A holistic approach to support order planning in a pharmaceutical distributor

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Master's Dissertation

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Abstract

Inventory management is one of the main concerns in the Pharmaceutical Supply Chain, which proves to be even more important to a pharmaceutical distributor, as incorrect management of the inventory can lead to severe inefficiencies, costs, and lastly, service level loss. Among the challenges that characterize the sector, shortages are one of the main concerns. Thus, an effective replenishment policy that ensures that the target service level is accomplished, allied to the ability to deal with the daily uncertainty that drives the industry and creates stock inefficiencies jointly with the capacity to ensure a balance in the warehouse operations, avoiding activity peaks, is extremely relevant.

Hence, the present work, carried alongside a national pharmaceutical distributor, aims to assist, from an analytical point of view, the increasing complexity of inventory management. By providing holistic support capable of acting upon three main indicators, service level, stock costs, and warehouse operations, the goal is to, firstly provide a dynamic replenishment policy capable of dealing with demand and supplier uncertainty. Secondly, the objective is to present recommendations able to react to the daily fluctuations of the sector. Lastly, the aim is to challenge the time-consuming process related to supplier scheduling while guaranteeing,*a priori*, a balance in the inbound activities.

In the first module, the proposed approach ensures that the most accurate policy parameters are determined, taking into account business constraints, so that a reliable and automatic purchase recommendation can be performed by the company's Material Requirement Planning (MRP) software. Preliminary results account for a reduction of 19% of the stock level when compared to the current stock level.

Regarding the second module, the suggested methodology provides a report where products that are at risk of shortages, during the upcoming horizon are considered. For those, a recommendation based on business constraints and on the cost and warehouse operations impacts minimization is proposed among the four possible options - emergency orders, lateral transshipments, order anticipation, and awaiting the next scheduled order.

Lastly, the tactical problem presented is divided into two optimization models. Firstly, the optimal review period for each supplier is assessed, considering stock costs and inbound operations workload. Having this parameter set, a second model is proposed to define the best week and weekday allocation for each supplier, considering its portfolio's magnitude and the workload at the warehouse operations. Preliminary results showed a 2% decrease in stock costs when comparing the proposed solution with the current calendar.

The experimental results showcased that, by allying analytical tools and business expertise, improvements in the main KPIs can be achieved. Furthermore, preliminary validation sessions with the stakeholders have proven that the methodologies are aligned with the company's objectives.

Resumo

A gestão do inventário revela-se das principais preocupações na Cadeia de Abastecimento Farmacêutica, tendo ainda um maior relevo para um distribuidor farmacêutico, dado que uma gestão incorrecta do inventário pode conduzir a ineficiências, custos e, finalmente, à perda de nível de serviço. Entre os desafios que caracterizam o sector, a escassez de produto constitui uma das principais inquietações. Deste modo, uma política de aprovisionamento eficaz que garanta o cumprimento do nível de serviço pretendido, aliada à capacidade de acautelar a incerteza diária que caracteriza o sector, gerando ineficiências de stock, e à capacidade de garantir um equilíbrio nas operações de armazém, evitando picos de atividade, são extremamente pertinentes.

Neste sentido, o presente trabalho, realizado num distribuidor farmacêutico nacional, visa colmatar, do ponto de vista analítico, a crescente complexidade da gestão de stocks. Proporcionando um suporte holístico capaz de atuar sobre três indicadores principais, nível de serviço, custos de stock e operações de armazém, o objetivo é, primeiramente, prover a empresa de uma política de reabastecimento dinâmica e robusta para responder às incertezas da procura e dos fornecedores. Em seguida, o propósito é apresentar recomendações capazes de reagir às flutuações diárias do sector. Por último, e desafiando o processo moroso de calendarização dos fornecedores, pretende-se assegurar, *a priori*, um equilíbrio nas actividades logísticas a nível do armazém.

Numa primeira etapa, a abordagem proposta garante a determinação de parâmetros de aprovisionamento, com base em restrições de negócio, que permitem que uma recomendação de compra fiável e automática possa ser realizada pelo software de planeamento das necessidades de materiais da empresa. Resultados preliminares apresentam uma redução de 19% do nível de stock, quando comparado com o nível atual.

Relativamente ao segundo módulo, um relatório que inclui produtos em risco de rutura durante o horizonte temporal relevante é providenciado. Para cada produto é proposta uma recomendação baseada nas restrições de negócio e na minimização dos custos e impactos nas operações de armazém, entre as quatro opções viáveis - encomendas de emergência, transferências internas, antecipação de compra e aguardar a próxima encomenda programada.

Por fim, o problema tático apresentado é dividido em dois modelos de otimização. Primeiramente, o período ótimo de revisão para cada fornecedor é avaliado, considerando os custos de stock e o esforço de receção nos armazéns. Posteriormente, um segundo modelo propõe a alocação semanal e diária para cada fornecedor, considerando a magnitude do seu portfolio de artigos, assim como o esforço operacional necessário na receção dos mesmos. Resultados preliminares revelam uma redução de 2% nos custos de stock, quando comparada a solução proposta com o calendário atual.

Os resultados experimentais atestam que, aliando ferramentas analíticas com o conhecimento de negócio, é possível obter melhorias nos principais indicadores. Adicionalmente, sessões de validação de resultados preliminares comprovam que as metodologias propostas se encontram alinhadas com os objectivos da empresa.

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People always tell you how in a snap of a finger these five-years pass. You would never believe them. The truth is that if more fulfilling these last years could have been, the faster they would have passed, because it is true that time flies when you are with those you love and doing what truly makes you happy.

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To my friends, being able to sail this boat with you made me realize that alone one cannot take the helm and change the course, without someone opening the sails. I want to thank all of you for showing me the true meaning of friendship. For all the craziness – or as some would say, irreverence -, all the hardships we overcame, all the moments that our complicity made us feel as one. Thank you for all that I have learned from you: you do not have to panic; your randomness will be the magic recipe for your success.

To my family, your endless support made me who I am today. To my mother, thank you for showing me what kindness truly means. To my father, thank you for every day turning the world upside down for us. To my brother, thank you for being my role model. The dedication and professionalism you put into your every accomplishment are true guidelines that I aspire to follow. For the three of you, your resilience showed me that there is no impossible. I will be forever grateful for all your love and strength.

Andreia Bastos

"Sedit qui timuit ne non succederet."

Horace

Contents

Acronyms and Symbols

CV	Coefficient of Variation
FTE	Full-Time Equivalent
KPI	Key Performance Indicator
LT	Lead Time
MRP	Material Requirement Planning
PSC	Pharmaceutical Supply Chain
R	Review Period
s	Reorder Point
S	Order-up-to Level
SKU	Stock Keeping Unit
WACC	Weighted Average Cost of Capital

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Chapter 1

Introduction

In the present chapter, the aim is to present an overview of the project, as well as its motivation and objectives, through sections 1.1 to 1.3. Lastly, in section 1.4 a brief synopsis of the structure of the dissertation is provided.

1.1 Motivation

In a world deeply affected by the recent global health crisis caused by Covid-19, the vulnerabilities of the pharmaceutical supply chain have been brought to the forefront of the public's attention (Derrong Li and Hertig, 2022). The pandemic has exposed challenges and uncertainties within the healthcare system, including unpredicted changes in demand for pharmaceutical products, supply shortages, and panic buying (Ayati et al., 2020). As a consequence, the adaptability of the pharmaceutical supply chain has been put to the test, forcing it to adapt to ever-changing circumstances while ensuring that shortages are minimized to guarantee access to the medicines and treatments needed.

Characterized by its complexity, the pharmaceutical supply chain comprises a large network of manufacturers, distributors, wholesalers, and lastly, providers to the end customer, pharmacies, and hospitals, as seen in Figure 1.1. In addition to the numerous players in the chain, since the entities function as separated agents, the need for strong and clear relationships increases, and the resultant inefficiencies propagate along the chain. Furthermore, due to its global relevance in the healthcare system, the whole chain is tightly regulated by the government, represented in an external regulatory entity, in Portugal being the INFARMED (Marques et al., 2020).

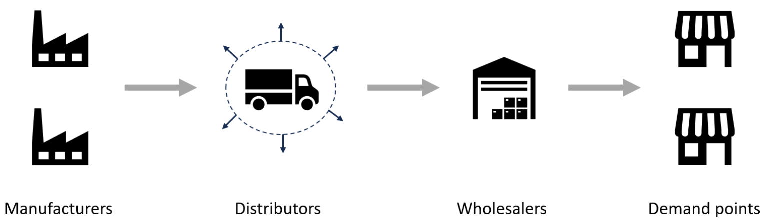

Figure 1.1: Pharmaceutical Supply Chain - Adapted from Mousazadeh et al. (2015)

Ruled by the direct impact that shortages impose on the final consumer, pharmaceutical supply chain management is deeply focused on guaranteeing the delivery of the right product at the right time to the right people in need. As a consequence, inventory levels across the supply chain are usually very high in order to assure the highest service level possible. Facing daily challenges in regards to shortage and high regulation adopting inventory management strategies that effectively manage costs, constraints, and product perishability whilst determining the appropriate quantity to order and when to order, is crucial (Uthayakumar and Priyan, 2013). Thus, the adoption of replenishment policies that can guarantee a reliable purchase recommendation proves to be a necessity.

Despite the adoption of inventory management systems aligned with the needs, the uncertainty felt at upstream levels caused by suppliers' unreliability and raw materials shortage (Sriram and Milind, 2020), and downstream, due to demand fluctuations (Marrone et al., 2023) triggers the need to develop reactive and proactive methodologies, that increase the flexibility in order to achieve higher service levels, greater resource utilization and responsiveness.

Pharmaceutical supply chain challenges' resolution and support go beyond the operational level. Tactical decisions such as supplier selection and evaluation (Barbosa-Povoa et al., 2019) enable a clear mapping of the suppliers' reliability and, allow the company to prioritize, manage and schedule their order planning accordingly.

The presented challenges and pains were the drivers for the development of the project alongside which the presented thesis was developed.

1.2 Project overview

This dissertation was developed in an Advanced Analytics & Business Consultancy company, that aims to combine the two pillars and offer unique and customized solutions. The presented project was conducted alongside a Portuguese pharmaceutical distributor, operating mainly in the domestic market. Being one of the leading competitors in the sector, the company owns 6 warehouses scattered throughout the country, collaborates with more than 5000 pharmacies and hospitaller units and presents a wide portfolio supplied by a range of diverse manufacturers.

Given the presented dimensions and complex characteristics of the supply chain, the company aimed to enhance its capacity to, primarily, ensure a correct and automatic purchase recommendation. Moreover, the company intended to solidify the ability to plan its inbound operations followed by the capacity to respond to the daily changes in demand. In this regard, after a preliminary analysis was conducted there were four main fronts that were identified as beneficial to the company; first, a forecast module was proposed to predict the markets' demand and to reduce the variability and prediction error. After that, there was the need to introduce a replenishment policy that would be able to, simultaneously, meet the needs of the customers while keeping the inventory levels balanced. Thirdly, through an operational standpoint, the aim was to set recommendations to handle the daily deviations caused by the uncertainty in demand, the high variability in the manufacturers' behavior, and the availability of the raw materials. Lastly, through a tactical lens, a scheduling plan was proposed so that suppliers' reviews would be coordinated in order to avoid peak activities in the inbound operations.

Despite the brief presentation of the four modules that encompass this consultancy project, the forecast module will not be considered within the scope of this thesis. Nevertheless, it is worth noting its development, as its results prove to be of relevance for the following modules.

Figure 1.2 highlights the main stages of the present thesis, with the respective timeline. Firstly, a thorough mapping of the processes and data was conducted, during sessions with the main stakeholders involved in the project. Subsequently, the determination of the most adequate replenishment policy was introduced, followed by the parameters formulation. The second module encompassed the development of the operational layer, that aimed to respond to the daily deviations. To this end, a preliminary analysis and problem formulation took place, followed by algorithm development. The third module consists of both the problem presentation and constraints definition and the development of the necessary optimization algorithms. Afterward, a validation phase is to take place, where results are validated and discussed and adjustments, if needed, are added in order to tune the models for the business reality of the company.

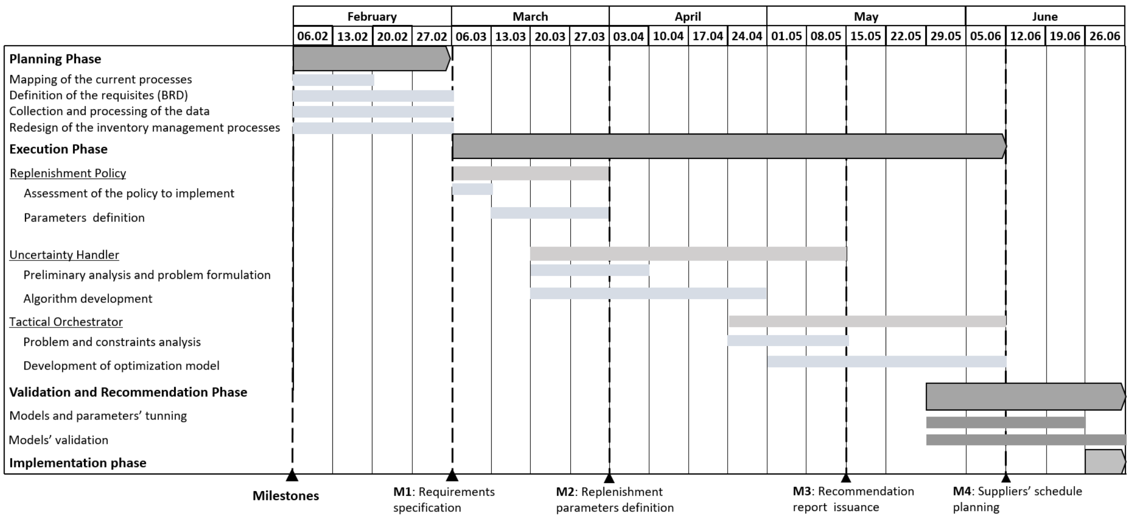

Figure 1.2: Project's timeline

1.3 Main objectives

The focus of the present thesis lies on the upstream level of a pharmaceutical distributor's supply chain. Adopting a holistic approach, that encompasses processes at operational and tactical-strategical levels, the goal is to provide a dynamic replenishment methodology definition and support the order planning processes on both a tactical and operational level, aiming to improve three main dimensions, stock level, service level to the client, and, lastly, warehouse operations.

The selection and implementation of an accurate replenishment policy is crucial to be able to accomplish both cost savings and customer satisfaction, hence, with the main axis presented, the importance of defining a precise and robust policy is highlighted.

Concerning the operational layer responsible for managing the volatility of market demand, inefficiencies in inventory management are recognized as one of the top ten concerns due to the associated costs of both overstocking and understocking (Privett and Gonsalvez, 2014). So, it is emphasized the importance of the ability to act upon prevention and reaction, enhancing the chain's flexibility. In addition to the relevance of the short-term operational level, tactical decisions are fundamental to secure a medium-term plan coherent with both upstream and downstream's fluctuating behaviors.

The development of the proposed modules will be closely monitored by three main indicators, that will serve as objectives to guide the success of the project. As mentioned, the main dimensions that will leverage the project are the stock levels, directly associated with costs, the service level, based on demand fulfillment Lastly, a not-so-frequently referred pillar, the warehouse operations, highlights the importance of balancing the inbound operations. This last axis' relevance was a result of the frequent strain experienced by inbound operations that often needed to rely on additional full-time employees. Across the modules, the indicators are going to be taken into account to guarantee that each measure's objectives are accomplished without neglecting the fulfillment of the others. The objectives are, then, set to reduce the stock levels in order for a direct cost reduction, increase in service level, promote customer satisfaction, and balance the inbound operations to avoid activity peaks.

Figure 1.3 highlights the three key dimensions and the trade-offs between costs, service level, and warehouse operations.

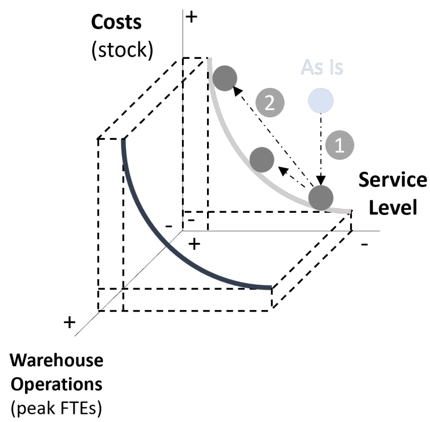

Figure 1.3: Trade-off between the three key dimensions

The presented graph emphasizes the need to carefully balance, at the first stage, the cost and service level dimensions and, in addition, consider the complexity that arises from the warehouse operations due to the context of the pharmaceutical distributor.

1.4 Dissertation structure

The present dissertation is organized into six chapters as follows. Chapter 2 provides a literature review on the key themes raised throughout the project, mainly the replenishment policies definition, possible measures to respond to the daily deviations, and how to strategically develop a cohesive schedule for suppliers. Chapter 3 provides a detailed description of the problem presented, followed by a presentation of the company's current situation and an overview of the proposed approach. Chapter 4 extensively explains the methodology used in order to support the approaches undertaken. Chapter 5 describes the results obtained. Lastly, Chapter 6 summarizes the key conclusions of the project, identifying some opportunities for future work.

Chapter 2

Literature Review

The objective of this chapter is to present the existing theoretical background on the presented modules. It will serve as a support to the methodologies proposed as well as to further develop the present state of art.

