	202246	29,57	19,66	500,00	474,85	1429,31	1874,59	1537,13	0,00	9862,42	11737,02	0	1651,95	0	262,28 €	0,00 €	0,00 €	0,00 €	0
101I0000001509	202247	377,12	337,46	999,79	949,50	1874,59	2446,97	1834,96	0,00	8912,92	11359,90	0	2160,78	0	343,07 €	0,00 €	0,00 €	0,00 €	0
101I0000001509	202248	629,78	612,01	0	0	2446,97	1817,19	1681,91	8712,09	8912,92	10730,11	0	2132,08	0	338,51 €	0,00 €	4 567,36 €	0,00 €	0
101I0000001509	202249	295,51	135,28	0	0	1817,19	1521,69	1014,39	0,00	17625,01	19146,70	0	1669,44	0	265,06 €	0,00 €	0,00 €	0,00 €	0
101I0000001509	202250	515,01	507,30	0	0	1521,69	1006,68	1006,68	0,00	17625,01	18631,69	0	1264,18	0	200,71 €	0,00 €	0,00 €	0,00 €	0
101I0000001509	202251	7,71	0,00	0	0	1006,68	998,96	998,96	0,00	17625,01	18623,97	0	1002,82	0	159,22 €	0,00 €	0,00 €	0,00 €	0
101I0000001509	202252	233,88	0,00	0	0	998,96	9158,05	8666,62	1727,38	9232,05	18390,10	0	5078,51	0	806,31 €	0,00 €	905,59 €	0,00 €	0
101I0000001509	202301	503,95	491,43	0	0	9158,05	8654,10	8225,04	0,00	10959,43	19613,53	0	8906,07	0	1 414,01 €	0,00 €	0,00 €	0,00 €	0
101I0000001509	202302	928,22	429,06	0	0	8654,10	7725,88	7199,48	0,00	10959,43	18685,31	0	8189,99	0	1 300,32 €	0,00 €	0,00 €	0,00 €	0
101I0000001509	202303	535,22	526,40	0	0	7725,88	7190,66	6158,63	0,00	10959,43	18150,10	0	7458,27	0	1 184,14 €	0,00 €	0,00 €	0,00 €	0
101I0000001509	202304	1063,31	1032,04	0	0	7190,66	14401,22	13779,19	0,00	2685,56	17086,79	0	10795,94	0	1 714,06 €	0,00 €	0,00 €	0,00 €	0
101I0000001509	202305	760,02	622,04	0	0	14401,22	13641,20	12601,95	0,00	2685,56	16326,76	0	14021,21	0	2 226,14 €	0,00 €	0,00 €	0,00 €	0
101I0000001509	202306	1105,48	1039,25	0	0	13641,20	12535,73	11662,77	0,00	2685,56	15221,29	0	13088,46	0	2 078,05 €	0,00 €	0,00 €	0,00 €	0
101I0000001509	202307	932,82	872,95	0	0	12535,73	11602,90	10229,39	0,00	2685,56	14288,46	0	12069,31	0	1 916,24 €	0,00 €	0,00 €	0,00 €	0
101I0000001509	202308	1444,71	1373,51	0	0	11602,90	11798,69	10550,50	0,00	1045,06	12843,75	0	11700,80	0	1 857,73 €	0,00 €	0,00 €	0,00 €	0
101I0000001509	202309	1404,11	1248,19	0	0	11798,69	11439,64	10288,87	0,00	0,00	11439,64	0	11619,16	0	1 844,77 €	0,00 €	0,00 €	0,00 €	0
101I0000001509	202310	1216,28	1150,77	0	0	11439,64	10223,36	10223,36	0,00	0,00	10223,36	0	10831,50	0	1 719,71 €	0,00 €	0,00 €	0,00 €	0
101I0000001509	202311	1821,54	1538,61	0	0	10223,36	8401,82	8401,82	0,00	0,00	8401,82	0	9312,59	0	1 478,55 €	0,00 €	0,00 €	31 824,38 €	1

