Digitalization and Optimized Inventory Management of a General Warehouse

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Master's Dissertation

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Abstract

Globalization and the constant technological innovation have promoted increased competitiveness between companies. In order to stay on top, firms must ensure that all their processes have a high level of optimization, looking for ways to increase their value and the value of their products in order to meet the challenges of the new reality of the market in which they operate.

This dissertation is the outcome of a curricular internship at BA Glass – more specifically in the purchasing department. BA Glass is a leading company in its industrial segment, selling glass containers to over 80 countries. In order to support its operations, BA has a spare parts warehouse that supplies the factory with the materials requests. The work undertaken was directed at making the inventory management more efficient so as to be able to have a better performance that, consequently, will be translated in a better productive process.

At the beginning of this project a review of the literature regarding warehouse management was conducted to provide an understanding of the problem being studied and how to approach it. Hence, the priorities addressed were clearly defined and included identifying obsolete materials, increasing the control over the inventory of spare parts, and improving the management of the operations concerning warehouse material flows.

To this end, several methodologies were adopted with the purpose of addressing the three identified challenges: a simulator was created to test different stock policies; objective parameters for determining obsolete materials were set and to delineate those that could be transferred to other plants, and lastly a digital solution was sought for the issuing of material from the warehouse.

Finally, the experimental results are provided and the impacts of utilizing these strategies are discussed hence validating the suitability of these measures.

This project allowed, on the one hand, a better understanding of the behavior of the materials present in the warehouse, since they were classified according to specific criteria and management models suitable for different types of materials were studied, models that proved to be more appropriate than the model currently used. On the other hand, the study of the warehouse material issuing process has led to a deeper understanding of BA's current situation and allowed to explore different digital solutions that exist in the market and that can contribute to the optimization of this process. Finally, the identification and transfer of obsolete materials permitted the Villafranca plant to free up warehouse space for the reception of new materials and the receiving plants to postpone the decision to order these parts.

Keywords: Inventory management, Spare Parts, Obsolete materials, Digitalization of operations

Resumo

A globalização e constante inovação tecnológica tem promovido o aumento da competitividade entre empresas. De modo a manterem-se no topo, as organizações têm de garantir que todos os seus processos têm um nível de optimização elevado, procurando formas de aumentar o seu valor e o valor dos seus produtos, de modo a responder aos desafios da nova realidade do mercado em que se inserem.

Esta dissertação é o resultado de um estágio curricular na BA Glass - mais especificamente no departamento de compras. A BA Glass é uma empresa líder no seu segmento industrial, vendendo recipientes de vidro a mais de 80 países. Para apoiar as suas operações, a BA dispõe de um armazém de peças de reserva que abastece a fábrica com os materiais solicitados. O trabalho desenvolvido teve como objectivo tornar a gestão de stocks mais eficiente de modo a poder ter um melhor desempenho que, consequentemente, se traduza num melhor processo produtivo.

No início deste projeto foi efetuada uma revisão da literatura relativa à gestão de armazém, a fim de permitir uma melhor compreensão do problema em estudo e a forma de o abordar. Assim, as prioridades foram definidas e incluíram a identificação de materiais obsoletos, o aumento do controlo do inventário de peças de reserva e a melhoria da gestão das operações relativas aos fluxos de materiais em armazém.

Para tal, foram adotadas várias metodologias com o objetivo de abordar os três desafios identificados: foi criado um simulador para testar diferentes políticas de stocks; foram definidos parâmetros objetivos para determinar materiais obsoletos e para delinear os que poderiam ser transferidos para outras fábricas e, por fim, procurou-se uma solução digital para a emissão de materiais a partir do armazém.

Finalmente, são fornecidos os resultados experimentais e discutidos os impactos da utilização destas estratégias, validando assim a adequação destas medidas.

Este projeto permitiu, por um lado, uma melhor compreensão do comportamento dos materiais presentes no armazém, já que estes foram classificados de acordo com critérios específicos e modelos de gestão adequados a diferentes tipos de materiais foram estudados, modelos estes que comprovaram ser mais apropriados do que o modelo usado atualmente. Por outro lado, o estudo do processo de consumo dos materiais de armazém direcionou para uma compreensão mais aprofundada da situação atual da BA e permitiu explorar diferentes soluções digitais que existem no mercado e que podem contribuir para a otimização deste processo. Por fim, a identificação e transferência de materiais obsoletos permitiu que para a planta de Villafranca se libertasse espaço de armazém para a receção de novos materiais e que as fábricas recetoras pudessem adiar a decisão de encomenda dessas peças.