Section 2.1. will focus on inventory management and its relevance to supply chain management, followed by section 2.1.1, the specific application to the Pharmaceutical Supply Chain (PSC). In Section 2.2., the focus will lay on the existing methods to prevent and react to stockout situations. Section 2.2.1, and its subsections, introduce an internal solution to stockouts, through lateral transshipments, while Section 2.2.2 refers to the possibility of resorting to the upper chain, through emergency orders. Regarding Section 2.3., the relevance of the inventory systems is highlighted and in Section 2.3.1. replenishment policies are introduced due to their relevance to the topic itself and as a base for the tactical definition of the suppliers' review period. Lastly, in Section 2.3.2. the importance of schedule planning order allocation is highlighted.

2.1 Inventory management

Inventory management has proven to be one of the main dimensions of interest regarding supply chain management (Priniotakis and Argyropoulos, 2018). Managing inventory has impacts across different levels, mainly financially and at the performance level, which showcases the ability to deliver and fulfill the customers' needs while staying competitive (Oballah et al., 2015). Hence, inventory management aims to minimize the costs incurred in having inventory whilst assuring a high service level, in order to retain customers and generate, ultimately, profit (Ahmad, 2022).

According to Guluma (2019), the key objective of inventory management "is to place an order at the right time from the right source with the right quantity and quality". Additionally,Silver et al. (2016) demonstrates that inventory level impacts the various activities of the supply chain, from purchasing to distribution and logistics.

The cost-based nature of inventory management (Saha and Ray, 2019) supports the relevance to address the main costs dimensions associated with inventory. These costs encompass several axis, namely monetary, space, labor and shipment, deterioration and obsolescence (Muller, 2019).

Despite the costs associated with acquiring and holding inventory, companies still showcase the need to have inventory (Oballah et al., 2015).

Inventory management involves considering three primary types of costs. Firstly, holding costs are determined based on the inventory stored at warehouses or in stores (Gurtu, 2021). The weighted average cost of capital (WACC) applicable to the company is used to calculate holding costs, which are dependent on the average purchase cost of each product, the quantity ordered and the time inventory is kept in store. Secondly, penalty costs arise from the inability to meet demand either entirely - resulting in lost sales, or unfulfilling on time, leading to potential backorders. Estimating penalty costs is challenging, so they are commonly regarded as a service constraint. Lastly, ordering costs pertain to expenses incurred during replenishment, encompassing activities such as handling, transportation and machine setup (Grob, 2018). Additionally, it is pertinent to address costs associated with warehouse operations, especially storing and picking costs. Storing costs encompass inbound operations, including receiving, sorting, and storing materials. Moreover, picking costs involve the outbound operations of selecting and collecting products to fulfill customer orders (Gagliardi et al., 2007).

The aim of inventory management also lies in responding to the uncertain environment that surrounds the company (Nemtajela and Mbohwa, 2017). Uncertainty may derive from various sources, this being external, such as fluctuations in demand, alterations in suppliers' capacity to deliver or produce, and internal, being either workforce shortage, human errors, or machine and procedure failures. In order to address this uncertainty, safety stocks, and order modification can be considered (Nemtajela and Mbohwa, 2017).

2.1.1 Inventory management in the pharmaceutical industry

The pharmaceutical supply chain complexity is a result of the presence of various actors along the chain- supplier, manufacturer, wholesaler, and pharmacy or hospital- as well as the complexity of the process that occurs within this vast network. Furthermore, external factors such as the high regulation of the sector also contribute to inefficiencies spread and augmented along the chain (Nguyen et al., 2022).

The pharmaceutical industry is a highly uncertain sector. Continuous drug developments and discontinuations and dynamic regulations constraints (Osorio Gómez and España, 2020), besides the complexity of the supply chain mentioned, imposes several challenges to the industry (Nguyen et al., 2022). One of the main challenges is drug shortage, which can arise from multiple sources, such as scarcity of raw materials and manufacturing issues, legislative and regulatory problems, distribution factors, and market-related issues. (Abu Zwaida et al., 2021)

2.2 Prevention and reaction to inventory shortage

In the pharmaceutical sector, the unavailability of products has become a more relevant topic since the pandemic hit, showcasing the relevance in preventing shortages. The consequences of low inventory are directly felt by patients; however, they affect the whole chain and the impacts can be perceived in terms of changes, delays and cancellation of treatments, impacting the performance of health professionals as well, and ultimately institutional costs (Postma et al., 2023).

As stated, the cost nature of inventory management aims to balance costs while ensuring a competitive service level in the industry, that allied to the primary aim of healthcare systems , ensuring that patients' demand is fulfilled, highlights the relevance of shortage costs (Saha and Ray, 2019). As previously referred, the difficulty to determine this cost can lead to an indirect determination by service constraints. Commonly, service level can be defined as the fraction of demand that is satisfied directly from stock on hand - the fill rate (Teunter et al., 2010), as this criteria directly reflects the service as experienced by the customer.

To provide a solution to product shortages, two approaches can be considered; either the company can act upon prevention or upon reaction, whenever the first is infeasible, or additionally if needed. These approaches differ in the time frame of action; while the preventive approach acts before the occurrence of shortages in order to reduce its risk of happening, the latter is performed after the stockout has occurred and aims to address them (Feng et al., 2017). As the reactive approach is based on stockout occurrence prior to the decision, usually a backorder policy is allowed. In the pharmaceutical sector, it is common practice to allow the request of a product that is not available or the quantity does not fulfill entirely the needs due to characteristics of the market, seasonality, variable demand, and shortages in resources (Li et al., 2023).

2.2.1 Lateral transshipments

Considering a multi-inventory system, lateral transshipments can be resorted to improve the resilience of the chain, preventing and reacting to shortages in inventory (Xu et al., 2023). According to Kundu and Rossini (2023), lateral transshipments can be defined as "stock movements between locations of the same echelon".

In spite of the flexibility that lateral transshipments possibility, its usage proves to increase the difficulty in inventory management, as these shipments depend on both the source's surplus and the destination's needs. This measure is widely used when the costs of transferring material within the echelon are lower than those of holding large quantities of inventory and when shortage costs are not significantly high to impose the need for high inventory levels (Olsson, 2015).

The most common classification of lateral transshipments contemplates the difference in the timing of the response. According to this, transshipments can be considered as proactive or preventive and reactive, as the previous distinction in approaches considers (Kumari et al., 2022).

2.2.1.1 Reactive lateral transshipments

Concerning reactive lateral transshipments, as they respond to a demand already realized, they can be found as a better solution when holding costs are low in comparison to the shipment costs and inability to reply to customers' demand (Kumari et al., 2022)

According to the research developed by Shokouhifar and Goli (2023), regarding the blood platelet supply chain, a reactive lateral transshipment approach was considered as an alternative to the planned orders from the blood banks to emergency situations. In this paper, a periodic review policy for order replenishment was considered, alongside the lateral transshipments between hospitals, as improvements in shortages and wastages were expected in case of shortages or disruptions. The model aimed to minimize economic costs, minimize shortages in stock- that would reflect in social costs- and minimize wastage - an environmental side. The study highlights the usefulness of lateral transshipments in filling in for the inability to respond to shortages by ordering directly from the supplier. Nevertheless, the model does not take into account some factors that could impact the performance and even the tactical choice of the transshipment versus a normal vertical order, such as the possibility of different lead times between the different hospitals.

2.2.1.2 Preventive lateral transshipments

Regarding proactive transshipments, as it establishes the transfer of goods in a defined time frame, according to inventory levels, it allows a reduction in holding costs in facilities with excessive inventory, balancing it throughout the echelon. This way, it is more effective when handling costs are high (Kumari et al., 2022). On another note, Tiacci and Saetta (2011) presents two preventive lateral transshipment policies that consider the same threshold that triggers the transshipment, despite contemplating different levels of final inventory in the different facilities. Transshipment based availability (TBA) aims to ship stock from locations where its level is higher than the expected stock level, while transshipment based on inventory equalization (TBE) intends to level the inventory within the echelon, by shipping different number quantities to each of the facilities.

Although there are a few studies in the literature regarding preventive lateral transshipments, some similarities were found with the case study of Kumari et al. (2022), based in the retail sector. In this paper, a multi-location inventory system and the multi-product system was considered, and the main objective relied on cost minimization. The results showed a significant improvement in cost and stockouts reduction, stating that preventive lateral transshipments could be seen as an effective strategy to improve customer satisfaction and goods availability.

2.2.1.3 Hybrid lateral transshipments

Lastly, a hybrid model was proposed firstly by Paterson et al. (2012). This hybrid transshipment considers a reactive policy that transfers stock whenever a stockout happens, however, the policy also aims to prevent potential future shortages. This way, the quantity transferred considers not only the demand not fulfilled but also additional inventory to prevent future shortages (Kumari et al., 2022).

2.2.2 Emergency orders

In spite of the celerity and the cost-effectiveness of the lateral transshipment strategy, the availability of inventory on the facilities of the same echelon restricts the capability of dealing with shortages in inventory. Another alternative lies in emergency orders (Liao et al., 2014). These are shipments where suppliers from the upstream part of the chain are involved and allow target and unscheduled orders(Tiacci and Saetta, 2011).

Poormoaied et al. (2020) present a model based on a periodic review replenishment policy where emergency orders are placed, if needed, after a certain time, u, has passed after the last scheduled order. If, at that point, the inventory level is below a threshold, then an emergency order is triggered. More recently, Sun et al. (2023) analyzed a similar approach to the one mentioned previously, although considering a quantity-based trigger for emergency orders, rather than an optimal time after the scheduled order. Moreover, it also added a layer of complexity by considering the existence of a delivery lead time.

Galli et al. (2020) presents a case study in the healthcare sector, where emergency orders are issued to cope with and prevent shortages in stock in between scheduled orders. Despite the need that arises from the uncertainty of demand allied with the aim of keeping a low inventory level for reactive measures, the aim of the paper is to reduce the need for emergency orders while keeping a low inventory level. This study aims to highlight the preventive layer associated with accurate prediction techniques rather than emphasizing the usage of reactive measures.

2.2.2.1 Lateral transshipments and emergency orders

Even though, as seen, emergency orders, in contrast to lateral transshipments, do not imply the need for stock in another location, this strategy also presents some downsides. In general, emergency orders tend to be more expensive, as there is a direct buy from the supplier and not a reallocation of the existing inventory, and tends to be slower, as internal shipments are only dependent on the same entity (Liao et al., 2014). As both approaches have disadvantages, a hybrid strategy may be deemed a viable approach to address the previous options' inefficiencies.

Liao et al. (2014) compares the three strategies, lateral transshipment, emergency order, and the hybrid approach, where emergency order satisfies the unmet demand after lateral transshipments are performed, in a preventive manner. This research shows that a hybrid strategy, in general, is more beneficial than individual policies, especially over lateral transshipments. Nevertheless, as the study also considers customer switching costs, the efficacy of the hybrid method versus emergency orders proves not to be the best in some cases, according to this metric.

In a more recent study, Xu et al. (2023) shows that the benefits of implementing a hybrid strategy surplus those where only emergency orders are accounted for. Moreover, it is also acknowledged that the lack of capacity to respond to disruptive situations such as stockouts leads to greater effort in the replenishment stage.

2.3 Policies to allocate and schedule suppliers

Due to the relevance that inventory systems present in a company's cost structure, it is crucial that the replenishment policy chosen is the most adequate to the sector and characteristics of the demand environment in which the company is in. This subject plays an even more important role when uncertainty and fluctuations in demand are regular, as this highly impacts both costs and service level (Kundu and Rossini, 2023). Inventory replenishment policies are defined at a tactical level in order to ensure inventory levels capable of satisfying demand with minimal shortages and, simultaneously, are not excessive to minimize the costs incurred (Saha and Ray, 2019). The aim is, therefore, to determine the optimal quantities to have in stock, quantities to order, and when to place those orders (Fattahi et al., 2015).

2.3.1 Replenishment policies

There are several replenishment policies presented in the literature, nevertheless, a simple division into four main categories can be performed according to two different axis, frequency of review of inventory and quantity ordered (Cunha et al., 2017).

Regarding the frequency of review, most commonly used to set apart the policies, the existent inventory systems can be divided into periodic and continuous reviews. These policies' efficiency is set through a cost-based approach as well as service level fulfillment (Saha et al., 2022).

According to Silver et al. (2016), the four main policies are presented in Table 2.1.

Table 2.1: Inventory management policies comparison

	Continuous Review		**Periodic Review**	
Characteristics	(s,Q)	(s,S)	(R,S)	(R,s,S)
Order Quantity	Fixed, Q	Up to S	Every R periods	Up to S
Reorder point	Stock < s	Stock < s	Every R periods	Every R periods & stock < s
Main advantage	Simplicity	Improved cost savings	Scheduled order improves organization	Lowest total costs
Main disadvantage	Unable to cope with large transactions	Variability in order quantity may lead to errors	Variable replenishment quantities and carrying costs	High computational effort

The main parameters present in both the review policies are s, the reorder point, S, the order up to level, Q a fixed quantity to order, and R the review period. These parameters' definition aims to develop the fittest replenishment policy for the company, at the product level. In order to define the reorder and the order-up-to level, it is important to distinguish two concepts, cycle stock and safety stock. While the first relates to the quantity delivered and the frequency of the orders placed, the second accommodates the uncertainty and so related to the service level fulfillment. This way, a decrease in cycle stock results in an increase in orders issued so that demand is fulfilled and impacts negatively the safety stock, increasing it. On the other hand, a decrease in the safety stock is related to an increase in the risk of stockout during the replenishment cycle, leading to an increase in the quantity ordered, and so, in the cycle stock (Krzyżaniak, 2022).

Considering the specificity of the present work, the pharmaceutical sector, as well as its demand characteristics, the following review on the replenishment policies will mainly lay on research based on the healthcare sector, or industries that, though different from the health and pharmaceutical fields, take into consideration key aspects of the sector, uncertainty in demand and replenishment lead time.

Cunha et al. (2017) considers a single-item one-echelon supply chain with uncertain demand, in which a periodic review (R,s,S) replenishment policy is considered. In this policy, every *R* periods, the inventory is analyzed and if the level falls below the reorder point, *s*, then a replenishment order is generated with a quantity equal to the difference up to *S*, the order-up-to level. The aim of the study was to determine the best parameters *R* and *S* for the case when the desired service level and the minimum costs incurred in the replenishment process were simultaneously met.

Sbai and Berrado (2023) presents a case study of a pharmaceutical supply chain where a multi-echelon system is considered. This study uses a continuous review policy with fixed order quantity (s,Q), where *s* is the reorder point, below which an order is set with a *Q* fixed quantity.

Ahmadi et al. (2020) demonstrates the applicability of a periodic review policy (R,s,S) in a healthcare case study. Considering a multi-periodic and stochastic model, the usage of a periodic review policy is based on its simplicity and prevalence when dealing with perishable items, as it is able, at discrete points in time, to indicate which is the stock-on-hand level. The parameters of the policy are determined through the application of a genetic algorithm. Furthermore, the paper also takes into account other relevant aspects of inventory management in the healthcare sector (Hansen et al., 2023), such as age-dependency on perishable items, like blood, and delivery lead time.

In a more recent study, Ahmadi et al. (2022) introduces intelligent inventory management and compares it with a periodic review (R,s,S) inventory management. A two-stage stochastic mixed-integer programming model is formulated to find the near-optimal parameters for the replenishment policy adopted. On the other hand, the intelligent inventory management uses reinforcement learning methods, specifically Q-learning and Deep Q-network in order to develop the inventory policy.

The importance of the definition of the parameters lies in the flexibility and safety provided by an adequate inventory management policy. It should accommodate the expected fluctuations in demand in order to decrease the need to react to those (Saha and Ray, 2019). Having a fitting policy also allows for cost savings, as mentioned, and service level improvements.

2.3.1.1 Review period

Considering the wide usage of the (R,s,S) policy due to its explicability and applicability in the specific case of the present work, as mentioned in the previous subsection, it is relevant to carry out a more in-depth analysis of its constituent parameters, namely the review period. Having reduced

R periods between reviews, meaning a high frequency of orders, results in high costs related to ordering and transportation. Nevertheless, having a considerable time gap between reviews can lead to increases in holding and shortage costs due to higher variability in demand (Flynn and Garstka, 1997).

The definition of the review period should also take into account the ABC classification that is widely used. This inventory classification can be used in order to prioritize the product that should be more attentively monitored and ease the inventory management tasks. The ABC classification aims to, using a Pareto analysis, optimize the inventory. The Pareto principle shows that 80% of the output from the system is due to 20% of the input. According to this, inventory is segregated into 3 categories- A, B and C. In this manner, A products account for 80% of total sales, B products for 15%, and C products for the remaining 5%. This classification can be based on a number of variables, being the most commonly used the demand distribution and the annual dollar usage, nevertheless, attributes such as inventory cost, order size requirement, stockout penalty cost, and stockability can also be considered (Qaffas et al., 2023). For the distinct categories, different approaches should be accounted for when monitoring the products; A products should be closely monitored, and so, have low review periods. This frequent replenishment will lead to a decrease in on-hand inventory, meaning low safety stock, as the product is frequently replenished. This will also have repercussions at cost level (Silver et al., 2016).