Table 46: Behaviour of Material ‘101I0000001565’ During the Twenty Weeks of Simulation – Scenario V19_C1_10_C3_dobro

Material	Semana	Procura Semanal Re	ResOrd	Chegada Materia	Chegada Material Re	Stock Inic	Stock Fin	StockFinal Antecipa	QuantEn	Stock Transit	Stock Tot	Quebra	Stock Med	Quebras Reais	C1 seman	C2	C3	Custo Gestao Stock	Nivel Servic
101I0000001565	202244	965,33	914,51	0	0	1828,79	863,46	0,00	10530,24	1499,79	2363,25	0,00	1346,13	0,00	102,90 €	0,00 €	6 236,80 €	0,00 €	0
101I0000001565	202245	961,12	923,32	0	0	863,46	0,00	0,00	0,00	12030,03	12030,03	97,65	431,73	97,65	33,00 €	3 881,75 €	0,00 €	0,00 €	0
101I0000001565	202246	1108,34	878,38	500,00	499,95	0,00	0,00	0,00	0,00	11530,08	11530,08	706,04	0,00	608,39	0,00 €	28 065,21 €	0,00 €	0,00 €	0
101I0000001565	202247	860,28	582,29	999,79	999,69	0,00	0,00	0,00	0,00	10530,39	10530,39	566,64	0,00	0,00	0,00 €	22 523,82 €	0,00 €	0,00 €	0
101I0000001565	202248	1200,55	831,86	0	0	0,00	10529,19	8228,52	0,00	1,20	10530,39	1767,18	5264,60	1200,55	402,44 €	70 245,56 €	0,00 €	0,00 €	0
101I0000001565	202249	1405,18	1154,30	0	0	10529,19	7358,03	6211,67	0,00	0,00	7358,03	0,00	8943,61	0,00	683,67 €	0,00 €	0,00 €	0,00 €	0
101I0000001565	202250	1391,50	1146,36	0	0	7358,03	5966,53	5966,53	0,00	0,00	5966,53	0,00	6662,28	0,00	509,28 €	0,00 €	0,00 €	0,00 €	0
101I0000001565	202251	7,94	0,00	0	0	5966,53	5958,60	5322,48	0,00	0,00	5958,60	0,00	5962,57	0,00	455,79 €	0,00 €	0,00 €	0,00 €	0
101I0000001565	202252	1481,49	0,00	0	0	5958,60	4477,11	2988,07	6603,93	0,00	4477,11	0,00	5217,85	0,00	398,86 €	0,00 €	3 911,34 €	0,00 €	0
101I0000001565	202301	1233,76	636,12	0	0	4477,11	3243,35	1473,62	0,00	6603,93	9847,28	0,00	3860,23	0,00	295,08 €	0,00 €	0,00 €	0,00 €	0
101I0000001565	202302	1104,90	852,91	0	0	3243,35	2138,45	616,50	0,00	6603,93	8742,38	0,00	2690,90	0,00	205,70 €	0,00 €	0,00 €	0,00 €	0
101I0000001565	202303	1155,35	916,81	0	0	2138,45	983,09	0,00	0,00	6603,93	7587,02	0,00	1560,77	0,00	119,31 €	0,00 €	0,00 €	0,00 €	0
101I0000001565	202304	992,50	605,13	0	0	983,09	6603,27	4939,96	4661,44	0,66	6603,93	9,41	3793,18	9,41	289,96 €	373,85 €	2 760,86 €	0,00 €	0
101I0000001565	202305	1116,03	840,04	0	0	6603,27	5477,84	3805,25	0,00	4662,10	10139,94	0,00	6040,55	0,00	461,75 €	0,00 €	0,00 €	0,00 €	0
101I0000001565	202306	1263,06	823,27	0	0	5477,84	4214,78	2581,42	0,00	4662,10	8876,88	0,00	4846,31	0,00	370,46 €	0,00 €	0,00 €	0,00 €	0