Keywords: Gestão de inventário, Peças de reserva, Materiais Obsoletos, Digitalização de operações portuguese

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"To my family."

Contents

Acronyms and Symbols

AV	Avintes
BOM	Bill of Materials
ERP	Enterprise Resource Planning
FTE	Full-time equivalent
KPI	Key Performance Indicator
LE	Leon
MG	Marinha Grande
MRO	Maintenance, Repair and Operations
MRP	Material Requirement Planning
RP	Reorder Point
SKU	Stock Keeping Unit
SS	Safety Stock
VF	Villafranca
VN	Venda Nova
WIP	Work in Process
WMS	Warehouse Management System

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Chapter 1

Introduction

Innovations in inventory management systems have been implemented over the years with the adoption of new management models suitable for different types of materials with specific demand behaviors and with the integration of information technologies in the warehouse for controlling and monitoring processes, providing real-time inventory data. This has made each factory more demanding in terms of material availability of their MRO (maintenance, repair and overhaul) inventories.

With an ever more stringent market, some companies have to operate 24 hours a day, 365 days a year, in order to guarantee and secure their place in the market. The productive process of the factories cannot stop, and this implies the continuity of other operations that support these processes, such as the supply of spare parts and consumables from the warehouse at the right time. This not only requires a great coordination between each supply chain echelon, but also the correct stock control in order to guarantee the availability of the required material at all times.

It has recently been observed that the consumers' concern with the environment makes them opt for glass containers instead of plastic ones, creating more opportunities of growth for the glass containers sector. Glass is 100% recyclable and corresponds to the foods and beverages packaging material with the highest collection rate in Europe.

The EU glass container sector accounts for about 62% of the total EU glass production, with 162 manufacturing plants distributed over all the European territory and providing more than 50000 jobs. The sector constitutes a very important contribution to the overall EU economy (FEVE, 2016).

This project was developed within the EU glass container market leader, BA Glass, with the goal of refining the processes in the BA general warehouses as well as improving inventory management practices. These warehouses hold a variety of goods with different demand behaviors that serve the daily operational needs of each factory. The optimization of stock control practices that suit each material consumption pattern as well as the digitalization of some of the warehouse procedures allow not only to adjust the inventory level but also to eliminate non-value adding activities related to material consumption by the User Areas (factory units responsible for a specific productive stage or type of equipment).

1.1 BA Glass

BA Glass is a Portuguese company that manufactures glass containers and due to its long-term growth strategy, it currently retains a big market share in the European glass market. With over 100 years of history, this company has been evolving over the years, since its foundation in 1912 in Campanhã, moving later to Avintes, until today.

This company started as a national glass trading company and was named after its founders - Barbosa e Almeida -, then evolved to become a glass producer. It has always invested in innovation, even when competing companies still opted for the most traditional methods, as is the case of when it acquired automatic machines, in 1965, increasing its capacity by 6 times the previous capacity or when a new oven was built in 1988 which allowed to increase the capacity by about 40%.

Through acquisitions and the creation of new plants in different European countries, the latest ones being the Yioula group plants, BA has been able to increase its production volume by 20 million glass containers per day. Furthermore, the acquisition of new international customers and the retention of old ones has been the reason why BA is able to keep growing in a competitive environment in which small and weak market players tend to lose even more power.

Currently, the company produces over 8 billion containers annually and its sales are distributed mostly in five segments namely, beer, food and oils, soft drinks, spirits and wine, being the food and oil the most dominant market. In order to produce this volume of containers annually, BA has twelve production plants located in seven different countries: Portugal, Spain, Romania, Germany, Poland, Bulgaria and Greece. Figure 1.1 shows BA Glass presence in the European continent.

The growth opportunity that the glass industry holds is the result of many combined factors, being one of them the consumers' increasing concern with environmental and health-related issues, which invites them to opt for glass containers instead of plastic ones, while at the same time, creating more opportunities for companies like BA to grow and enter new retailing markets. The glass container industry has a circular value chain since it receives recycled glass as one of the inputs – cullet – and the final product, after being used, can be transformed again into cullet. Moreover, the closeness to its upstream and downstream value chains (suppliers and clients) which is distinctive of this industry, facilitates and foments the business growth.