Nematollahi et al. (2018) presents a two-level pharmaceutical supply chain comprising one distributor and one retailer with stochastic demand. A periodic review replenishment model (T,R), another notation used for the (R,S) previously referred. This study's goal is to fulfill a multi-objective model, that aims to ally the economic profit along the chain to the social benefit of guaranteeing a satisfactory level of service, decreasing the shortages and its impacts on patients' health. In order to do so, a Pareto optimal set of the multi-objective collaborative model, an augmented ε -constraint method is applied in order to achieve the optimal review period R and safety stock level. Additionally, some restrictions are considered. A maximum R of 14 days between reviews is imposed, as it is common practice in the industry. Furthermore, the distributor's lead time is also considered.

Moreover, Cunha et al. (2017) also refers to a case where a periodic review policy (R, S) is employed. In this single-item one-echelon supply chain backlogs, lost sales and uncertainty in demand are not negligible and the goal is to get optimal review periodicity and the inventory target level using two-stage stochastic programming.

Ambekar and Kapoor (2019) presents an optimization model for the current inventory policy of the public distribution system of food grain distribution stage. In this, a periodic review-based inventory policy was considered and through a simulation model, the objective was to get the optimal parameters of the policy, the review periods and base sock levels, in order to minimize the total costs on the supply chain. In this simulation, three main costs were considered, ordering, backorder, and holding costs, and three combinations were proposed based on the holding cost and altering the backorder costs as a multiple of the previous. A simulation was then conducted and using a Genetic Algorithm, the optimal parameters of the policy were achieved. The study also shows the penalty effects of the unavailability of the food grains repercussed in the backorder costs.

2.3.2 Schedule and order allocation

Allied to a correct definition of the review period, it is also important to consider factors such as the availability of human resources to place and receive orders when considering the optimal replenishment strategy. These factors are not usually taken into account when optimizing the policies due to the complexity that they introduce (Maestre et al., 2018).

From this perspective, more than optimizing the parameters, a new dimension is unraveled, where tactical decisions such as planning and scheduling, both order placement and reception, are the focal point.

In a case study concerning a healthcare facility, Cunha et al. (2017) presents a model that aims to optimize a hospital's inventory costs in pharmaceutical products logistics, both internal, among the echelon, and with suppliers. The model seeks to obtain the optimal quantities to acquire internally and externally and, additionally, define the schedule of delivery of the products.

Kees et al. (2019) purposes a plan for distributing pharmaceutical products from various suppliers. Based on an ABC classification, different replenishment frequencies are attributed to each supplier. Moreover, suppliers' lead time and uncertainty in demand are considered and a safety stock is contemplated in order to accommodate those factors. Shortages are also mentioned and can be due to restrictions imposed either in workload or storage space. Despite the layer of complexity introduced in this study, as a result of all the parameters mentioned, it fails into considering the reliability of the suppliers, as deliveries are set not to fail. Kees et al. (2019) intends to guide the decision process concerning the purchase and replenishment of the hospital supply chain. Furthermore, the problem is formulated to give visibility to focal parameters in inventory management; determining order quantity and frequency, optimal contract conditions with suppliers, optimal inventory levels at each care unit and pharmacy, and optimal allocation of resources to the replenishment process. By doing so, ultimately, the paper targets cost minimization- encompassing purchasing, transport, ordering, and labor costs- as well as minimizing the shortages of products.

Agra et al. (2019) also developed a case in healthcare in order to plan, on a weekly basis, the distribution of medical products. This approach aimed to guarantee a balanced allocation of resources without jeopardizing the restrictions of inventory capacities, safety stock levels, and vehicle capacities, as well as the minimization of deliveries made. The problem was formulated using a mixed integer formulation, nevertheless, as the complexity presented surpassed the model's ability to perform, a matheuristic was used in order to solve it.

In accordance with the previous, Jurado et al. (2016) too analyzed the health sector, where demand is considered to be uncertain and the complexity of the industry is taken into account. In this paper, workforce restrictions are considered alongside the goal to minimize inventory costs, order numbers, and demand dissatisfaction. The operational constraints enclose the capacity limitations of the pharmacies to receive and place orders. The identification of the optimal stock levels and parameters that indicate the quantity and frequency of order placement are expected through the usage of a chance-constrained model predictive control strategy.

Chapter 3

The Problem

In this Chapter, the challenge addressed in this project is going to be explained in further detail. Section 3.1 presents a description of the problem, as well as its improvement opportunities and main concerns. In Section 3.2, the existing practices are appropriately acknowledged, and Subsections 3.2.1, 3.2.2, and 3.3.3 outline the key processes in their current state (As-Is). The following Section, 3.3, mentions some analysis conducted in order to understand the key indicators and practices performed. Lastly, Section 3.4 introduces the modules proposed for addressing the presented problem, along with their main stages.

3.1 Problem description

Stock management has pivotal importance in companies with clear impacts on costs. Deciding upon the replenishment policy and the desired stock levels that most fit the company's needs helps to balance the inventory in order to avoid surplus and/or deficit stock. Nevertheless, as a consequence of the pharmaceutical sector's characteristics, having a replenishment policy that is aligned with expected demands does not eliminate the repercussions of the daily fluctuations that can occur due to variations both upstream and downstream in the value chain. This issue offers considerable challenges in the pharmaceutical industry, as significant changes in expected demand might result in stock inefficiencies. Furthermore, alterations in manufacturing processes caused by raw material shortages or regulatory limits might compromise order fulfillment, resulting in a bullwhip effect. This phenomenon, also known as demand amplification, describes the order variability that occurs throughout the supply chain. It proves that even a low variability in consumer demand can be magnified, creating large swings, the more upstream into the chain it is considered (Wang and Disney, 2016).

To handle these difficulties, it is critical to adopt robust demand forecasting tools, improve communication and collaboration across the supply chain, and preserve flexibility in the replenishment process. Recognizing that upstream changes are unavoidable and beyond the control of the distributor and focusing the emphasis on downstream alternatives might help forecast and respond to these changes, reducing their impact. In this regard, having a reactive sales forecast that can detect demand peaks and anticipate seasonal patterns is critical, as it reduces the risk of stockouts.

During the preliminary analysis, it was confirmed that the difficulties encountered along the three main axes- stock level management, service level, and operation management- were directly related to inefficiencies in the existing system. The current reactive sales prediction approach, which relied on sales data from the preceding months, allied to the lack of a robust replenishment policy definition, led to a mostly business expertise based policy. This qualitative perspective was vital for the replenishment process as the current suggestions of the Material Requirements Planning (MRP) software implemented were not fully aligned with the market's needs. Thus, a replenishment policy module was of prime importance. By developing a dynamic methodology that is capable of considering the forecast errors, suppliers' variability, and the desired service level, this module will allow the company to accurately define a purchase recommendation.

By jointly considering the inefficiencies in the sales prediction, the inaccuracy in the replenishment process, and the sector's uncertainty and variability, it is understood the cause of nearly 30% of the total orders being issued as out-of-calendar purchases. This strategy was used to a further extent than its purpose, to support targeted situations where, by the market's inconsistencies, reactive and proactive actions were needed to prevent shortages and guarantee the fulfillment of the demand. Nevertheless, analysis of the causes behind the high reliance on reactive measures revealed that business-related issues were the main factor. Firstly, partial deliveries by the laboratories contributed to the need for reactive measures in order to address stock shortages. Secondly, the presence of "sold-out" products[1] also contributed to that phenomenon. While the implementation of analytic-based and robust methodologies in forecasting and replenishment policies was expected to reduce the need for reactive measures, it is critical to recognize that a significant portion of these measures will persist due to the external sector's immutable characteristics. Raw material shortages, production constraints, and market dynamics all contribute to the requirement for reactive actions in efficiently controlling stock levels, highlighting the importance of a module that is able to account for these deviations in time to prevent shortages while trying to suggest the most adequate solution among the possible options.

Concerning a more tactical layer linked with warehouse operations balancing, the company presents the need to better control the inbound activity peaks. Though a methodology is currently implemented, it is extremely time-consuming and not automatized yet. This translates into a manual process where, by analyzing the predefined review frequency of each supplier, the number of Stock Keeping Units (SKUs) that each manufacturer supplies, and the workload associated with the review and the reception, a weekly and weekday allocation is conducted. The inefficacy of the process triggered the need to add an additional layer of complexity, by challenging the current supply delivery frequencies, as well as to standardize and automatize the process to promote a smooth balance in the warehouse operations.

[1] Products that are replenished by the supplier in quantity lower than 50% of the quantity purchased

3.2 Current practices

The pharmaceutical distributor, a major player in the market, offers a wide variety of products to a spectrum of national suppliers and customers. Six strategically positioned warehouses located in important areas of Portugal, and grouped in two regions, serve as the backbone of this network. All of the warehouses manage product reception and distribution, however, due to their different sizes and relative importance, they can be divided into two categories: central warehouses and peripheral warehouses. The two central regional warehouses are in charge of providing the respective peripheral warehouses in the event of product shortages or unavailability as a result of centralized product management. Within the organization, each location keeps its own unique portfolio, despite the replenishment process being centralized at the main facility, the northern central warehouse. Centralizing this process of order placement enables better management and offers a comprehensive viewpoint, allowing more flexibility in tactical decision-making. Nevertheless, each facility is replenished directly from the supplier, excluding some products that due to portfolio management are replenished from the regional central warehouses.

Within the following subsections, some considerations are going to be presented regarding the current practices to have a better understanding of the business.

3.2.1 Sales prediction and Replenishment policy

Currently, the business sales forecasts are based on an average sales approach, taking into account a variable time frame in accordance with the ABC classification of its products. This classification is based on the product sales that were seen in the previous 12 months, and it is updated as needed after each monthly review. Sales predictions are then calculated as the average of actual sales within the last 3, 6, and 12 months for A, B, and C products, respectively. It is also important to mention that the actual quantities sold are not in accordance with the orders requested by the downstream chain to the distributor. As a business characteristic, the raw demand observed from the pharmacies is usually inflated, as it is frequent that multiple orders are issued, multiple times a day, until demand is met. Having visibility of this, the company already performs some data treatment, eliminating, on a daily basis, duplicated orders, in the case of totally unfulfilled demand. The discrepancy can be seen in Figure 3.1.

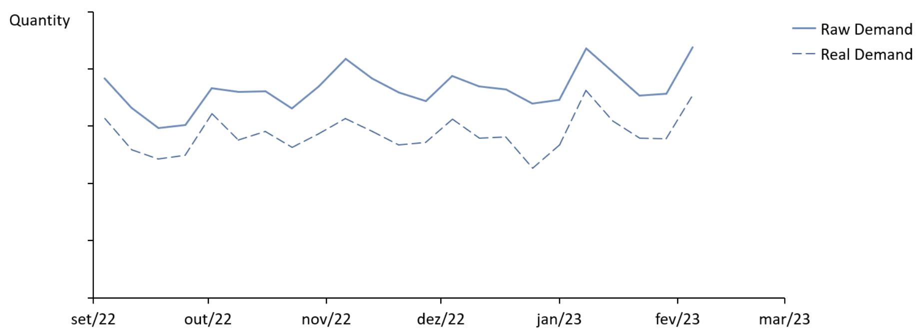

Figure 3.1: Comparison between raw demand and real demand

Based on the descriptive analysis and the mapping sessions performed with the stakeholders, the predicted sales frequently show a misalignment with the actual demand. As a result, the purchasing division extensively relies on its business knowledge to determine the most adequate quantity for each order performed at the SKU-warehouse level. Nevertheless, for some products, the full replenishment of the needs does not depend on the company's capability of doing so. In the pharmaceutical sector, the release of specific products referred to as "apportioned", is dependent on the company's market share percentage. Due to its scarcity, either caused by the lack of raw materials or production and regulation constraints, the demand proves to be higher than the company's ability to supply. Moreover, "sold-out" products exhibit similar behavior, however, the replenishment is not based on the market share but on the suppliers' intention to rationalize the product amongst the distributors. The fact that this misalignment of the quantity available and the quantity required by the market can be driven by external variables, contributes to the difficulties in the replenishment process.

3.2.2 Handling daily uncertainties

Concerning the operational level, Figure 3.2 shows the workflow of the purchasing team and their daily tasks.

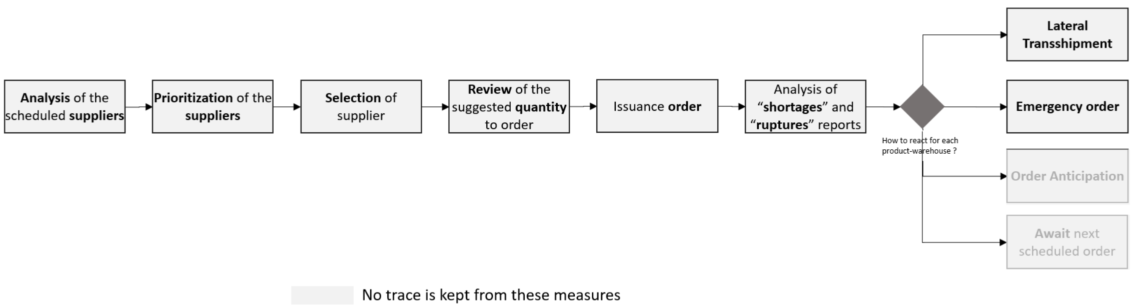

Figure 3.2: Workflow of the purchasing department

Accordingly, each member of the purchasing team starts by analyzing the suppliers previously allocated by their importance, considering the ABC classification. In this, the members review the suppliers' active portfolio [2] and issue a purchasing order with the products that need to be replenished with the quantities considered to be needed for the six warehouses.

After performing this task, the purchasing team then extracts two reports, one containing "shortages", products with stock on hand level of zero, and another with "ruptures", which are products that, according to the sales' prediction, are in risk of stockout within the next 5 days. In this analysis, business knowledge is key to obtaining the fittest decision to take in order to respond to "shortages" and "ruptures". To do so, the members assess the viability of out-of-calendar purchases and internal transshipments. Furthermore, performing an order anticipation or waiting for the next scheduled order are current practices, however, due to the lack of traceability

[2] By active portfolio is meant all the products with orders and receptions within the last relevant time horizon

for these measures, they will not be taken into consideration as practices in the current approach. This decision-making process does not have any standard procedures to follow, leading to different ways of performing the process, as well as different outcomes on what measures should be taken for similar situations. Moreover, there is not any structural document where the information needed to make the best decision is gathered, highlighting the current role of business sensitivity in the process.

As previously stated, certain products, "apportioned" and "sold-out", are particularly difficult to replenish and, as a result of scarcity and access barriers, are frequently considered in these reports. As a common practice, the purchasing team does not induce reactive measures, as they will not lead to considerable changes in the stock levels.

3.2.3 Scheduling order and review frequencies

Currently, each supplier's week and weekday allocation is defined once a year. This process is performed manually, taking into account constraints imposed by the suppliers, such as delivery frequency and restrictions regarding weekday deliveries. Given these restrictions and the goal of balancing inbound warehouse activities, this supplier's scheduling process proves to be extremely time-consuming. It is worth noting that this process only encompasses the definition of the week and weekday allocation as the review frequency is established beforehand and is considered immutable for this procedure.

The aim of this distribution is to both balance the workload of the purchasing team regarding the reviewing process and also to ensure that the warehouse operations do not experience planned peaks in the inbound area. To determine the annual distribution, the team begins by examining each supplier's number of distinct SKUs, which are directly converted into reception lines for simplification, and then the quantity that is, on average, received of each product. This phase is critical for determining which suppliers should be set apart due to their size and workload associated in order to minimize peaks in warehouse operations. This allocation is firstly performed on a weekly basis and subsequently on a weekday basis. Once the timeline for the supplier review plan is set, those are then assigned to the purchasing team members, taking into account a balanced workload distribution. This allocation attempts to maximize efficiency and effectiveness in managing supplier reviews while maintaining workload balance across the team.

3.3 Preliminary analysis

An intensive mapping of the main stakeholders, the commercial department, purchasing department, procurement department, and operations department was performed at the start of the project. This allowed for a better understanding of the business and the fundamental drivers of the current practices. In the present section, some preliminary descriptive analyses are going to be presented.

3.3.1 Demand Preliminary Analysis

Currently, the company resorts to an ABC classification in order to categorize the products by their relevance. Figure 3.3 presents the current distribution, where 3% of the products are class A, 18% belong to class B and the remaining to class C.

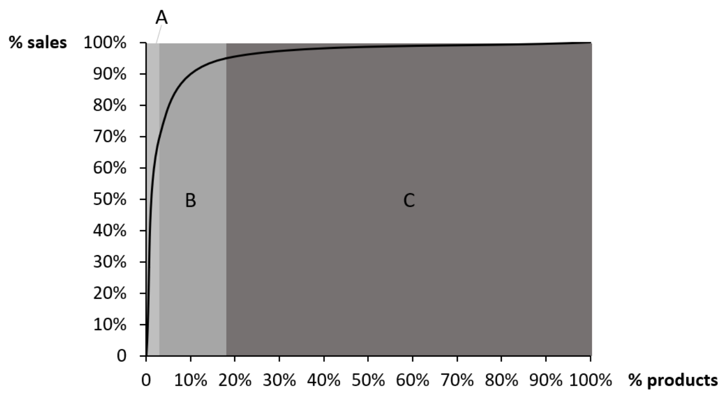

Figure 3.3: ABC analysis

Despite not being currently implemented, it is worth noting that a new classification was presented to the company and, due to the relevance of the information that it portrays, is going to be adopted in the company. The SEIL classification- Smooth, Erratic, Intermittent, and Lumpy is based on two dimensions, the variability in demand quantity - squared coefficient of variation- and the variability in demand timing - average inter-demand interval (E et al., 2022), i.e., a smooth product presents high stability in terms of the quantity ordered and the time frame when it is ordered. On the opposite end, the lumpy products have high volatility in being demanded and in the quantities ordered, as well as when this demand exists. This classification, shown in Figure 3.4 bought a new dimension to the company, that revealed the benefits of understanding the demand pattern and the predictability and volatility of each product.