101I0000001565	202307	1170,77	849,32	0	0	4214,78	3044,01	1378,32	0,00	4662,10	7706,11	0,00	3629,39	0,00	277,44 €	0,00 €	0,00 €	0,00 €	0
101I0000001565	202308	1052,85	784,04	0	0	3044,01	6652,14	4931,66	4660,34	1,12	6653,26	0,00	4848,07	0,00	370,60 €	0,00 €	2 760,20 €	0,00 €	0
101I0000001565	202309	1116,74	881,66	0	0	6652,14	5535,39	3949,56	0,00	4661,46	10196,86	0,00	6093,77	0,00	465,82 €	0,00 €	0,00 €	0,00 €	0
101I0000001565	202310	1227,88	838,82	0	0	5535,39	4307,52	4307,52	0,00	4661,46	8968,98	0,00	4921,46	0,00	376,21 €	0,00 €	0,00 €	0,00 €	0
101I0000001565	202311	1162,50	747,02	0	0	4307,52	3145,02	3145,02	0,00	4661,46	7806,48	0,00	3726,27	0,00	284,84 €	0,00 €	0,00 €	146 862,50 €	0,9128

Table 47: Behaviour of Material ‘104I0000000003’ During the Twenty Weeks of Simulation – Scenario V7_C1_10_C3_dobro

Material	Semana	Procura Semanal Re	ResOrd	Chegada Materia	Chegada Material Re	Stock Inic	Stock Fin	StockFinal Antecipa	QuantEn	Stock Transit	Stock Tot	Quebra	Stock Med	Quebras Reais	C1 seman	C2	C3	Custo Gestao Stock	Nivel Servic
104I0000000003	202244	156,43	146,66	0	0	151,56	0,00	0,00	2646,79	0,00	0,00	4,87	75,78	4,87	7,74 €	258,54 €	3 191,56 €	0,00 €	0
104I0000000003	202245	160,87	154,65	0	0	0,00	0,00	0,00	0,00	2646,79	2646,79	165,74	0,00	160,87	0,00 €	8 804,06 €	0,00 €	0,00 €	0
104I0000000003	202246	184,11	140,27	0	0	0,00	0,00	0,00	0,00	2646,79	2646,79	349,85	0,00	184,11	0,00 €	18 584,19 €	0,00 €	0,00 €	0
104I0000000003	202247	126,93	85,30	0	0	0,00	0,00	0,00	0,00	2646,79	2646,79	476,78	0,00	126,93	0,00 €	25 326,77 €	0,00 €	0,00 €	0
104I0000000003	202248	217,32	150,92	0	0	0,00	0,00	0,00	3405,17	2646,79	2646,79	694,11	0,00	217,32	0,00 €	36 870,91 €	4 106,04 €	0,00 €	0
104I0000000003	202249	249,54	182,84	0	0	0,00	0,00	0,00	0,00	6051,96	6051,96	943,65	0,00	249,54	0,00 €	50 126,63 €	0,00 €	0,00 €	0
104I0000000003	202250	220,03	181,23	0	0	0,00	0,00	0,00	0,00	6051,96	6051,96	1163,68	0,00	220,03	0,00 €	61 814,47 €	0,00 €	0,00 €	0
104I0000000003	202251	1,31	0,00	0	0	0,00	0,00	0,00	0,00	6051,96	6051,96	1164,99	0,00	1,31	0,00 €	61 884,00 €	0,00 €	0,00 €	0
104I0000000003	202252	247,67	0,00	0	0	0,00	2623,23	2321,21	0,00	3428,73	6051,96	1412,66	1311,62	247,67	133,99 €	75 040,39 €	0,00 €	0,00 €	0
104I0000000003	202301	258,86	145,91	0	0	2623,23	951,71	621,01	0,00	3428,73	4380,44	0,00	1787,47	0,00	182,60 €	0,00 €	0,00 €	0,00 €	0