With the abrupt demand expansion and production growth, BA facilities and processes need to follow this trend. Furthermore, capital expenditures and the hiring of human resources are needed in order to allow these processes to adjust to BA's new wide range of operations. What determines BA's ability to adapt is the way the company faces and manages change. Given its history, BA has shown that it is able to deal with this challenging environment.

1.2 Project Framework and motivation

BA has five different productive plants in the Iberian Peninsula and each one of them has its own general warehouse. These warehouses have been a target of study over the years, since BA is

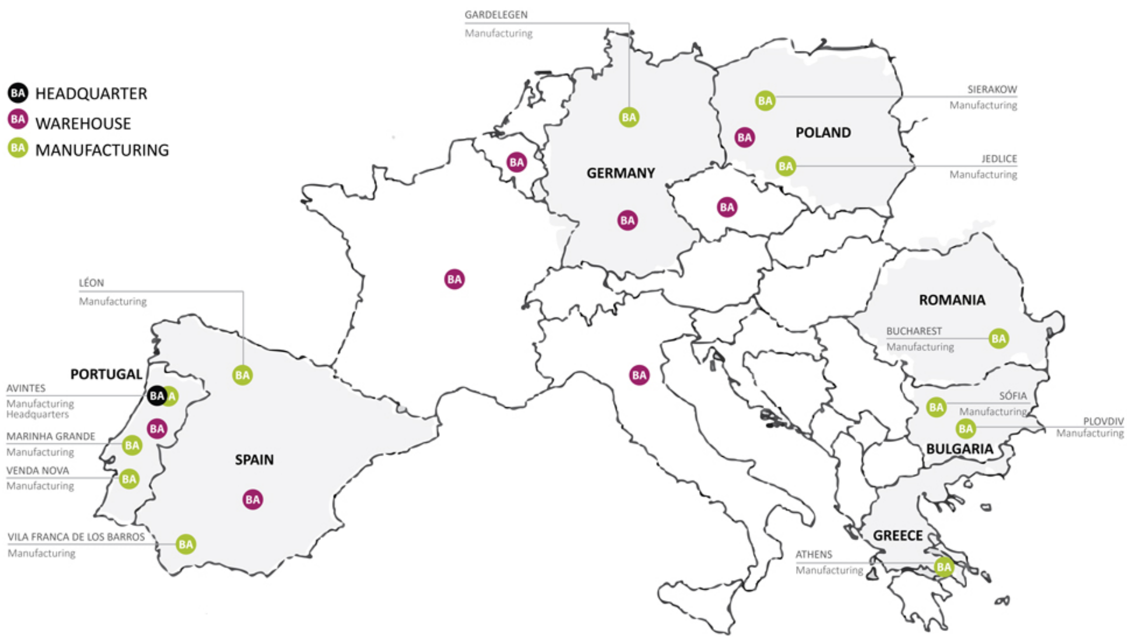

Figure 1.1: BA Glass presence in Europe Source: BAGlass (2016)

constantly trying to find ways to adjust its inventory volume in order to become as efficient as possible. They store not only consumable goods that are requested by the factory User Areas, but also the refractories of the furnaces, spare parts and lubricants.

The current project was developed with the goal of optimizing the warehouses inventory management processes in relation to replenishment, storage and consumption of warehouse goods. The stock level of the warehouse is inadequate for some materials, especially for obsolete materials that have a strong presence in these facilities. These problems are mainly due to the static nature of some segments of the warehouse management system. The aforementioned procedures have been revised over time; however, even though some have been automated, they still rely on a considerable amount of human intervention. Additionally, the inefficient inventory management is also correlated to the lack of forecast methods suitable for the prediction of the consumption of these materials. Regarding the material consumption, this process is not optimized since each time a material is collected from the warehouse it needs to the issued in SAP by the warehouse clerk who only works an 8-hour shift 5 days a week and the needs for materials are constant.

This report was developed within the Iberian Purchasing at BA that incorporates five different local departments. Each warehouse of the five Iberian plants - Avintes, Marinha Grande, Venda Nova, Villafranca and Leon - has its own local purchasing responsible that is accountable for the supply of materials for its warehouse.