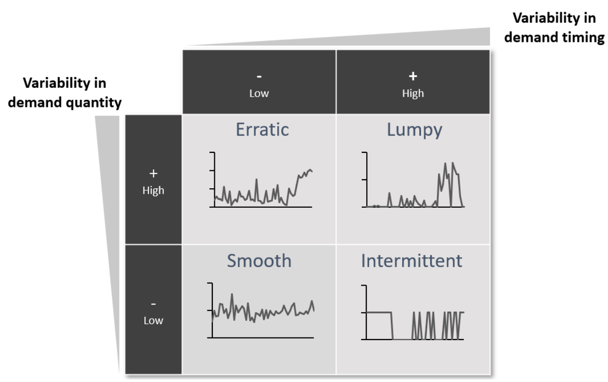

Figure 3.4: SEIL classification - Adapted from E et al. (2022)

Figure 3.5 demonstrates the distribution for a crossover between the ABC classification and SEIL classification. An analysis of the presented figure allows the company to understand the dimension that A-Smooth products present, as they are the most valuable for the company in terms of quantity and turnover and also are the more secure to predict sales as they are stable in regard to quantity sold and when it is sold.

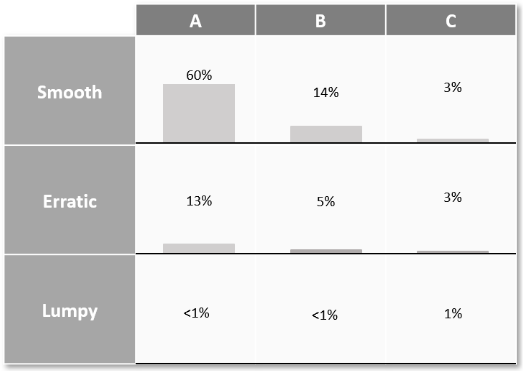

Figure 3.5: ABC-SEIL crossover classification and product distribution

One of the most relevant topics highlighted during the mapping sessions was the importance that "apportioned" products had in the daily operations of the company. In this regard, the products represent overall around 1% of the total portfolio of the company, nevertheless, when presented at ABC granularity, it is shown that for A products, around 32% of the sales recall to A "apportioned" and 39% from A not "apportioned". This comparison shows the preponderance of the "apportioned" in the analysis. Figure 3.6 details this desegregation for the remaining ABC classes.

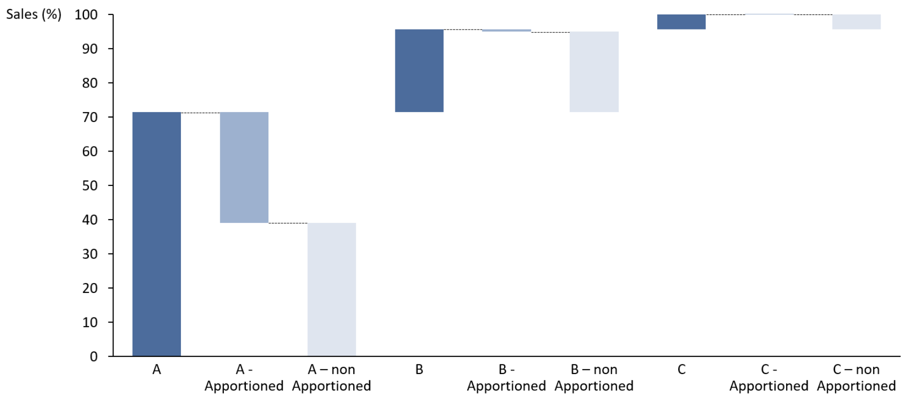

Figure 3.6: Demand categorized by ABC Class and "apportioned"

3.3.2 Service Level Preliminary Analysis

As the company is situated mid-chain, between the manufacturers and laboratories and the pharmacies, establishing two different service levels is of extreme importance.

Firstly, due to the characteristics of the pharmaceutical sector and lack of raw materials, the upstream chain proves to be highly inconsistent, both with delivery lead time and with quantity delivered. Though non-compliance in terms of quantity can be explained by external factors, such as raw materials shortage, compliance with the established lead time is only dependent on the supplier, and only 42% of the deliveries prove to be on time. Figure 3.7 presents a distribution by ABC classification proving that the capability of the distributor to meet the goals towards the customer is also conditioned by suppliers' poor service level, as the number of suppliers that deliver beyond the established lead time prove to be higher than the ones that comply with the theoretical time. Moreover, as 31% of the delayed suppliers are class A, it emphasizes the impact that these delays have on the performance of the distributor towards the customer.

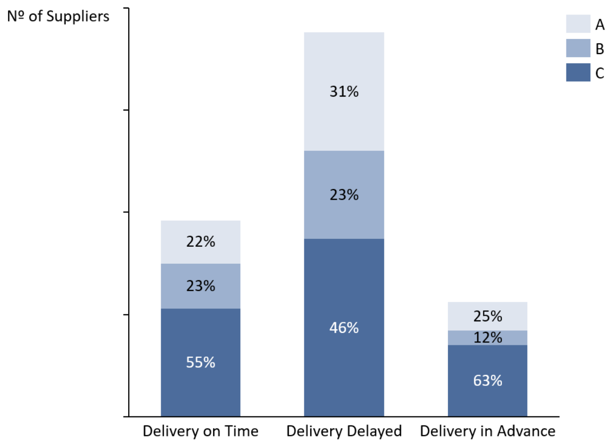

Figure 3.7: Suppliers' delivery time compliance analysis, according to the ABC classification

Moreover, an indicator particularly important for the company is the service level to the client. Currently, the company presents an overall service level of 96%, excluding from the analysis "apportioned" and "sold-outs", given that the failure to meet customer needs is not due to the distributor's inability to supply, but rather due to a generalized lack of product in the upstream chain. This service level is calculated based on the sales fulfilled over the total sales received, as through this calculation, the shortages are evidenced.

3.3.3 Stock Level Preliminary Analysis

One of the main challenges presented by the company was the ability to keep stock levels within the objective while fulfilling the increasing number of customers' requests. So, the aim to improve inventory management revealed the need to closely monitor the stock levels at product and ABC class granularity.

Figure 3.8 it is shown that 67% of the current stock, excluding "apportioned" and "sold-outs" belongs to A products, nevertheless, in order to have a target service level of 99%, the company would only need 70% of that amount. This proves that the challenges of having an optimal stock level are indeed, a reality. Regarding the C products, it is shown that this only accounts for 12% of the existing stock, nevertheless, this value is enough to ensure a 99% service level for those products. Thus, C products having a high inventory level can create inefficiencies due to their low turnover rate. Despite these high overall stock levels, not all account for the company's responsibility. A customer segment denominates "groups of pharmacies" contributes to a large portion of that stock. For these customers, a direct contact between manufacturers and pharmacies is established and stock is directly assigned to these customers. In this arrangement, the pharmaceutical distributor acts only as a cross-docking service. Usually, the laboratories assign a percentage of low-turnover products in order to promote sales, however, the pharmacies can choose not to purchase and the remaining stock is at the distributor's responsibility, increasing stock unwillingly.

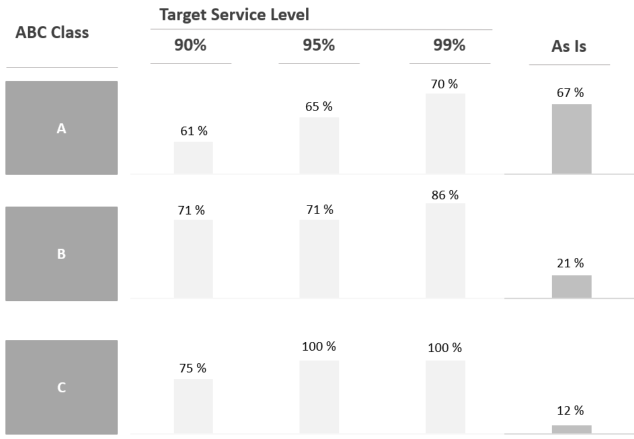

Figure 3.8: ABC class and service level analysis of the current stock level

3.3.4 Operations Preliminary Analysis

Another relevant dimension is the warehouse operations, due to suppliers' volatility in complying with lead times. The alteration of the proposed arrival leads to peaks in inbound operations.

To address this challenge, the company has created a calendar for the suppliers more tailored to real lead times, that since the beginning of the year has proved to be more efficient, which is reflected in more balanced warehouse operations. As each one of the 6 warehouses has specific and variable capacities, portfolio on hand, and workforce in the inbound operations, it is extremely difficult to coordinate and manually create a schedule that fits all the locations according to the limited number of lines that each location has. To compare the variability of the inbound operations, the coefficient of variation (CV), calculated according to Equation 3.1, was used. As demonstrated in Figure 3.9, which presents the variability along the weekdays, and Figure 3.10, which showcases the variability within the month throughout each month, it is noticeable that when comparing the two years, in 2023, a lower variability is shown.

$$CV = \frac{\text{Standard Deviation}}{\text{Average}} \tag{3.1}$$

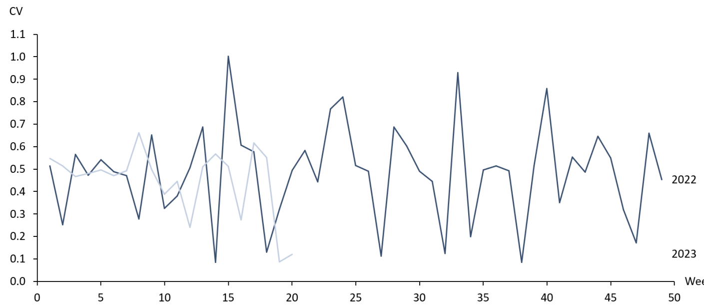

Figure 3.9: Inbound receptions variability at week granularity

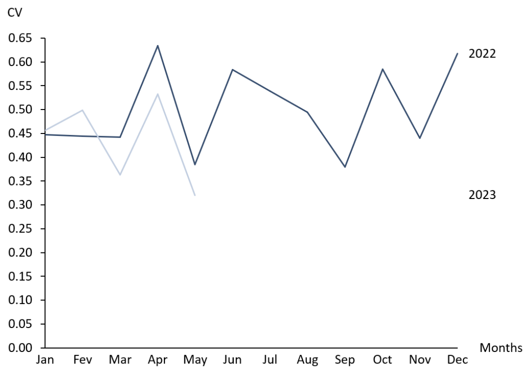

Figure 3.10: Inbound receptions variability at month granularity

These improvements in warehouse operations are a consequence of the process previously mentioned.

3.4 The proposed approach

Considering the importance of addressing the challenges associated with the current replenishment process, daily uncertainties, and the need for a more adaptable and efficient supplier scheduling, a more robust and analytical based approach is proposed to these subjects. This comprises three distinct modules: the first module, the replenishment policy module, the second, where the daily uncertainties are handled, and, lastly, a third module, where a tactical perspective is adopted.

Firstly, the replenishment policy module aims to provide the company with an appropriate replenishment algorithm parametrization so that a reliable and automatic purchase recommendation through the MRP software can be guaranteed. As a first step in this approach, it is necessary to determine the most appropriate replenishment policy. Considering that the company already follows a periodic replenishment approach and has the capability to incorporate parameters into the existing software, as a similar approach is now considered, the decision has been made to adopt the periodic review policy (R, s, S). This policy, as demonstrated in Chapter 2, has proven to be successful in the healthcare sector, confirming its applicability to the current project. Additionally, the main stakeholders involved were already familiar with the proposed approach, and the policy's explainability further solidified its selection as the most suitable choice.

Having set the replenishment policy to adopt, the definition of the parameter was based on the sales forecast, developed prior to this module.

Regarding the module that supports the responses to the daily uncertainty, the main objective is to provide a list of recommendations that present the most suitable and cost-effective options for products that are at risk of stockout, based on sales predictions and the parameters resulting from the replenishment policy. The recommendations will be leveraged through four options: order anticipation, emergency orders, lateral transshipments and await the next scheduled order. This module will be used daily and its goal is to replace the "shortages" and "ruptures" report that the purchasing team uses daily.

The proposed approach will start by identifying the products that have no stock or that are at risk of shortage within a time horizon to be defined more in-depth in the following chapter. Then, business rules and restrictions are applied in order to create a cost and a warehouse balance base to, through an optimization model, suggest the most appropriate decision, at SKU-warehouse granularity.

The last module's aim is, from a tactical point of view, to lever the company with a new analytic layer, by determining the best review period for each supplier, followed by the schedule planning that best balances operations and costs. The definition of this calendar is predicted to be done only once a year and weekly adjustments should continue to be an *ad-hoc* measure, performed manually when needed. The proposed approach will be divided into two main modules, being the first the definition of the best order frequency for each supplier. Sequentially, an optimization approach to decide the weekday allocation is performed. The module takes into consideration stock costs and the warehouse operations balancing to determine all the variables. Though not yet implemented, the module also encompasses a third stage where suppliers are assigned to each purchasing team member.

Chapter 4

Methodology

This chapter aims to demonstrate the methodology developed to address the replenishment policy definition, followed by the challenge to effectively handle daily uncertainty and to ensure an optimal suppliers' allocation. Section 4.1 encompasses the methodology used to define the parameters that characterize the (R,s,S) replenishment policy, and in subsection 4.1.1. the components that integrate each parameter are further explained. Section 4.2 focuses on the daily deviations and how to react to and prevent them, with subsection 4.2.1 providing a comprehensive description of the approach and its phases. Subsections 4.2.2 and 4.2.3 aim to present the model, its restrictions, characteristics, and the formulated solution. Moving on to section 4.3, the latest problem is introduced. Subsections 4.3.1, 4.3.2, and 4.3.3 present the methodology, model and restrictions used to ensure a balanced supplier scheduling.

4.1 Replenishment policy - Methodology Definition

The objective of this module is to develop a replenishment policy algorithm that facilitates order planning. By generating the policy's parameters to be directly implemented into the MRP software, the approach supports the assessment of the most suitable order quantity for each SKU-warehouse combination.

The company already presents a structured replenishment process, nevertheless, the limitations that precede the process introduce incoherence in the quantity suggested. By being based on a forecast that does not account for the fluctuations and seasonality, highly frequent in the industry, and the nonexistence of safety stock that deals with those unaccounted situations, the inaccuracy of the purchase recommendations is explained.

Hence, it is imperative to implement a replenishment policy that relies on advanced sales forecasting and incorporates well-defined parameters aligned with the external environment, while ensuring the attainment of the desired service level. The parameters' definition on a daily base and in *ad hoc* situations allow for the reliability of regular updates according to the external factors reflected in the forecast and also for the freedom to adjust the parameterized service levels in a developed interface.

As mentioned in Chapter 3, the policy chosen is the period review (R,s,S), which is characterized by the reorder point, *s*, and the order-up-to level, *S*. The determination of these parameters involved the combination of mathematical formulations, and specific business requirements. A holistic approach was considered to ensure that the parameters aligned with both operational and tactical objectives, namely, the desired level of service fulfillment and the assigned review period, *R*. Furthermore, the calculations are considered at SKU-warehouse granularity, recognizing the varying needs and characteristics of each location.

The following subsections will focus on the calculations established for the parameters, as well as incorporating some concepts that are relevant to comprehensively understand the parameters' definition.

4.1.1 Reorder and Order-up-to levels definition

The definition of the reorder point, *s*, and the order-up-to level, *S*, are based on their respective functions within the replenishment policy. The reorder point is designed to ensure that the existing stock is sufficient to meet demand until the following scheduled order. On another standing point, the order-up-to-level is responsible for determining the inventory needed to support the replenishment frequency. Both of these parameters consist of two distinct components, the cycle stock, and the safety stock. The cycle stock is intended to fulfill the expected needs until the next review period. It represents the portion of inventory that is used in a regular and predictable manner based on historical demand patterns or forecast sales. These concepts are illustrated in Figure 4.1

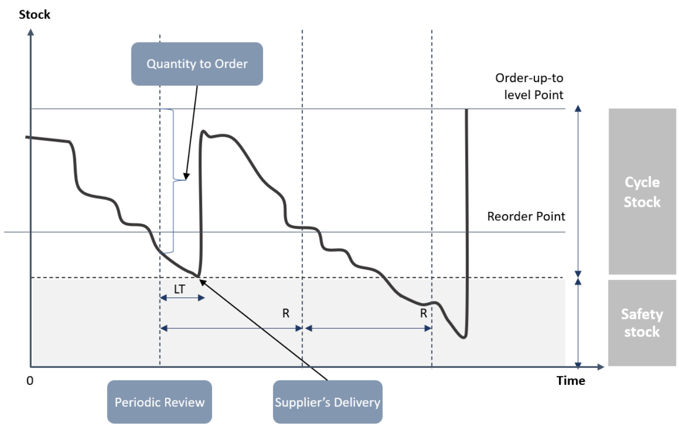

Figure 4.1: (R,s,S) inventory policy - Adapted from Silver et al. (2016)

In contrast, the safety stock is included to account for the multiple sources of uncertainty. It serves as a buffer to absorb unpredictable variations and mitigate the risk of stockouts.