104I0000000003	202302	195,16	156,10	0	0	951,71	756,55	465,82	0,00	3428,73	4185,28	0,00	854,13	0,00	87,25 €	0,00 €	0,00 €	0,00 €	0
104I0000000003	202303	213,87	174,59	0	0	756,55	542,68	270,04	0,00	3428,73	3971,41	0,00	649,61	0,00	66,36 €	0,00 €	0,00 €	0,00 €	0
104I0000000003	202304	183,10	116,13	0	0	542,68	3734,44	3418,21	0,00	53,87	3788,31	0,00	2138,56	0,00	218,46 €	0,00 €	0,00 €	0,00 €	0
104I0000000003	202305	203,94	156,51	0	0	3734,44	3584,38	3266,40	0,00	0,00	3584,38	0,00	3659,41	0,00	373,82 €	0,00 €	0,00 €	0,00 €	0
104I0000000003	202306	235,87	159,72	0	0	3584,38	3348,51	3030,23	0,00	0,00	3348,51	0,00	3466,44	0,00	354,11 €	0,00 €	0,00 €	0,00 €	0
104I0000000003	202307	220,89	158,25	0	0	3348,51	3127,61	2807,35	0,00	0,00	3127,61	0,00	3238,06	0,00	330,78 €	0,00 €	0,00 €	0,00 €	0
104I0000000003	202308	205,64	160,02	0	0	3127,61	2921,97	2597,18	0,00	0,00	2921,97	0,00	3024,79	0,00	308,99 €	0,00 €	0,00 €	0,00 €	0
104I0000000003	202309	195,97	160,24	0	0	2921,97	2726,00	2428,14	0,00	0,00	2726,00	0,00	2823,99	0,00	288,48 €	0,00 €	0,00 €	0,00 €	0
104I0000000003	202310	239,72	164,56	0	0	2726,00	2486,28	2486,28	0,00	0,00	2486,28	0,00	2606,14	0,00	266,23 €	0,00 €	0,00 €	0,00 €	0
104I0000000003	202311	198,80	133,31	0	0	2486,28	2287,48	2287,48	0,00	0,00	2287,48	0,00	2386,88	0,00	243,83 €	0,00 €	0,00 €	348 870,20 €	0,6393

Table 48: Behaviour of Material ‘101I0000001443’ During the Twenty Weeks of Simulation – Scenario V7_C1_10_C3_dobro

Material	Semana	Procura Semanal Re	ResOrd	Chegada Materia	Chegada Material Re	Stock Inic	Stock Fin	StockFinal Antecipa	QuantEr	Stock Transito	Stock Tot	Quebra	Stock Me	Quebras Reais	C1 seman	C2	C3	Custo Gestao Stock	Nivel Servico
101I0000001443	202244	1322,05	1222,48	0,00	0,00	1207,83	0,00	0,00	22776,95	10581,41	10581,41	114,22	603,92	114,22	45,91 €	4 515,00 €	13 235,48 €	0,00 €	0
101I0000001443	202245	431,18	413,73	451,33	402,00	0,00	0,00	0,00	0,00	32956,36	32956,36	143,39	0,00	29,18	0,00 €	5 668,36 €	0,00 €	0,00 €	0
101I0000001443	202246	1794,21	1744,72	3519,11	3134,47	0,00	1196,86	1170,25	0,00	29821,89	31018,75	0,00	598,43	0	45,49 €	0,00 €	0,00 €	0,00 €	0
101I0000001443	202247	47,19	26,62	2598,23	2314,24	1196,86	3463,92	3395,69	18853,31	27507,65	30971,56	0,00	2330,39	0	177,15 €	0,00 €	12 465,30 €	0,00 €	0
101I0000001443	202248	691,12	68,23	0,00	0,00	3463,92	2772,80	2151,07	0,00	46360,96	49133,76	0,00	3118,36	0	237,06 €	0,00 €	0,00 €	0,00 €	0