1.3 Project Goals

The project was developed with the goal of identifying new practices that can be implemented in the warehouse management processes and that will result in the adjustment of the stock level and the automation of the warehouse procedures. This stock level adjustment will involve not only revising the replenishment methods, but also identifying obsolete items.

This goal can be divided into two main objectives, being the first one the revision and improvement of the warehouse replenishment process of consumables and spare parts by linking it to the customer demand which, in this case, is the User Areas of the factory. In this objective, stock levels are expected to be matched automatically with its demand behavior.

The second objective is the digitalization of the warehouse materials' consumption, eliminating the need for factory workers to reserve materials in advance before collecting them from the warehouse. Therefore, the digitalization is simplifying this process by eliminating some of the bureaucracy associated with it. This objective includes the implementation of material data reading technology in order to make the consumption of warehouse goods faster and more reliable and at the same time reducing the number of parts that disappear from the warehouse due to their collection without previous reservation.

1.4 Methods followed in the project

The methodology used in this project can be summarized in the following steps: observation of general warehouse processes, mapping of the AS-IS, testing of improved opportunities and evaluation of results.

Firstly, the observation of the warehouse processes and inventory control systems used in BA facilities was undertaken, with special attention given to the consumables, lubricants, refractory and spare parts stocks. This inventory control process starts with the replenishment of the material; then, the storage in warehouse facilities; and, finally, the issue of the goods so that they can be used in the factory operations.

Afterwards, the observations were documented and process maps of the AS-IS process were elaborated. Key performance indicators (KPIs) that evaluate the AS-IS warehouse management processes were calculated, namely coverage in days, turnover rates and service level. With the support of literature regarding warehouse control practices implemented in general warehouse inventories, improvement opportunities to the current control system were presented.

In order to test new inventory models, a simulation of the replenishment process was designed in R and the results were analyzed. In this stage, KPIs obtained from each model were compared not only with the AS-IS model KPIs, but also with the indicators of the other simulated models in order to draw conclusions regarding the best model.

As for the digitalization part of the dissertation, the identification of improvement opportunities in the warehouse goods issue and receipt was conducted. New opportunities were tested with the calculation of an estimate for the number of warehouse FTEs reduced.

1.5 Dissertation Structure

The dissertation is structured in six main chapters. The first chapter corresponds to this exact chapter. In this chapter, the goals and motivations of the project are presented as well as the methodology followed in order to achieve the desired goals. Moreover, a brief presentation of the company in which this dissertation was based on is provided and the highlights of the market in which it operates are given.

The second chapter contains a broad theoretical background of the subjects that are going to be addressed in this dissertation which are included in the main topic of warehouse management systems and optimization. These subjects are the current trends that are specific to the above-mentioned systems; logical models behind WMS (warehouse management system); forecast of warehouse demand; inventory classifications used to enhance selective inventory control; and MRO inventory management specific practices.

In the third chapter, the AS-IS of warehouse materials replenishment, storage and consumption processes are presented and the inventory management problems that are going to be targeted in this dissertation are listed.

In the fourth chapter, the methodology used to obtain solutions for the issues raised in the previous chapter are provided as detailed as possible and according to the subjects analyzed in the literature review.

In the fifth chapter, the expected results with the implementation of these solutions are calculated and presented.

Finally, in the sixth chapter, the key conclusions of this dissertation are enumerated as well as future work that was not explored in this dissertation but may become the focus of other projects.

Chapter 2

Theoretical Background

In this chapter, a review on warehouse management literature is made with greater focus on current trends in the field of maintenance, repair and operations (MRO) warehouses. Furthermore, warehouse management practices regarding inventory classification and control are discussed. Warehouse management systems and the technologies that are currently being implemented in different companies are also revised.

2.1 Warehouse Management

Warehouses are an integral part of the supply chain infrastructures. Their management is not only a critical operational part of the supply chain management, but also an essential strategic one since it coordinates different aspects of the business, such as production, suppliers, customers and products.