In Equation 4.1, it is evidenced that the reorder point is influenced by the predicted sales, $\hat{x}$, occurring during the review period, *R*, plus the lead time of the supplier, *LT*. This accounts for the demand requirements within the protection period horizon. In addition, due to the complex environment in which the company operates, it is essential to consider a buffer - safety stock, *SS*.

Regarding the order-up-to level, S, it takes into account the desired purchase periodicity, N, in addition to the delivery lead time, LT, considering the SS component, as seen in Equation 4.2.

$$s = \hat{x}_{R+LT} + SS \tag{4.1}$$

$$S = \hat{x}_{N+LT} + SS \tag{4.2}$$

Safety stock

According to King (2019), safety stock can be defined as the inventory carried to prevent stockouts, which can be caused by uncertainty in demand, forecast inaccuracy, and variability in lead times. By maintaining an appropriate level of safety stock, the company can enhance its ability to respond to unexpected changes in demand and guarantee the fulfillment of the desired service level.

As the demand is considered uncertain and foretasted, the variability associated is determined by σ_D, accounted during the protection period P. Regarding the variability associated with the lead time, σ_{LT}, the same is calculated over the average daily forecast during the protection period D_{avg} (Equation 4.3).

$$SafetyStock = Z \cdot \sqrt{(P \cdot \sigma_D^2) + (\sigma_{LT} \cdot D_{avg})^2} \tag{4.3}$$

Despite the uncertainties mentioned, due to business constraints, the lead time variability is not taken into consideration. This relies on the fact that, as the company currently does not account for a buffer layer, the increment of the safety stock is viewed cautiously so that stock levels are maintained within the objectives.

Service level

According to Radasanu et al. (2016), service level can be defined as the probability to fulfill the demand required without incurring shortages during the next replenishment cycle. Setting the service level strategically requires careful consideration of its impact on the stock. While a higher service level is essential for ensuring customer satisfaction, it also implies a higher safety stock to accommodate the unpredictability at both ends of the supply chain. This has immediate repercussions at the parameters s and S due to its dependence on the safety stock component. However, it is important to recognize that the service level represents a trade-off between customer satisfaction and inventory costs and efficiency. Higher service levels entail higher inventory carrying costs and potentially increased operational complexity. Therefore, companies often adopt different service levels for different classifications of products, commonly based on the ABC classification. This ensures that products that are more valuable for the company present a lower risk of stockouts.

4.2 Handling Daily Uncertainties - Methodology Definition

The goal of the proposed model is to provide recommendations to deal with and mitigate the consequences of the daily fluctuations inherent to the pharmaceutical sector. Through a daily report that identifies products that are expected to face stockouts on the relevant upcoming horizon, the members of the purchasing departments will be able to visualize the recommendation alongside the viable options, so that an informed decision can be made.

Table 4.1 demonstrated the three main steps that the present model encompasses, performed at SKU-warehouse level.

Table 4.1: Stages of the support module for daily uncertainties

Stage	Step Description
Identification of products in risk of stockout	1. Setting the time horizon to consider 2. Assess the predicted sales and compare to the stock on-hand 3. Determine products at risk or already in stockout
Assess the possible measures to apply	1. For each decision, consider the business restrictions and determine the admissible measures
Cost and warehouse balancing analysis	1. For each measure feasible, determine the costs associated 2. Assess the impacts of each binary in the warehouse operations 3. Through an optimization model, determine the recommendations that minimize the costs and warehouse unbalance

4.2.1 The approach

An optimization model based on a linear multi-objective programming formulation was developed in order to assess the strategy that would lead to a more cost-beneficial and warehouse operations balancing solution for the set of SKU-warehouses in analysis.

To detect possible stockouts at the product-warehouse level, the proposed model integrates several key components. Firstly, sales predictions are considered to estimate future demand. Additionally, the parameters outputted from the established replenishment policy are used to accurately assess the needs. Furthermore, the stock on hand is used to assess if a measure is required.

The module resorts to four pillars to support the reaction and prevention of uncertainty- order anticipation, emergency order, lateral transshipments, and await the next scheduled order.

Regarding order anticipation, this decision aims to identify suppliers whose portfolio has a high number of products at risk of stockout. The determination of products at risk of a stockout is considered at the SKU-warehouse granularity, nevertheless, to decide upon order anticipation, aggregation at the supplier level is conducted. Hence, this recommendation leads to a full review of the supplier's active portfolio, and, consequently, an increment in the purchasing team's workload. The main characteristic of this suggestion is the alteration of the scheduled order to an earlier date, which leads to an increment of the time horizon to be replenished by that order, as demonstrated in the example of Figure 4.2, and, consequently, the replenishment parameters are redefined in order to accommodate the extended horizon. Due to these unplanned alterations, order anticipation creates considerable entropy at the warehouse operations, affecting the balance in the receptions already planned. Nevertheless, as this measure dismisses the scheduled order, these alterations can be conceived as a reallocation of workload between the two days.

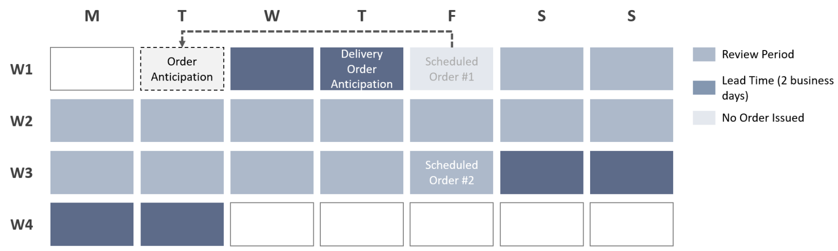

Figure 4.2: Order anticipation - replenishment period determination

Regarding emergency orders, the decision-making is considered at the SKU-warehouse level, as this option addresses more targeted situations. This measure does not impact the already scheduled order that follows, aiming only to reduce shortages up until that moment. So, the impacts that emergency orders cause in warehouse operations are significantly lower than those created by order anticipation, due to the number of products received, nevertheless, it does not lead to a workload reallocation, but additional inbound effort.

Lateral transshipments are characterized by shipments of products at a regional level and among the two central warehouses. The first premise to be taken into consideration is that transfers are only allowed if the stock level at the source warehouse is above the order-up-to-level. Adopting a more conservative approach, an additional layer of safety is applied to that threshold to ensure that unexpected demand would not result in stockout at the source caused by internal product movements. A parameterized buffer of 20% is considered allowing only surplus stock over this level to be shipped. To assess which warehouses are admissible to be considered as the source, the surplus at SKU-warehouse granularity is calculated for the admissible warehouses. This decision does not impact the original scheduled order, nor the overall stock levels, as a reallocation of the stock occurs.

Lastly, the option to await the next scheduled order does not impose any restrictions. Due to its passive nature, this option leads to a decrease in service level as it does not address the shortages verified.

Following this stage, a cost-based analysis is conducted. For each option, costs and the impacts in inbound operations are calculated based on the nature of the decision.

As a consequence of the definition of the cost, not all are applied to every measure presented. Holding costs are only applicable to decisions that lead to an increment of stock levels - order anticipation and emergency orders. Handling and transportation costs are only considered for lateral transshipments. Operations costs take into consideration the destination warehouse, so have to be considered in all the reactive measures. Stockout costs are considered in all four options.

As a last step, a linear programming model is developed where costs and inbound operations unbalancing is taken into consideration in the objective function with the aim of being minimized.

4.2.2 Model Formulation

In the present subsection, the goal is to better define the model as well as the constraints and assumptions are taken into account to develop the module.

For each SKU-warehouse, the period to consider in order to assess the risk of stockout comprehends the horizon between the day in analysis and the scheduled order date that follows. At this period, the supplier's lead time is added in order to encompass possible stockout occurrences, as exemplified in Figure 4.3. This period varies at the supplier level and warehouse level, as some discrepancies in the delivery time were found among the warehouses. This granularity allows for a more accurate assessment of the possible shortages and needs. For the horizon considered, the predicted sales are determined and compared with the existent stock on hand. Each SKU-warehouse binary is then considered at risk if the stock available does not fulfill the predicted sales. By considering only the stock on hand, the presented approach adopts a conservative point of view as the primary focus lies on clients' service levels. Despite being able to trace orders in transit and being visible in the report, the unpredictability that characterizes the pharmaceutical industry requires more cautious considerations.

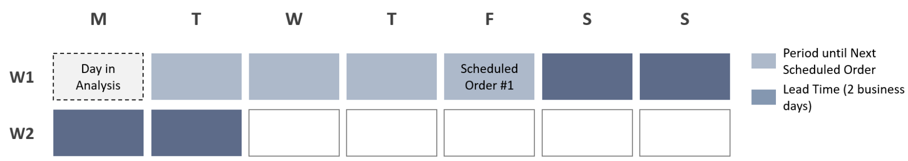

Figure 4.3: Stockout assessment - period to consider

The following stages exhibit variations based on the solution under consideration, to evaluate the measure's admissibility.

Concerning order anticipation, the decision is taken at the supplier level, and after assessing the products at risk of stockout, these are aggregated at the mentioned granularity. As the suggestion leads to a considerable increase in workload not only at the order reception level but also impacting the purchasing team member's work balance, a threshold is considered in order to approve the decision. By setting a 10% threshold after a sensitivity analysis was conducted with the stakeholders, only suppliers whose active portfolio at risk is higher than this limit are considered admissible for this measure.

After determining the suppliers and SKU-warehouses to be considered, the order quantity definition follows. As mentioned, order anticipation requires a redefinition of the replenishment parameters so that the horizon considered is dully replenished. This step is vital in order to determine the quantity expected to be ordered, which is calculated according to Equation 4.4.

$$Quantity\_To\_Order = Order\_up\_to\_level - Stock\_on\_hand \tag{4.4}$$

Regarding the emergency order option, as the period to replenish is equal to the period in which the risk of stockouts is assessed, the quantity requirements for this option are already determined, also based on the Equation 4.4, with the respective input values for each SKU-warehouse.

Considering the possibility of lateral transshipments, it is mandatory to determine the surplus quantity of the remaining warehouses from which the transfers are possible to be executed. The surplus quantity is calculated as the excess stock between the stock on hand and the order-up-to level, considering the buffer layer added by the multiplier, as demonstrated in Equation 4.5.

$$Surplus = Stock\_on\_hand - Order\_up\_to\_level \cdot Multiplier \tag{4.5}$$

Admissible transshipments are then considered only from sources with a positive surplus. In addition to that, business constraints ensure that only sources with surplus that can fully fulfill the needs of the destination warehouse are considered. The reasoning behind this decision is that if partial transshipments were to be considered, the SKU-warehouse binary would appear in the report multiple days as shortages would still be predicted to occur. To prevent over usage of the reactive measures these are not considered, even though benefits at the service level could be obtained. Nevertheless, the visibility of partial transshipments and the corresponding fulfillment percentages is given to the purchasing team, as the company presents specific constraints where partial shipments have to be considered, as in the cases of centralized products.

For awaiting the next order scheduled, no further calculations are needed.

In the last phase, a cost-based analysis and then optimization are conducted. Regarding the cost analysis, four main costs were considered for the module. In Chapter 2, their main characteristics are already enunciated, so the following will briefly describe some aspects that are important to the formulation of the present module.

Holding Costs

As holding costs derive from the existence of inventory stored, these will only be applied to order anticipation and emergency orders directly to the quantity ordered.

Stockout Costs

Lost sales costs were not thoroughly mapped at the company, so in order to incorporate this indicator that serves as a loss in service level measure, assumptions were set jointly with the company. As a consequence of the difficulty to trace the products' margins, it was assumed that 100% of the sales price to the pharmacy was lost. Furthermore, to quantify the stockout, the depth of the shortage will be considered.

As previously mentioned, in the pharmaceutical sector, regulations, and product scarcity lead to a limitation in product delivery. These products, "apportioned" and "sold out", are not considered in the stockout costs as they are not a consequence of the distributor's incapacity to predict and react to the market's changes.

Operation Costs

As a key dimension of the project, warehouse operations costs are estimated to reflect the unbalancing at the inbound level caused by the recommendations. These costs will be applied to every reactive measure presented, hence excluding the decision to wait for the next order scheduled. In order to calculate the cost of the warehouse operations, first the inbound processes were mapped at the different warehouses that, due to different sizes and capacities, present distinct inbound line limits that can, utmost, be received. Noting that though this restriction exists, there is flexibility in surplussing the limited number of lines. Considering this limit, as well as the number of employees assigned to the reception operations, an average cost per inbound line was determined at the warehouse level. As mentioned, each distinct SKU leads to an inbound line, for simplification purposes. So, having the number of distinct SKUs that each recommendation impacts, warehouse operations costs can be easily attained. Moreover, a sensitivity analysis was conducted so that the qualitative aspect of surplussing the limit inbound lines could be taken into consideration. Through a parameterized factor, β, attributed to the lines that are received beyond the limit number, it was possible to demonstrate its relative importance to the overall costs.

Handling and Transportation Costs

When considering lateral transshipments it is crucial to keep track of the costs related to handling and transportation of the products between warehouses. It is relevant to mention that costs related to the routes are not considered as the routes between the regional warehouses and the central ones already exist and are performed frequently.

The definition of all the costs is going to be presented in the following subsection.

4.2.3 Model Optimization

The present section aims to formulate the previous methodology presented. Firstly the variables and parameters used in the formulation are presented in Table 4.2. In subsection 4.1.3.1 the relevant costs are defined and the objective function, which is focused on minimizing total costs and warehouse unbalancing. The following section refers to the model constraints and the business restrictions applied.

Table 4.2: Table of notation for the uncertainty handler module's formulation.

Sets	
R	Set of recommendations (indexed by r) - emergency order, order anticipation, lateral transshipment, await next order scheduled
W	Set of warehouses (indexed by w)
P_w	Set of products in warehouse w that belong to the list of products at risk of stockout
S_p	Set of suppliers that have products p in the list of products at risk of stockout
Parameters	
$Qt\_Ordered_{p,w,r}$	Quantity of product p ordered for warehouse w according to recommendation r

$Qt\_Stockout_{p,w,r}$	Quantity predicted to stockout of product p for warehouse w according to recommendation r
$Qt\_Shipped_{p,i,j}$	Quantity of product p shipped between source warehouse i and destination warehouse j
$WACC$	Weighted average cost of capital
$Period\_hold_{p,w,r}$	Predicted period, in days, during which the stock of product p accounted for in the recommendation r is going to be kept at warehouse w
N_FTE_w	Number of FTEs in each warehouse w
W_FTE	Wage of each FTE
$N\_lim\_lines_w$	Number of limit lines to be received in each warehouse w
H	Number of working hours per FTE
$Unit\_Transp\_Cost$	Cost of transporting one unit between warehouses
$Unit\_Handling\_Cost$	Cost of handling one unit at each warehouse
ASP_p	Average sales price to the pharmacy for each product p
APC_p	Average purchase cost of product p to the manufacturer
β	Parameterized weight attributed over the limit inbound lines
$Line\_oper_w$	Cost of the impact of one line to be received within the limit value for each warehouse w
NW_p	Number of warehouses that have each product p at risk of stockout
N_s	Number of products that supplier s has in the list of products at risk of stockout
$Add\_lines_{p,w,r}$	Number of additional reception lines for each product p in each warehouse w according to each recommendation r
$W\_Add\_lines_{p,w,r}$	Weight of additional reception lines for each product p in each warehouse w according to each recommendation r, variable equal to 1 if the number of lines is within the objective number for the warehouse w, β if beyond
Decision Variables	
$X_{p,w,r}$	Binary variable that equals 1 if for product p in warehouse w recommendation r is chosen, and 0 otherwise
Auxiliary Variables	
$A_{s,r}$	Binary variable that equals 1 if the recommendation "Order Anticipation" is chosen for products of supplier s, and 0 otherwise

4.2.3.1 Cost definition and objective function

In the present mathematical formulation, the objective function is to minimize the sum of the total costs and the unbalance caused in the warehouse operations.