101I0000001443	202249	622,93	621,72	0,00	0,00	2772,80	2149,86	1100,72	0,00	46360,96	48510,82	0,00	2461,33	0	187,11 €	0,00 €	0,00 €	0,00 €	0
101I0000001443	202250	1056,18	1049,14	4012,74	3574,15	2149,86	4667,84	4660,80	17588,20	42786,81	47454,65	0,00	3408,85	0	259,14 €	0,00 €	12 552,11 €	0,00 €	0
101I0000001443	202251	8,25	7,04	0,00	0,00	4667,84	24947,02	24947,02	0,00	40087,58	65034,60	0,00	14807,43	0	1 125,65 €	0,00 €	0,00 €	0,00 €	0
101I0000001443	202252	423,27	0,00	0,00	0,00	24947,02	24523,75	23473,78	0,00	40087,58	64611,33	0,00	24735,38	0	1 880,36 €	0,00 €	0,00 €	0,00 €	0
101I0000001443	202301	1215,90	1049,97	0,00	0,00	24523,75	23307,85	22261,39	0,00	40087,58	63395,43	0,00	23915,80	0	1 818,06 €	0,00 €	0,00 €	0,00 €	0
101I0000001443	202302	1146,74	1046,46	0,00	0,00	23307,85	38953,76	37701,36	0,00	23294,93	62248,69	0,00	31130,81	0	2 366,54 €	0,00 €	0,00 €	0,00 €	0
101I0000001443	202303	1304,77	1252,41	0,00	0,00	38953,76	37649,00	36726,87	0,00	23294,93	60943,93	0,00	38301,38	0	2 911,64 €	0,00 €	0,00 €	0,00 €	0
101I0000001443	202304	1118,35	922,13	0,00	0,00	37649,00	36530,65	33807,01	0,00	23294,93	59825,58	0,00	37089,82	0	2 819,54 €	0,00 €	0,00 €	0,00 €	0
101I0000001443	202305	2746,07	2723,63	0,00	0,00	36530,65	49450,38	48199,50	0,00	7629,12	57079,50	0,00	42990,51	0	3 268,11 €	0,00 €	0,00 €	0,00 €	0
101I0000001443	202306	1689,36	1250,89	0,00	0,00	49450,38	55390,14	53704,21	0,00	0,00	55390,14	0,00	52420,26	0	3 984,95 €	0,00 €	0,00 €	0,00 €	0
101I0000001443	202307	1854,63	1685,93	0,00	0,00	55390,14	53535,51	52233,51	0,00	0,00	53535,51	0,00	54462,83	0	4 140,22 €	0,00 €	0,00 €	0,00 €	0
101I0000001443	202308	1521,58	1302,00	0,00	0,00	53535,51	52013,93	50532,45	0,00	0,00	52013,93	0,00	52774,72	0	4 011,89 €	0,00 €	0,00 €	0,00 €	0
101I0000001443	202309	1481,48	1481,48	0,00	0,00	52013,93	50532,45	48023,69	0,00	0,00	50532,45	0,00	51273,19	0	3 897,75 €	0,00 €	0,00 €	0,00 €	0
101I0000001443	202310	2708,91	2508,75	0,00	0,00	50532,45	47823,53	47823,53	0,00	0,00	47823,53	0,00	49177,99	0	3 738,47 €	0,00 €	0,00 €	0,00 €	0
101I0000001443	202311	2681,40	2598,15	0,00	0,00	47823,53	45142,14	45142,14	0,00	0,00	45142,14	0,00	46482,84	0	3 533,59 €	0,00 €	0,00 €	88 884,88 €	0,9945

APPENDIX XXIII – ROUTINE TO UPDATE THE POWER BI REPORT

Figure 117 details the steps that ensure the update of the Power BI Report.