Warehouse management corresponds to the control and optimization of the complex operations that take place in warehouses. The key elements involving warehouse management are: inventory tracking and management which corresponds to the monitoring of stock level, allowing the warehouse staff to know how much product is ready to be shipped to the customer and how much should be order/produced; picking products from their warehouse location and packaging them to be delivered to the customer; receiving inventory from trucks at loading docks and stowing materials in their short or long-term location; shipping to the customer; and reporting in order to access performance indicators such as the accuracy in fulfilling orders, staff efficiency and number of orders fulfilled on time (Lopienski, 2019).

Regarding inventory management, it aims to balance advantages and drawbacks that come from different stock levels. High stock levels represent, as a rule, high inventory expenses but also high service level. These inventory expenses can be specified in: capital costs that correspond to the opportunity costs of storing one item instead of storing another; service costs, i.e. stock management and insurance costs; storage costs that include costs of space, handling and other costs associated with the warehouse; risk costs, namely, detection costs, damage costs, obsolescence costs and theft costs.

Despite all these expenses that are associated to the high inventory levels, the ease and speed of supply to the customer is a benefit that can be highlighted when compared with the less positive points mentioned above. On the other hand, low stock levels imply less storage costs, but represent an increase in the difficulty of satisfying the demand, followed by a reduction in the customer's service level (Rushton et al., 2010).

2.1.1 Warehouse Management System

With the purpose of managing these facilities, companies all over the world have gradually been adopting Warehouse Management Systems (WMS). Although many companies believe that another designation for these systems is Inventory Control System, in fact these two terms present some differences, namely the fact that the latter refers to a system that manages inventory inside the facility, but does not measure productivity inside the warehouse unlike the former designation (Richards, 2011). Warehouse Management Systems are information technologies that control the reception, storage, separation, issue and document sending of warehouses. Inventions such as RFID, barcode and data communication technologies have changed the way WMS perform mainly by tightening inventory control and by decreasing the response time while, at the same time, detaining a bigger variety of SKUs and improving service level (Gomes et al., 2018). Warehouse Management Systems are information solutions that companies have been adopting. The SAP Extended Warehouse Management is a clear example of one of these.

Warehouse replenishment is the process that ensures that the right material and the necessary quantity is available in the warehouse storage location. An inefficient replenishment leads to order shortage and overall reduction of service level. A real-time Warehouse Management System guarantees replenishment whenever it is needed with real-time data transfer. The logic behind replenishment in Warehouse Management Systems depends on the type of demand the stored items have. Materials can be demand-dependent materials, meaning that they will be requested whenever a certain good is requested. Otherwise, if the demand of different products is unrelated to the other items' demand, then that product is an independent demand material (Richards, 2011).

2.1.2 MRP - Dependent demand model

For items for which demand is dependent, such as packaging material or components that are assembled in order to produce finished product, the most common model used is the Material Requirement Planning. It is a systematic approach for material planning that helps users to understand the repercussions that a change in each planning level can have in the other levels. Moreover, material requirement planning receives information from the master production schedule, bill-of-materials and inventory status records. Starting from the master production schedule, the MRP system is able to establish the link between parent items and their components by calculating components gross requirements through the parents' planned orders (Orlicky, 1975).

2.1.3 Stock Management Policies

In relation to inventory management of goods, decisions have to be made regarding the frequency of review of the inventory status, the time at which a new order should be placed and what quantity should be ordered. In order to provide solutions to these issues, various inventory management models have been created. These models can be classified according to several factors that characterize them. One of these factors can be the nature of demand, leading to the division of these models into deterministic and probabilistic models. Deterministic models can provide a good estimation when they are used within a stable business setting; however, they have proven to perform poorly when used in highly variable environments with fluctuating order patterns. By contrast, probabilistic models have proven to have a good performance as they help to understand the impact of stochastic factors on warehouse operations. In addition, inventory models can also be divided based on the possibility of repetitive orders, meaning that they could be single-period or multi-period models; they can also be classified based on the timing of review of inventory status (continuous or periodic) or even according to the nature of procurement lead time (constant or varying) (Shenoy and Rosas, 2018).

Some of the models used more frequently are the Newsvendor model, the Continuous Review model with Fixed Order Quantity (s, Q), the Periodic Review model (T, S) and the Periodic Review with Order-up-to level and reorder point (T, s, S). The Newsvendor model - also known as the Single-period model - is used for one-time order items and the quantity to be produced is the unknown variable that must be calculated balancing stock-out and under-stock costs. With this model, there is no possibility to satisfy pending orders, meaning that, if the ordered quantity is not supplied in that exact moment, it is not possible to be supplied in subsequent moments.