Holding Costs

Holding cost is obtained by multiplying the unitary average purchase cost of each product by the increment in stock caused by the purchase of the related quantity, taking into consideration the weighted average cost of capital during the period that the stock is planned to be in the warehouse (Equation 4.6).

$$HoldingCost = \sum_{p\in P}\sum_{w\in W}\sum_{r\in R} X_{p,w,r}\cdot APC_p\cdot Qt\_Ordered_{p,w,r}\cdot \frac{WACC}{365}\cdot Period\_hold_{p,w,r},\quad r\in\{"EmergencyOrder","OrderAnticipation"\} \tag{4.6}$$

Stockout Costs

Regarding the stockout cost, this is calculated taking into consideration the depth of the shortage,i.e., the quantity in stockout, multiplied by the average sales price to the pharmacy (Equation 4.7).

$$StockoutCost = \sum_{p\in P}\sum_{w\in W}\sum_{r\in R} X_{p,w,r}\cdot ASP_p\cdot Qt\_Stockout_{p,w,r} \tag{4.7}$$

Operation Costs

To determine the operation cost, first, the operating cost per line in each warehouse needs to be determined (Equation 4.8). In order to do so, it is considered the number of limit lines in each warehouse divided by the number of Full Time Equivalents (FTEs) in the respective locations, multiplied by their wage per hour.

$$CostofLineReception_w = \frac{N\_lim\_lines_w}{N\_FTE_w\cdot H}\cdot W\_FTE, \forall w\in W \tag{4.8}$$

Having the line cost in each warehouse, the operation cost is determined by multiplying the number of added lines for each product-warehouse-recommendation set by the weight attributed to those additional lines. Lastly, the cost of each line in each warehouse, previously defined, is also taken into consideration (Equation 4.9).

$$OperationCost = \sum_{p\in P}\sum_{w\in W}\sum_{r\in R} X_{p,w,r}\cdot Add\_lines_{p,w,r}\cdot W\_Add\_lines_{p,w,r}\cdot CostofLineReception_w \tag{4.9}$$

Handling and Transportation Costs

The handling cost regards the maneuver of material and is only considered for internal transshipments. This is calculated by multiplying the unitary handling cost by the quantity shipped from the warehouse source *i* to warehouse destination *j* (Equation 4.10).

$$HandlingCost = \sum_{p\in P}\sum_{i\in W\setminus\{j\}}\sum_{j\in W} X_{p,w,r}\cdot Unit\_Handling\_Cost\cdot Qt\_Shipped_{p,i,j} \tag{4.10}$$

Regarding the transportation cost, this also considers the quantity shipped between the binary warehouse source, *i* - warehouse destination, *j* impacted by the unitary transportation cost (Equation 4.11).

$$TransportationCost = \sum_{p \in P} \sum_{i \in W \setminus \{j\}} \sum_{j \in W} X_{p,w,r} \cdot Unit\_Transp\_Cost \cdot Qt\_Shipped_{p,i,j} \tag{4.11}$$

Warehouse Operations Balancing

The warehouse operations balancing costs are calculated taking into account if the lines to be inbound are received within the limit number or not and the value attributed to the reception of each line (Equation 4.12) .

$$WarehouseBalancingCost = \sum_{p \in P} \sum_{w \in W} \sum_{r \in R} X_{p,w,r} \cdot Add\_lines_{p,w,r} \cdot W\_Add\_lines_{p,w,r} \cdot Line\_oper_w \tag{4.12}$$

Considering all the terms above, the objective function is given by the sum of all the costs and the impacts in warehouse operations (Equation 4.13) :

$$\begin{aligned} Minimize \sum HoldingCost + StockoutCost + OperationCost + HandlingCost \\ + TransportationCost + WarehouseBalancingCost \end{aligned} \tag{4.13}$$

4.2.3.2 Constraints

Having defined the objective function, it is relevant to formulate the problem's constraints. In this section, the model, and business constraints are going to be presented.

Ensuring that only one recommendation is proposed

For each combination of SKU-warehouse that is at risk of stockout, the recommendation provided should only be one of the four possible solutions (Equation 4.14) .

$$\sum_{r \in R} X_{p,w,r} = 1, \forall w \in W, p \in P \tag{4.14}$$

Order anticipation and recommendation coherence

As mentioned, the decision for order anticipation has impacted the supplier's level. Therefore, it is mandatory to ensure that if for one of the products the suggestion given is to perform an order anticipation, for all products of that supplier must be recommended an order anticipation. In Equation 4.15 the number of warehouses in which each product has to be placed is determined. Furthermore, Equation 4.16 guarantees that the auxiliary variable is only equal to 1 if the recommendation is "Order Anticipation" while Equation 4.17 ensures the aggregation of the recommendation at the supplier's level, considering the number of products and warehouses that are at risk.

$$NW_p = \sum_{w \in W} X_{p,w,r}, \forall p \in P, r \in R \tag{4.15}$$

$$A_{s,r} = 0, r \notin \{"OrderAnticipation"\} \tag{4.16}$$

$$A_{s,r} \cdot N_s - \sum_{p \in P} \frac{X_{p,w,r}}{NW_p} = 0, \forall s \in S, w \in W, r \in \{"OrderAnticipation"\} \tag{4.17}$$

Non-negativity of the variables

Equation 4.18 guarantees that the variables set in the formulation are according to their specifications.

$$X_{p,w,r}, A_{s,r} \in \{0,1\} \tag{4.18}$$

Business restrictions

As previously stated, there are some business constraints that limit the possible options for each SKU-warehouse. As the peripheral warehouses present a smaller capacity, the scope of their portfolio is smaller. Products that, by portfolio management, are not considered in those warehouses, are also not considered in the scope of the report. There are products that, even though are considered in the catalog of the smaller warehouses, have centralized order planning due to minimum quantity restrictions. For the latest, the recommendation provided is, forcefully, to transfer, even if the central warehouse does not have excess stock. This suggestion aims to provide visibility of the product's condition.

Regarding products considered as "C" in the ABC classification, the only recommendation possible is to wait for the next scheduled order, as they have a diminished relevance in sales values. As so, the aim is to portray the possible options, nevertheless, with the final recommendation of waiting.

It is also relevant to display in-transit shipments. Although this quantity is not considered in the available stock, due to delivery uncertainties, it allows the purchasing member to make a more informed decision. For products with quantity in transit, the recommendation is restricted to waiting for the next scheduled order.

Finally, it is considered that transshipments are only viable as a final recommendation if the percentage of the needs in the destination warehouse are fully fulfilled by the source's surplus.

4.3 Tactical Support- Methodology Definition

The main goal of this tactical module is to guarantee a supplier order allocation that ensures the balancing of warehouse operations. The allocations defined are based on the optimal review frequencies suggested and will be considered for the replenishment of all the warehouses as well as a base for the purchasing team to schedule their workload and suppliers' assignments. As a tactical decision, this module is set to perform yearly or every six months and in specific *ad-hoc* situations where a restructure is needed.

The proposed approach suggests the establishment of two models in order to first determine the optimal review frequency for each supplier and sequentially, considering the suggestions, assess the fittest week and weekday allocation for order scheduling. A third phase is still in development, however, its aim relies on the distribution of the suppliers through the purchasing team members.

Though this methodology proves to be a simplification of a more complex and non-linear solution, the benefits of being able to compute a globally optimal solution do not surplus the complexity brought by this approach. Moreover, the possibility to discretize the model and consider all the viable possibilities for each of the three variables was considered, nevertheless, the computational complexity of this approach could decrease the performance of the module due to the need for *ad hoc* use cases. Hence, as a two-model approach that encompasses the benefits of the computation speed and the ability to achieve results in line with the company's objectives, it proves to be the most suitable option.

Figure 4.4 illustrates how the present approach aims to evaluate the trade-off between the stock costs and the workload balance in warehouse operations. As seen, more frequent replenishment lead to lower stock costs as a consequence of the lower inventory level needed to fulfill the needs, however, it requires a higher workload at the warehouse operations level. On the contrary, less frequent replenishment implies higher stock costs as the quantity of stock necessary to guarantee the service level established is also greater, despite the fact that generates less inbound effort on the receptions.

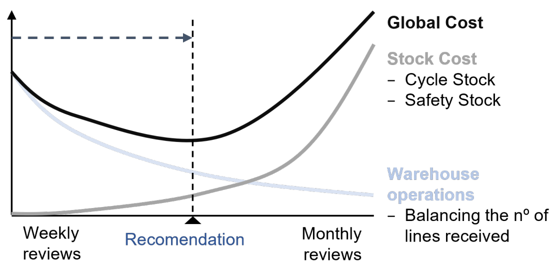

Figure 4.4: Stock costs vs Inbound operations balancing - Recommendation point

Through balancing these costs, a minimum cost can be achieved. This demonstrates the importance of defining appropriate review periods for each supplier.

4.3.1 Model formulation

As mentioned, this module has two main optimization models, in order to achieve a calendar with the suppliers' order scheduling. Resorting to two linear programming models tightly connected, the proposed output's objective is to, at a tactical level, improve warehouse operations, guaranteeing, upfront, the most fitting calendar, while ensuring that the suggested review frequency, which impacts stock levels, also aims to minimize this important dimension.

Review frequency

Regarding the primary model, the main concern is to determine, for each supplier, the review frequency with a robust and analytic base, that opposes the current practice in which this decision is already established. As already in practice, the possible review frequencies considered are weekly, 7 days, biweekly, 14 days, and lastly, monthly, 28 days.

In order to assess the best review period, two main inputs are considered. A simulation built based on the replenishment policy, however, outside of the scope of this thesis, revealed a major contribution as the input. Within this context, three scenarios according to the three possible review frequencies are generated to assess the average stock on-hand needed for the forward planned horizon in each situation. This inventory level is calculated according to the order receptions and predicted sales and also takes into account the parameterized service level to guarantee an alignment with the company's goals. Having this parameter set for each calendar frequency, it was possible to calculate the stock cost for each supplier's review frequency.

Concerning the warehouse operations balance, a similar analysis to assign a cost base was conducted. Resorting to the same simulation, the impact of the different workloads according to each frequency was calculated based on an assumption. It was determined that the most adequate measure to reflect the impacts of different frequencies was the average weekly workload in warehouse operations. This indicator was calculated by dividing, for each scenario, the total number of active SKUs[1] of each supplier by the frequency of the scenario. This measure showcases a higher workload of receiving all the SKUs in weekly orders versus the dilution of impact over the 4 weeks, in the case of monthly deliveries.

In order to ensure that all restrictions, being business or methodology related, are considered and the approach is followed, the formulation of the present phase of the tactical model encompasses the following stages:

1. Considering the simulation conducted to the three scenarios with different review periods for all the suppliers, the average stock on hand is calculated for the upcoming period in analysis

2. For each supplier, the number of active SKU was assessed

3. For each calendar, the average warehouse operations workload was calculated considering the number of active SKUs and the frequency in analysis

4. Stock costs were calculated at the product level and considering the average stock on-hand for each simulation. This took into consideration the average purchase cost for each product.

5. Weekly workload in the warehouse operations was determined as a result of the assumption that the effort of reception would be diluted for each week considered in the order frequency

[1] By active SKUs, it is understood all the SKUs in the supplier's portfolio that have predicted quantity to be sold in the upcoming defined period.

Subsequently, the mathematical formulation associated with this optimization model is presented. Table 4.3 contains the variables and parameters used in the model.

Table 4.3: Table of notation for the definition of the optimal review frequencies.

Sets	
S	Set of suppliers (indexed by s)
F	Set of review frequencies (indexed by f) - 1(weekly), 2(biweekly), 4(monthly)
P_s	Set of active products of supplier s
Parameters	
$Avg\_stk\_oh_{P_s,f}$	Average stock on-hand for each product p of each supplier s, considering the order frequency f
$N\_active\_SKU_s$	Number of active products for each supplier s
APC_p	Average purchase cost of product p to the manufacturer
$WACC$	Weighted average cost of capital
Decision Variables	
$R\_freq_{s,f}$	Binary variable that equals 1 if for supplier s the review frequency f is chosen, and 0 otherwise

Objective function

The objective function considered in the present formulation is to minimize the total stock costs and the average weekly workload to assess the best order frequency for each supplier, for the horizon considered.

Stock costs

The stock cost is given by multiplying the average stock on hand in each week for each scenario at a specific review frequency by the average purchase cost of each product (Equation 4.19).

$$StockCosts = \sum_{s\in S}\sum_{p\in P_s}\sum_{f\in F} R\_freq_{s,f} \cdot Avg\_stk\_oh_{P_s,f} \cdot APC_{P_s} \cdot WACC \tag{4.19}$$

Average weekly workload

Regarding the average workload each week, this was determined considering the number of SKUs to receive in each frequency. This calculation is set by dividing the number of SKUs of each supplier by the review frequency chosen (Equation 4.20).

$$AverageWeeklyWorkload = \sum_{s\in S}\sum_{f\in F} \frac{R\_freq_{s,f} \cdot N\_active\_SKU_s}{f} \tag{4.20}$$

Considering the terms above, both the *Average Weekly Workload* and the *Stock Costs* were normalized in order to eliminate the scale factor and allow a direct comparison between the variables. By using a min-max normalization method, the variables were re-scaled for values between 0 and 1. Hence, with the objective to minimize the cost of stock and the balancing in inbound operations, Equation 4.21 presents the definition of the objective function.

$$Minimize \sum StockCost + AverageWeeklyWorkload \tag{4.21}$$

Constraints

Having set the objective function, it is mandatory to define the constraints associated with the model. Therefore, next are presented some business and methodological restrictions.

Ensuring that only one order frequency is assigned to each supplier

It must be assured that each supplier is only assigned to one order frequency (Equation 4.22).

$$\sum_{s \in S} \sum_{f \in F} R\_freq_{s,f} = 1 \tag{4.22}$$

Non-negativity of the variables

Equation 4.23 guarantees that the variable set in the formulation is according to its specifications.

$$R\_freq_{s,f} \in \{0,1\} \tag{4.23}$$

Business restrictions

Regarding the business side, there are some suppliers with already fixed review frequencies established by contractual terms, which cannot be altered.

4.3.1.1 Week and weekday allocation

The subsequent model is characterized by the assignment of a week and a weekday to each supplier, ensuring that coherence in terms of the delivery day is kept. After having set the optimal review frequency, the impact of the allocations will lay over the warehouse operations solely as the stock level is not altered by a different calendar allocation; so this section will not contemplate that cost.

So, the problem is going to consider the allocation for a base of four weeks. As previously mentioned, a unique calendar is going to be set for all the warehouses, meaning that for each supplier only one weekday can be assigned and the number of weeks to be allocated depends on the review frequency.

According to this, the following formulation was considered for the present problem. It was worth noting that in order to maintain the problem of linear programming optimization, the objective is to minimize the daily deviations from the number of limit lines received each day, for each warehouse. In Table 4.4 are presented the variables and parameters used in the formulation.

Table 4.4: Table of notation for the optimization model for week and weekdays.

Sets	
S	Set of suppliers(indexed by s)
T	Set of weeks for which the suppliers can be allocated (indexed by t) - weeks 1 to 4
D	Set of weekdays that can be assigned to the suppliers (indexed by d) - weekdays 1 to 5
W	Set of warehouses (indexed by w)
Parameters	
$N\_lim\_lines_w$	Number of limit lines to be received in each warehouse w
N_SKU_s	Number of active SKUs to be considered for supplier s
$Order\_freq_s$	Order frequency for supplier s, determined in phase 1
Aux_freq_s	Binary variable that equals 1 if supplier s has biweekly review period and 0 otherwise
Decision Variables	
$All_{s,t,d}$	Binary variable that equals 1 if supplier s is allocated to week t and weekday d , and 0 otherwise
Auxiliary Variables	
$Dev_{t,d,w}$	Continuous variable that expresses the daily deviations in warehouse w for weekday d and week t
$Day\_coh_{s,d}$	Binary variable that equals 1 if supplier s is allocated weekday d , and 0 otherwise

Objective function

By setting the objective function to minimize the deviations for each weekday in each week, it is ensured the balance in the warehouse operations, avoiding high variability among the weekdays (Equation 4.24).

$$Minimize \sum_{t\in T}\sum_{d\in D}\sum_{w\in W} Dev_{t,d,w} \tag{4.24}$$

Constraints

Having set the objective function, the relevant thinking process lays the constraints to be set.

Relating the daily deviations with the decision variable

In order to guarantee the linearity of the model, there was the need to create a variable, $Dev_{t,d,w}$. The Equation 4.25 defines that the deviations are calculated taking into consideration the active number of SKUs to be received in a determined week and weekday and the limit number of inbound lines in the warehouse to be considered.

$$\sum_{s\in S} All_{s,t,d}\cdot N\_SKU_s - N\_lim\_lines_w - Dev_{t,d,w} = 0, \forall w \in W, t \in T, d \in D \tag{4.25}$$

Ensuring that the sum of allocations within the 4 weeks is coherent with the order frequency

In order to guarantee that the number of allocations that each supplier has to have is in line with the frequency assigned, Equation 4.26 had to be considered.

$$\sum_{t \in T} \sum_{d \in D} All_{s,t,d} \cdot Order\_freq_s - 4 = 0, \forall s \in S \tag{4.26}$$

Ensuring that if the review frequency is biweekly, the two weeks chosen are not sequential

As the module will determine which week is allocated to the supplier, in the case of biweekly suppliers, it is needed to ensure that the weeks chosen are not sequential. For this, Equation 4.27 ensures that non sequential weeks are considered.

An auxiliary variable was created to ensure that the following restrictions are only applied to review frequencies of 2 (Equation 4.28).

$$\sum_{d \in D} (All_{s,t,d} - All_{s,t+2,d}) - (1 - Aux\_freq_s) \cdot M \leq 0, \forall t \in \{1,2\}, s \in S \tag{4.27}$$

$$Aux\_freq_s = 1, \forall s \in S, Order\_freq_s = 2 \tag{4.28}$$

Ensuring that only one weekday is allocated to each supplier

In order to ensure that the weekday is coherent and only one is allocated to each supplier, it is needed to associate an auxiliary variable, "Day_coh", to ensure that the day assigned is maintained throughout the set delivery weeks. As the previous constraints already ensure that the supplier is allocated to the correct weeks, Equation 4.29 guarantees that only one weekday is assigned to each supplier and Equation 4.30 ensures that all the allocations are set for the same weekday.

$$\sum_{d \in D} Day\_coh_{s,d} = 1, \forall s \in S \tag{4.29}$$

$$All_{s,t,d} - Day\_coh_{s,d} <= 0, \forall t \in T, \forall s \in S \tag{4.30}$$

Non-negativity of the variables

Equation 4.31 guarantees that the variables set in the formulation are according to their specifications.

$$Dev_{t,d,w} \in \mathbb{R}, Day\_coh_{s,d}, Aux\_freq_s, All_{s,t,d} \in \{0,1\} \tag{4.31}$$

Business restrictions

In terms of business restrictions, it is considered that, similarly to the review frequency definition, some suppliers have set contractual weekdays allocated, which cannot be altered.