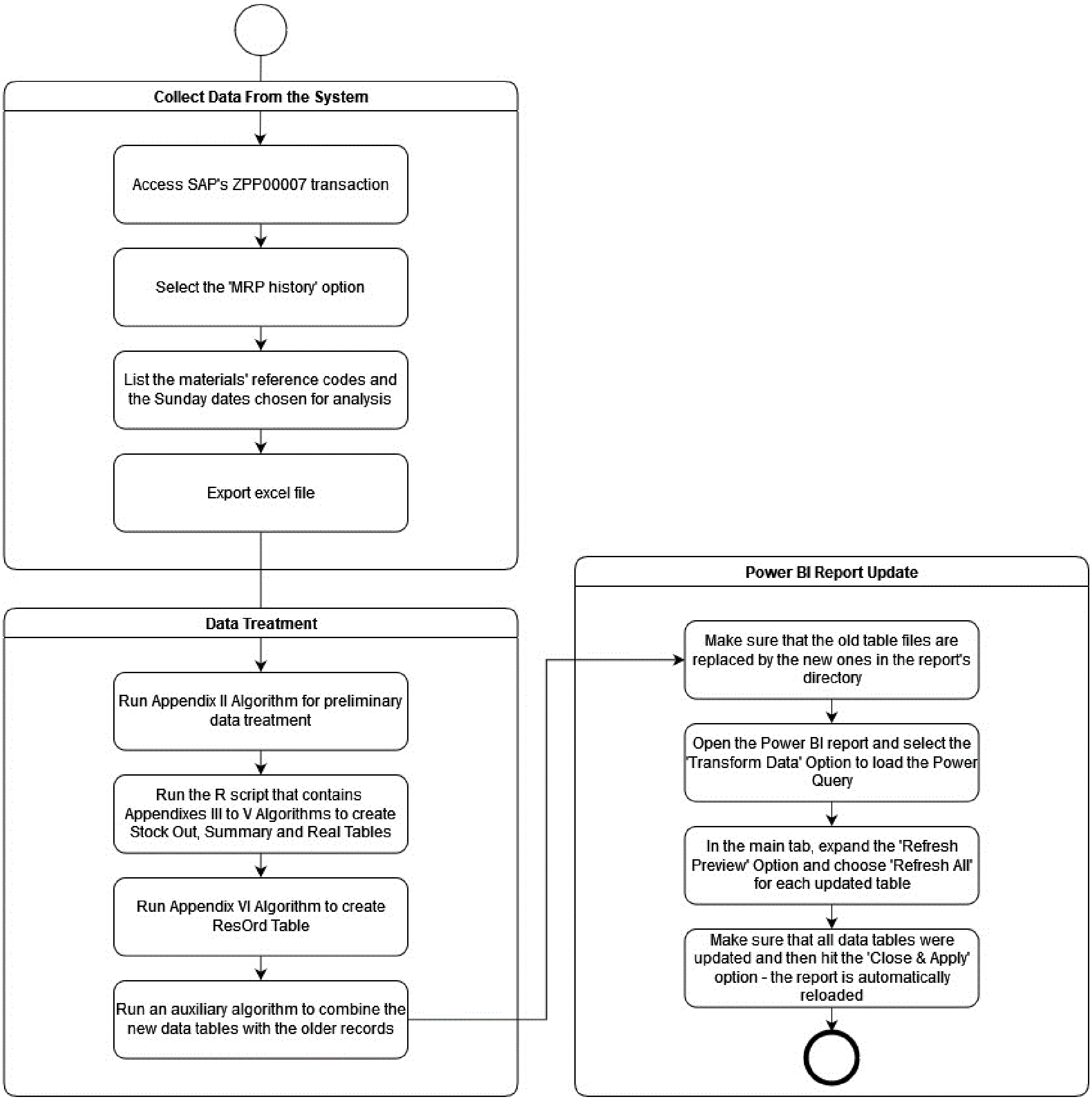


Figure 117: Main Steps to Update the Power BI Report