Contrarily, multi-period models are designed with the goal of ensuring the replenishment of items along the year. These models can be submitted to a Continuous Review policy - in case the replenishment trigger is the quantity in stock - or a Periodic Review policy - in case replenishment is triggered with time (Chase et al., 2018).

2.1.3.1 Continuous Review, Fixed Order Quantity (s, Q) model

When using a continuous review policy model, stock level is continuously being assessed and a new reorder to the supplier is carried out when on-hand stock falls below a predefined reorder point, s. Hitting the reorder point is the event that will generate a new order of fixed quantity Q. Figure 2.1 shows the behavior of this model.

An adequate reorder point guarantees that the demand during the placement and reception of the order - lead time, L - is secured, even when the demand and lead times are uncertain. According to Chase et al. (2018), this model is recommended for items with a high level of importance such as critical spare parts, since it controls the inventory level closely; however, it requires more maintenance time, due to the fact that every good reception or issue must be registered.

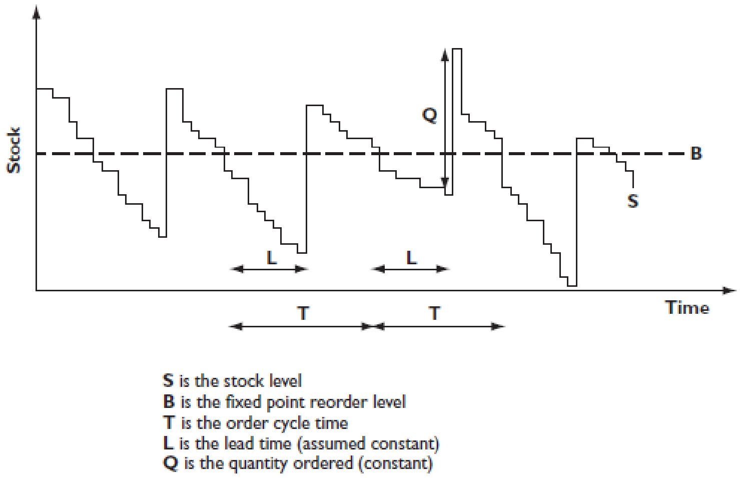

Figure 2.1: Continuous Review (s,Q) model (Source: Rushton et al. (2010))

2.1.3.2 Periodic Review, Target Stock (T,S) model

The Periodic Review model requires that the stock level is examined at regular intervals and new orders are processed with order quantities that are dependent on the level of on-hand stock, allowing the stock level to reach a predetermined level. This model usually has a higher average inventory level, since stock level must be protected during the review interval. The ordered quantity includes an allowance for the time that it takes for the supplier to deliver the ordered quantity. An example of this model behavior is presented in Figure 2.2 and Equations 2.1 and 2.2 display how S is calculated based on safety stock (SS) (Rushton et al., 2010) (Chase et al., 2018).

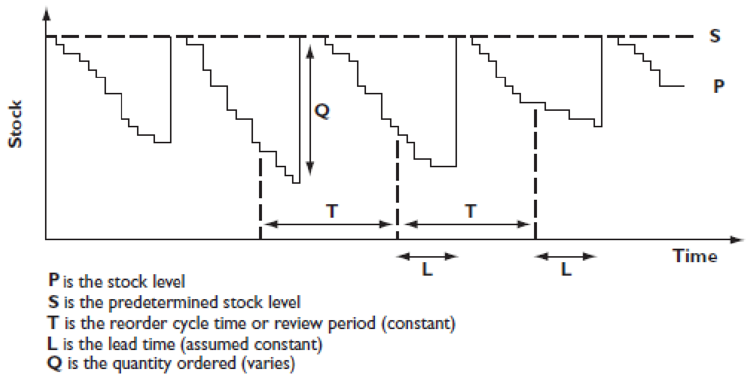

Figure 2.2: Periodic Review (T,S) Model (Source: Rushton et al. (2010))

$$S = \mu_{DL+T} + SS \tag{2.1}$$

$$SS = Z \cdot \sigma_{DL+T} \tag{2.2}$$

where μ_{DL+T} is the expected demand over lead time plus review period, SS is the safety stock, Z is the safety factor and σ_{DL+T} standard deviation of demand over lead time plus review period.