Chapter 5

Results

The results obtained from the application of the modules presented in the methodology are observed in this chapter. In sections 5.1., and 5.2., the results of the corresponding modules are going to be presented considering a simulation conducted at a historical date. In the following section, 5.3. the experiments presented are a result of the comparison between the proposed calendar and the existing calendar currently implemented within the company.

5.1 Replenishment policy - Results

A simulation was conducted at a specific historical date in order to perceive the potential of the presented methodology in stock level improvements. The preliminary results presented in Figure 5.1 demonstrate that an overall decrease in the stock of 19% can be achieved by implementing the (R,s,S) parametrization. These results can be explained as the current replenishment process is mainly conducted by the business expertise. Though the MRP software presents order quantity suggestions, the purchasing team members do not find themselves aligned with the presented recommendations.

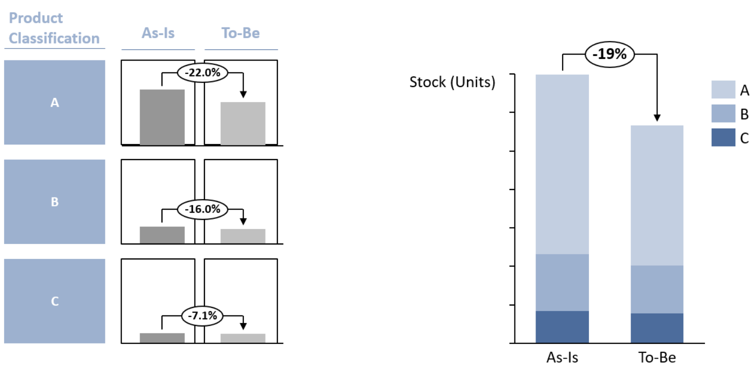

Figure 5.1: Replenishment policy module preliminary results - stock analysis

At a more detailed level, when analyzing the ABC classification of products, it becomes apparent that a significant reduction in the stock level of A products is recommended. This decrease is mainly due to business related aspects. It is relevant to note that the proposed approach does not consider the stock belonging to "groups of pharmacies", terminology defined in Chapter 3, as it is not managed internally by the distributor. Thus, this reduction is preeminently a consequence of this segment's excess of stock that becomes the distributor's responsibility when is not bought by the "groups of pharmacies". This observation proves to be a major leverage to the company, enabling them to prove, with measurable results, to the pharmacies the consequences of the excessive amounts of stock that they inject into the distributor. A more moderate decrease is seen in B and C classes as these do not account for a significant amount of stock due to "groups of pharmacies", so the impacts shown are a consequence of the poor replenishment process based on inaccurate sales predictions. Additionally, the effectiveness of the proposed approach is influenced by the behavior and uncertainty associated with suppliers. Suppliers characterized by uncertain behaviors impose on the distributor the need to carry a larger buffer to address this variability.

5.2 Support for the daily deviations - Results

The approach proposed involved generating a report that identified products at risk of stockout at the product-warehouse level, using historical data for a specific date. Recommendations were provided based on viable options and business constraints.

To compare the current situation (As-Is) with the proposed scenario (To-Be), a simulation was conducted. The historical data was used both as the basis for the As-Is and the To-Be scenarios so that a comparison between scenarios could be established. As the previous company's decisions were based on the theoretical lead time, this parameter was also considered in the To-Be scenario, even though the model will be further based on the real lead time calculated in the replenishment model. Moreover, the shortages were based on the actual sales that took place during the period in analysis, as the forecast predictions on which the present approach will be based, were not yet considered. A more realistic dimension was conveyed by using this approach, rather than being based on a rolling mean prediction of the sales. In order to simulate the As-Is scenario the report of "shortages" and "ruptures" was simulated, by considering the actual sales over the following five days to the date in analysis. With this information, products at risk of stockout were considered in the analysis enabling to attain information about the emergency orders, lateral transshipment, and awaiting the next scheduled order. Although the company does not directly track this last measure, considering that there were no order anticipations performed, the products not included in the measures with available tracking, were set to awaiting the next scheduled order decision.

To compare the two scenarios, a cost-based analysis was performed, along with the determination of key project indicators such as service level, stock level, and balancing of warehouse operations.

Primarily, an overall comparison between the As-Is and the To-Be is presented in Figure 5.2. The results show an overall reduction of 32% in the number of measures considered. Despite the decrease observed, the number of transshipment verified an increment of around 50%, due to changes in additional business restrictions that imposed the usage of transfers to certain products.

Following the overall profile, emergency orders also registered a significant decrease as a result of the enhanced detection of actual needs. In regard to awaiting the next scheduled order, a reduction was also observed. This can be attributed to two key factors. Firstly, as some measures prove to be used ineffectively, products that presented actual needs were considered in this decision. Furthermore, the introduction of additional restrictions holds the potential to yield distinct outcomes, thereby influencing the allocation in the To-Be scenario to other measures. As for order anticipation, no suggestions were generated in the proposed simulation to the specified date.

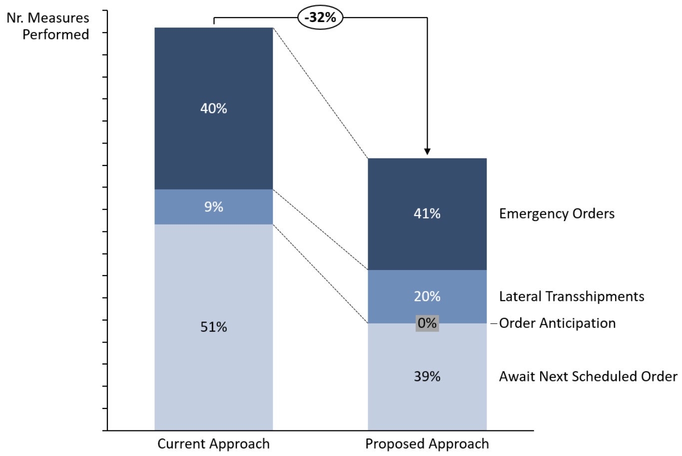

Figure 5.2: As-Is vs To-Be simulation results on the daily deviations support

Regarding the main indicators of the project, Figure 5.3 show beneficial outcomes mainly at the service level, with an increase of 25 percentage points, and at the warehouse operations balancing, that registered a decrease in 30% in the number of lines - distinct SKUs - received. The increase observed at stock level, of 34% is a consequence of a more accurate replenishment process when assessing the quantities needed to be ordered. Though having a lower stock level, in the As-Is scenario, the emergency orders performed highlighted the inefficiencies in the replenishment process. By accounting for 55% of the stockouts the after the supplier's lead time, this scenario shows that the quantities ordered were not sufficient to replenish the period intended.

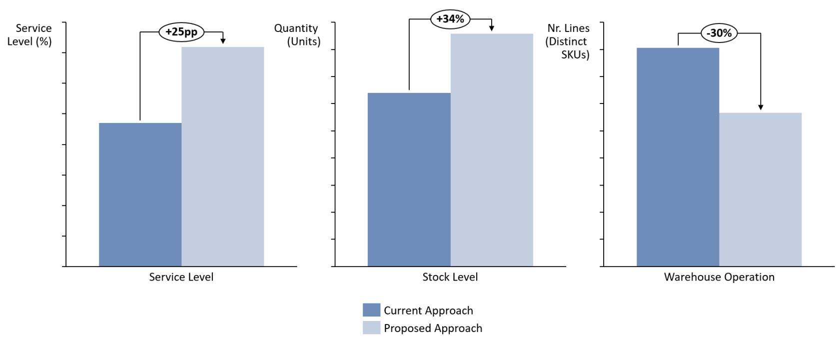

Figure 5.3: As-Is vs To-Be simulation results on the main KPIs

It is also important to provide a more detailed explanation of the two reactive measures.

Decisions regarding emergency orders have confirmed the incapacity to accurately support the daily uncertainties. It was verified that 33% of the emergency orders issued in the As-Is scenario proved to be unnecessary as the existing stock on hand was sufficient to fulfill the requirements until the next scheduled order.

Moreover, lateral transshipments were deeply affected by the introduction of the new process. During the mapping sessions, it was notorious the change in *status quo*. One of the main changes was the impossibility of multiple-sourced transshipment, imposing further that a transshipment could only be performed if it fully fulfills the needs of the destination warehouse. This caused immense disruption, as 33% of the shipments in the actual process were multi-sourced and from this, 16% were executed between the same binary source-destination, as seen in Figure 5.4. Furthermore, the incorporation of several sets of restrictions that lead, forcefully, to lateral transshipments proves to be the main reason for the increase observed in the usage of this measure. In the To-Be scenario, only 12% of the recommended transfers account for transshipments based on the nature of the reactive measure itself. These shipments will be denominated as reactive transshipments.

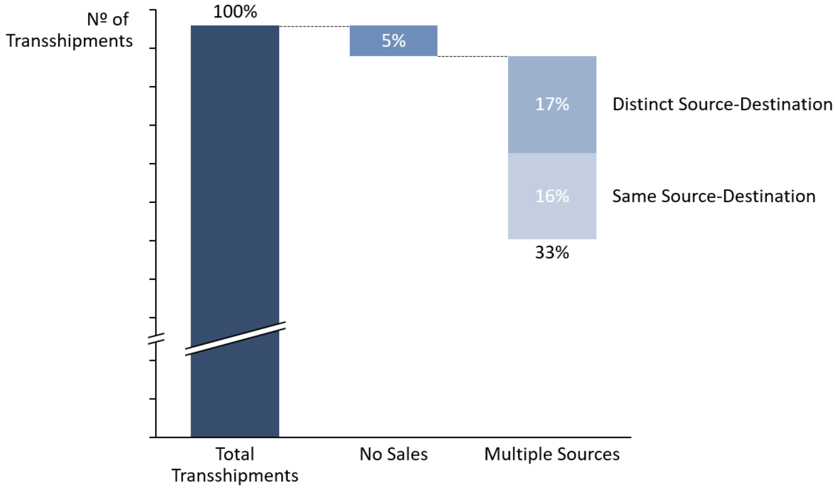

Figure 5.4: Transshipments categories distribution - As-Is scenario

5.2.1 Cost Analysis

Conducting an in-depth analysis of costs is pertinent, considering that the optimization module was developed on a cost-based approach. As the module involves overall cost optimization, it is fitting to conduct an overall cost analysis as well.

Figure 5.5 demonstrates that an overall reduction of 32% in costs was achieved with this simulation. As seen, operation costs hold for the largest percentage in both the approaches as they are included in both the reactive measures, while handling and transportation costs are only accounted for in transfers and holding costs in emergency orders. Moreover, the decrease observed is based on the reduction in the number of emergency orders performed, as well as a reduction in the number of reactive transshipments. Moreover, the latest also justifies the reduction in transportation and handling costs. Regarding holding costs, a more accurate quantity order led to an increase in stock level, and consequently, in holding costs. As the proposed approach is supported by the replenishment policy, it already encompasses a correct dimension of the order to be issued so that stockouts after lead time do not occur.

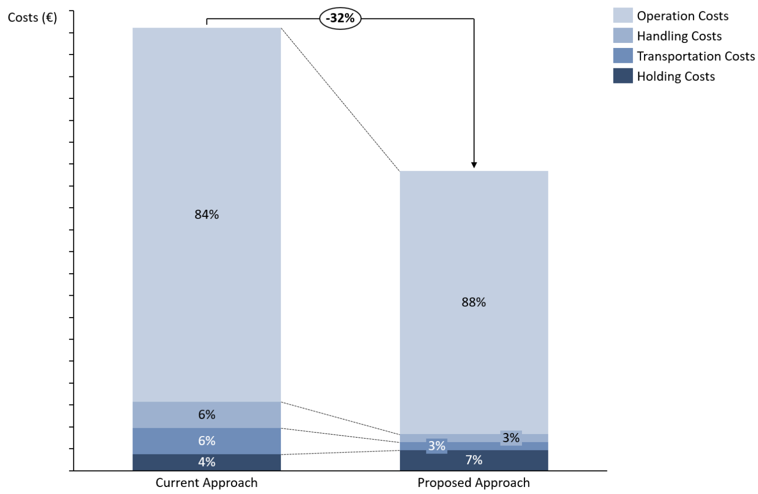

Figure 5.5: Cost comparison between the current and the proposed approaches

In the following section, the results from the order planning support at the tactical level are going to be presented.

5.3 Tactical decision support -Results

In the tactical module, the objective was to develop an order schedule supplier allocation plan. This plan aimed to determine the optimal week and weekday allocation for each supplier, taking into consideration the complexity introduced by the optimal review frequency definition.

The presented approach aims to effectively manage the peaks in inbound operations and to be aligned with the strategic objective of maintaining appropriate stock levels. The redistribution of suppliers based on their ABC classification and different review frequencies is illustrated in Figure 5.6. This distribution takes into account both the number and quantity of SKUs that each order frequency would require to be received on a weekly basis. It is demonstrated that a shift in classe C distributors from a biweekly to a monthly review frequency is recommended. This adjustment allows for a more efficient allocation of resources for lower priority suppliers, as their review frequency can be reduced without compromising stock management. For A distributors, a more balanced distribution is suggested, combining both weekly and biweekly review frequencies. This approach enables better inventory management for high-priority suppliers, ensuring timely replenishment while avoiding excessive stock levels.

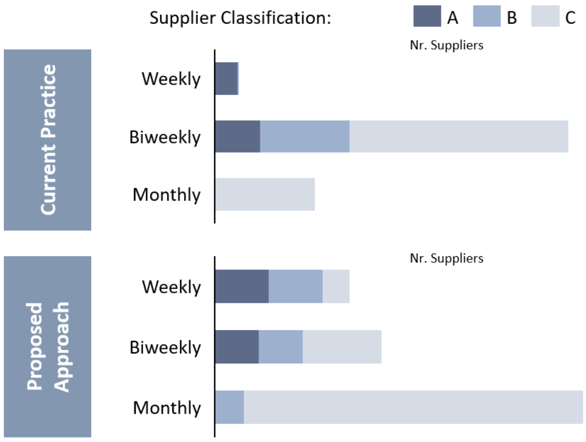

Figure 5.6: Suppliers' review frequency comparison between current and proposed approach

In terms of stock costs, Figure 5.7 demonstrates a 2% reduction in costs. This reduction is directly connected to the changes in review frequency. The As-Is scenario shows a higher concentration of suppliers in the biweekly frequency, which results in a larger proportion of costs associated with that frequency. By shifting some suppliers from biweekly to monthly reviews, the cost allocation becomes more balanced. The decrease in costs can be justified by the increment in weekly order frequencies, as more frequent replenishments lead to lower stock costs due to the need of carrying less stock.

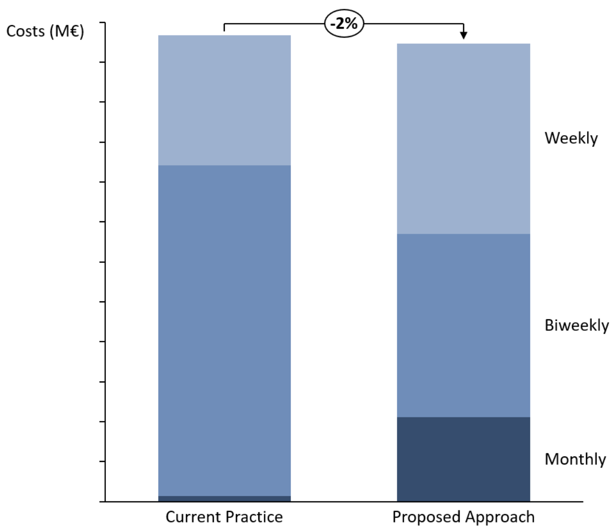

Figure 5.7: Stock cost comparison between the current and the proposed approach

Implementing these changes in supplier allocation and review frequencies is expected to optimize operational efficiency, reduce costs, and align stock levels with strategic objectives. By adjusting this parameter based on supplier priority and characteristics, the project aims to achieve a better balance in operations and improve overall stock management.

Furthermore, the analysis also indicates improvements in the key dimensions of operational balancing and stock costs. Figure 5.8 shows that the average value of lines received in the proposed approach is significantly lower than the current approach. In alliance with this consideration, the maximum amplitude of 20% shows that both in percentage values and in absolute values, the approach leads to a lower and less dispersed number of distinct SKUs received. Furthermore, as the module aims to balance the overall operations on a monthly base, it is also relevant to mention the dispersion observed throughout this time period. Considering the coefficient of variation (CV), it was concluded that the As-Is scenario presented a CV of 0.52 and the proposed approach a CV of 0.33. This confirms that a monthly balance is achieved, as the variability within this period proves to be significantly lower in the To-Be scenario. This improvement in operational balancing contributes to smoother operations and increased efficiency.

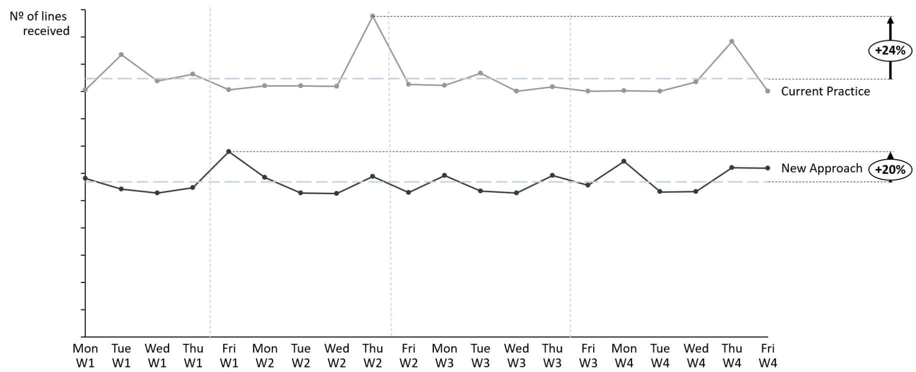

Figure 5.8: Inbound receptions comparison between the current and proposed approach

It is important to acknowledge that the presented results are influenced by business restrictions that impose certain rigidity on the problem. So, even with few degrees of freedom, the results show positive outcomes.

Chapter 6

Conclusions and future work

The presented work aimed to support through a holistic approach the order planning processes carried out in the pharmaceutical distributor acting both on the tactical and operational levels. The objective was, firstly, to propose a replenishment policy adequate to the company's needs and existing software compatibility. Moreover, at an operational level, the aim was to prevent and react to the daily deviations that characterize the pharmaceutical sector. Regarding the tactical point of view, the goal was to support the scheduling decision by defining the most adequate one for each supplier and the allocation that would best lead to cost saving and balancing in the operations scenario. The lack of structure information and flexible methodologies for the presented axis were the main drivers for this project, conducted in order to improve service level, stock levels and balance warehouse operations.

Driven by the lack of reliable purchase recommendations in the replenishment process, the first module proposed a periodic review (R,s,S) replenishment policy.

A preliminary simulation was conducted where the actual stock levels were compared to the ones proposed by the parameters that are determined based on the (R,s,S) calculations. An overall decrease in 19% of the stock levels is proposed. The considerable reduction in A-class products proves to be a great business leverage to the company towards the "groups of pharmacies".

Apart from the stock reduction benefits, qualitative advantages are also demonstrated. By presenting the parameters associated with each product-warehouse, the company gains a comprehensive understanding of the stock held as a result of maintaining a target service level and the inventory that is a consequence of the supplier's inadequate service level. Moreover, the distributor is also able to grasp the repercussions of the "groups of pharmacies" stock that becomes its responsibility. These prove to be valuable insights that endow the company to better negotiate and manage external factors.

Regarding the second module presented, through an optimization model, the proposed approach was to convey analytic and robust supported decision-making.

Preliminary results obtained from a simulation using historical data indicate that a decrease in 32% in the number of measures performed can lead to a decrease of 32% in overall costs. Improvements were also observed in the main KPIs. Regarding the service level, increments of 25 percentage points were accounted for, as well as a reduction of 30% in the number of distinct SKUs received at inbound operations. Moreover, this last indicator's performance is also influenced by the inefficient usage of the reactive measures on the As-Is scenario, as proved by 33% - of the emergency, orders were found to be unnecessary. As a result of the enhanced replenishment process and process redefinition, the proposed approach effectively leverages both the previous module and the necessary business expertise. This leads to significant improvements in addressing operational deficiencies, particularly in reducing stockouts after the suppliers' lead time, which were observed to account for 55% in the As-Is scenario. Considering this, the 34% increase in stock level is regarded as a more precise order quantity that guarantees coverage for stockouts, resulting in a corresponding increase in the required quantity.

Furthermore, preliminary validation sessions have shown the contribution of the report in workload reduction, based on its structured information display. This allows for additional time to engage in value-added activities. Moreover, the benefits of the coherence that the proposed approach presented were also highlighted, as it would significantly impact the non standardized process of evaluation of the daily reports.

The third module focused on developing a suppliers' allocation schedule with the objective of optimizing stock costs and balancing warehouse operations.

Results show that the proposed approach suggested a more balanced distribution of class A suppliers through weekly and biweekly frequencies and a substantial change in class C suppliers to monthly review. This strategic distribution ensures that suppliers with higher order frequencies, which may result in more frequent inbound operations, are appropriately managed. The first model was both a stock cost and warehouse balancing based approach. Regarding the costs, a reduction of 2% was observed, indicating the effectiveness of the proposed approach. In the second model, the To-Be approach led to a lower workload in inbound operations due to the decrease in the average number of SKUs received. Furthermore, less variability in the inbound operations was observed and measured through the decrease from 0.52 to 0.33 in the coefficient of variation along the month.

This approach adds an automatized layer that enables, through parameter definition, to generate of the most adequate scenario. This proves to be an improvement to the current manual and time-consuming definition of the strategy.

Through these simulations, it was confirmed the necessity to address the challenges that motivated the project. The three key indicators monitored closely through the project showed that, firstly, a service level improvement can be achieved by action dully on the shortage risk. Secondly, warehouse balancing in the operations can be accomplished both at the operational level and, primarily, at a tactical level. Thirdly, stock levels can be reduced and rearranged more efficiently from a holistic perspective, and on daily measures, its management can also be improved. The project's findings emphasize that balanced trade-offs between these three dimensions can improve performance.

Despite the mentioned benefits, the proposed approaches present some limitations as well as areas that can be further improved. The lack of a solid cost structure and comprehensive cost documentation posed challenges in accurately estimating and calculating costs. This limitation can impact the accuracy and reliability of the cost analysis, potentially leading to suboptimal decision-making.

Another limitation is the dependency on the business knowledge and external factors' dynamism, making it challenging to be directly incorporated into the modules. The decision-making process is heavily influenced by the expertise and experience of the purchasing team. The flexibility and openness of the recommendations presented in the report address this limitation to some extent. The recommendations provided serve as a valuable reference and guide, but the final decision-making authority remains with the team.

As for future work opportunities, an analysis could be conducted to "groups of pharmacies" due to the high impact that this segment proved to have in the preliminary results. By incorporating sales predictions and a replenishment structure to this segment, the overall impacts obtained would be more aligned with the present context within the company.

In summary, the implementation of the presented analytical tools and approaches for order planning has brought several benefits to the company. The process has become less time-consuming, more automated, and standardized, leading to increased efficiency and effectiveness and more informed decision-making. By combining the analytical tools with the expertise and knowledge of the purchasing team, the company can align the order planning process with its main drivers and goals.

To conclude, the main contribution to the literature was the distinct three-dimensional based analysis of the holistic supply chain matrix. By specializing in the pharmaceutical industry, external uncertainty was a preponderant factor of the complexity added to the methodologies.

Bibliography

Abu Zwaida, T., Elaroudi, K., and Beauregard, Y. (2021). The challenges of drug shortages in the canadian hospital pharmacy supply chain — a systematic literature review. *Journal of Public Health*, 30(11):2593–2604.

Agra, A., Cerveira, A., and Requejo, C. (2019). *Logistic Operations in a Hospital: A Multi-item Inventory Distribution Problem with Heterogeneous Fleet*. Springer International Publishing.

Ahmad, H. (2022). Inventory management analysis in creating corporate profits.

Ahmadi, E., Masel, D. T., Hostetler, S., Maihami, R., and Ghalehkhondabi, I. (2020). A centralized stochastic inventory control model for perishable products considering age-dependent purchase price and lead time. *TOP*, 28:231–269.

Ahmadi, E., Mosadegh, H., Maihami, R., Ghalehkhondabi, I., Sun, M., and Süer, G. A. (2022). Intelligent inventory management approaches for perishable pharmaceutical products in a healthcare supply chain. *Computers and Operations Research*, 147.

Ambekar, S. and Kapoor, R. (2019). Optimization of inventory policies of food grain distribution stage in public distribution system. *Benchmarking*, 26:692–713.

Ayati, N., Saiyarsarai, P., and Nikfar, S. (2020). Short and long term impacts of covid-19 on the pharmaceutical sector.

Barbosa-Povoa, A. P., Jenzer, H., and De Miranda, J. L. (2019). *Pharmaceutical Supply Chains-Medicines Shortages*. Springer.

Cunha, P. S., Raupp, F. M., and Oliveira, F. (2017). A two-stage stochastic programming model for periodic replenishment control system under demand uncertainty. *Computers and Industrial Engineering*, 107:313–326.

E, E., Yu, M., Tian, X., and Tao, Y. (2022). Dynamic model selection based on demand pattern classification in retail sales forecasting. *Mathematics*, 10(17).

Fattahi, M., Mahootchi, M., Husseini, S. M. M., Keyvanshokooh, E., and Alborzi, F. (2015). Investigating replenishment policies for centralised and decentralised supply chains using stochastic programming approach. *International Journal of Production Research*, 53:41–69. 50.

Feng, P., Fung, R. Y., and Wu, F. (2017). Preventive transshipment decisions in a multi-location inventory system with dynamic approach. *Computers and Industrial Engineering*, 104:1–8.

Flynn, J. and Garstka, S. (1997). The optimal review period in a dynamic inventory model. *Operations Research*, 45(5):736–750.

Gagliardi, J. P., Renaud, J., and Ruiz, A. (2007). A simulation model to improve warehouse operations. *2007 Winter Simulation Conference*.

Galli, L., Levato, T., Schoen, F., and Tigli, L. (2020). Prescriptive analytics for inventory management in health care. *Journal of the Operational Research Society*, 72(10):2211–2224.

Grob, C. (2018). *Inventory Management in Multi-Echelon Networks: On the Optimization of Reorder Points*. AutoUni – Schriftenreihe. Springer Fachmedien Wiesbaden.

Guluma, D. A. (2019). Inventory management practices, challenges and prospects-the case of asella malt factory. *ICTACT JOURNAL ON MANAGEMENT STUDIES*, page 4.

Gurtu, A. (2021). Optimization of inventory holding cost due to price, weight, and volume of items. *Journal of Risk and Financial Management*, 14(2).

Hansen, Z. N. L., Andreu, C. M., Khan, O., Haug, A., Hvam, L., and Hansen, N. E. (2023). Identification of key drivers for improving inventory management in pharmaceutical supply chains. *Production Engineering*.

Jurado, I., Maestre, J. M., Velarde, P., Ocampo-Martinez, C., Fernández, I., Tejera, B. I., and del Prado, J. R. (2016). Stock management in hospital pharmacy using chance-constrained model predictive control. *Computers in Biology and Medicine*, 72:248–255.

Kees, M. C., Bandoni, J. A., and Moreno, M. S. (2019). An optimization model for managing the drug logistics process in a public hospital supply chain integrating physical and economic flows. *Industrial and Engineering Chemistry Research*, 58:3767–3781.

King, P. L. (2019). *Lean for the process industries: dealing with complexity*. CRC Press.

Krzyżaniak, S. (2022). Optimisation of the stock structure of a single stock item taking into account stock quantity constraints, using a lagrange multiplier. *Logforum*, 18(2):261–269.

Kumari, A. G., Wijayanayake, A. N., and Niwunhella, D. H. (2022). An effective lateral transhipment model for a multi-location inventory setting to minimize stockouts. pages 225–230. Institute of Electrical and Electronics Engineers Inc.

Kundu, K. and Rossini, M. (2023). Case study on simulation analysis of a logistics network with multiple products by applying lateral transshipments algorithms. *Management Research Review*, 46:508–533.

Li, J., Almentero, B. K., and Besse, C. (2023). Explainable machine learning fornbsp;drug shortage prediction in a pandemic setting. *Machine Learning, Optimization, and Data Science*, page 141–155.

Liao, Y., Shen, W., Hu, X., and Yang, S. (2014). Optimal responses to stockouts: Lateral transshipment versus emergency order policies. *Omega (United Kingdom)*, 49:79–92.

Maestre, J. M., Fernández, M. I., and Jurado, I. (2018). An application of economic model predictive control to inventory management in hospitals. *Control Engineering Practice*, 71:120–128.

Marques, C. M., Moniz, S., de Sousa, J. P., Barbosa-Povoa, A. P., and Reklaitis, G. (2020). Decision-support challenges in the chemical-pharmaceutical industry: Findings and future research directions.

Marrone, P. V., Mathias, F. R., Bernardo, W. M., Orlandini, M. F., Serafim, M. C. A., Scoton, M. L. R. P. D., Lopes, J. M., Pereira, S. L., and Dias, E. M. (2023). Decision criteria for partial nationalization of pharmaceutical supply chain: A scoping review.

Mousazadeh, M., Torabi, S., and Zahiri, B. (2015). A robust possibilistic programming approach for pharmaceutical supply chain network design. *Computers Chemical Engineering*, 82:115–128.

Muller, M. (2019). *Essentials of inventory management*. Harpercollins Leadership.

Nematollahi, M., Hosseini-Motlagh, S. M., Ignatius, J., Goh, M., and Nia, M. S. (2018). Coordinating a socially responsible pharmaceutical supply chain under periodic review replenishment policies. *Journal of Cleaner Production*, 172:2876–2891.

Nemtajela, N. and Mbohwa, C. (2017). Relationship between inventory management and uncertain demand for fast moving consumer goods organisations. *Procedia Manufacturing*, 8:699–706.

Nguyen, A., Lamouri, S., Pellerin, R., Tamayo, S., and Lekens, B. (2022). Data analytics in pharmaceutical supply chains: state of the art, opportunities, and challenges. *International Journal of Production Research*, 60:6888–6907.

Oballah, D., Waiganjo, E., and Wachiuri, E. W. (2015). Effect of inventory management practices on organizational performance in public health institutions in kenya: A case study of kenyatta national hospital.

Olsson, F. (2015). Emergency lateral transshipments in a two-location inventory system with positive transshipment leadtimes. *European Journal of Operational Research*, 242:424–433.

Osorio Gómez, J. C. and España, K. T. (2020). Operational risk management in the pharmaceutical supply chain using ontologies and fuzzy qfd. *Procedia Manufacturing*, 51:1673–1679. 30th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM2021).

Paterson, C., Teunter, R., and Glazebrook, K. (2012). Enhanced lateral transshipments in a multi-location inventory system. *European Journal of Operational Research*, 221:317–327.

Poormoaied, S., Atan, Z., de Kok, T., and Woensel, T. V. (2020). Optimal inventory and timing decisions for emergency shipments. *IISE Transactions*, 52:904–925.

Postma, D. J., Notenboom, K., Smet, P. A. G. M. D., Leufkens, H. G. M., and Mantel-Teeuwisse, A. K. (2023). Medicine shortages: impact behind numbers. *Journal of Pharmaceutical Policy and Practice*, 16.

Priniotakis, G. and Argyropoulos, P. (2018). Inventory management concepts and techniques. volume 459. Institute of Physics Publishing.

Privett, N. and Gonsalvez, D. (2014). The top ten global health supply chain issues: Perspectives from the field. *Operations Research for Health Care*, 3:226–230.

Qaffas, A. A., Hajkacem, M. A. B., Ncir, C. E. B., and Nasraoui, O. (2023). Interpretable multi-criteria abc analysis based on semi-supervised clustering and explainable artificial intelligence. *IEEE Access*.

Radasanu, A. C. et al. (2016). Inventory management, service level and safety stock. *Journal of Public Administration, Finance and Law*, (09):145–153.

Saha, E., Rathore, P., Parida, R., and Rana, N. P. (2022). The interplay of emerging technologies in pharmaceutical supply chain performance: An empirical investigation for the rise of pharma 4.0. *Technological Forecasting and Social Change*, 181.

Saha, E. and Ray, P. K. (2019). Modelling and analysis of inventory management systems in healthcare: A review and reflections. *Computers and Industrial Engineering*, 137.

Sbai, N. and Berrado, A. (2023). Simulation-based approach for multi-echelon inventory system selection: Case of distribution systems. *Processes*, 11:796.

Shokouhifar, M. and Goli, A. (2023). Designing a resilient–sustainable supply chain network of age-differentiated blood platelets using vertical–horizontal transshipment and grey wolf optimizer. *International Journal of Environmental Research and Public Health*, 20.

Silver, E. A., Pyke, D. F., and Thomas, D. J. (2016). Inventory and production management in supply chains.

Sriram, P. and Milind, A. (2020). A model to assess supply risk for antibiotics in swedish context: Analysis of supply structure of 39 selected antibiotics.

Sun, Q., Gao, Y., Lu, Q., and Yan, Y. (2023). A pricing and transshipment hybrid strategy for perishable product in two external scenarios for supply disruption. *Kybernetes*.

Teunter, R. H., Babai, M. Z., and Syntetos, A. A. (2010). Abc classification: service levels and inventory costs. *Production and Operations Management*, 19(3):343–352.

Tiacci, L. and Saetta, S. (2011). A heuristic for balancing the inventory level of different locations through lateral shipments. *International Journal of Production Economics*, 131:87–95.

Uthayakumar, R. and Priyan, S. (2013). Pharmaceutical supply chain and inventory management strategies: Optimization for a pharmaceutical company and a hospital. *Operations Research for Health Care*, 2(3):52–64.

Wang, X. and Disney, S. M. (2016). The bullwhip effect: Progress, trends and directions. *European Journal of Operational Research*, 250(3):691–701.

Xu, J., Keblis, M. F., Feng, Y., and Zhou, S. X. (2023). Optimal replenishment and transshipment management with two locations. *Naval Research Logistics*.