2.1.3.3 Periodic Review, Min-Max (T,s,S) model

Another stock policy that is also commonly used is the Periodic Review with order up to level. This policy - also known as Min-Max - differs from the previously mentioned model in some specific details: when stock level is reviewed, a new order will only be placed if the stock level falls bellow the reorder points, s. The ordered quantity Q^* is placed in order to raise the stock level to the maximum level, S (Vrat, 2014). Equations 2.3 to 2.6 show how s and S are calculated based on D (total demand during the inventory planning horizon), L (lead time), T (review period), Z (standard normal distribution at the desired service level) and X (random variable representing the demand over T + L).

This Periodic Review model (T, s, S) is frequently adopted in machinery spare parts for the manufacturing industry or even in vehicle spare parts for garages, where products present an intermittent demand, meaning that the demand pattern is characterized by low, sporadic or irregular demand periods separated by extended time gaps of zero consumption. This model allows the stock to be replenished up to the maximum level even if the consumption decreases over time (Jin, 2019).

$$\mu_X = (T+L) \cdot \mu_D \tag{2.3}$$

$$\sigma_X^2 = (T+L) \cdot \sigma_D^2 + \mu_D^2 \cdot \sigma_L^2 \tag{2.4}$$

$$s^* = \mu_X + Z\sqrt{\sigma_X^2} \tag{2.5}$$

$$S^* = s^* + Q^* \tag{2.6}$$

2.1.4 Inventory Classification Models

Selective inventory control is a practice that companies usually use in order to understand which materials are more important (depending on their value, criticality or other criteria) and, for that reason, should be controlled more closely. In order to identify the importance level of each material, different ways to classify warehouse goods have emerged, being the most popular one the ABC analysis.

This ABC analysis operates on the basis of “vital few, trivial many” and the classical 80-20 Pareto principal. Materials are grouped in categories (A, B or C) according to their value or volume of rotation. Class A materials represent 20% of the SKUs which rotation corresponds to around 80% of the total warehouse rotation. Class B corresponds to 30% of materials which rotation is around 15% of the overall rotation. And, finally, class C material are 50% of the SKUs in the warehouse which rotation is low, they are responsible for only around 5% of the overall rotation. Usually, either the percentage of SKUs corresponding to each class is set or the percentage of stock rotation. In the case of this dissertation, the percentage of SKUs was set. A representation of this method can be visualized in Figure 2.3. Despite this method being so commonly used, some researchers such as Smirnov (2020) have proven that these techniques of ranking materials according to their consumption/demand value and volume leads to cost inefficient solutions for warehouse management, since only one factor (annual consumption) is being used to categorize materials. Furthermore, other drawbacks of the analysis is that highly critical warehouse materials that have low consumption can be overlooked. The need to periodically review and update becomes critical for warehouse management and it becomes difficult to control all management problems like big volumes of low value items. For this reason, new methodologies are referred to later on have been developed in order to classify materials taking into consideration more than one criterion at the same time.

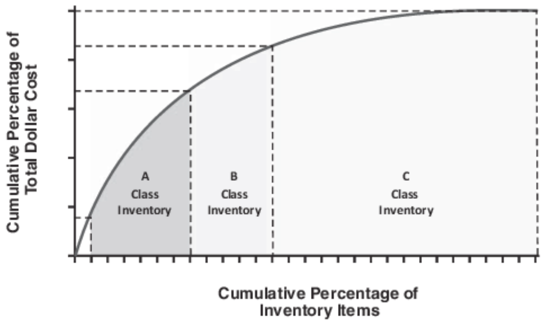

Figure 2.3: ABC analysis

Another popular technique for inventory classification is the VED (Vital, Essential, Desirable) analysis that classifies materials according to their criticality. This methodology is commonly used in the classification of spare part warehouses where criticality is often the most relevant criterion when defining the stock management policy. Items are considered in the Vital class if their failure has a big impact in the production process, meaning that their stockout can lead to a machine shutdown in extreme situations. Regarding Essential goods, these are the materials whose shortage in warehouse can represent a high cost for the company, but do not lead to an operations stop; and, finally, Desirable goods stockout can lead to a minor disruption for a short duration in production. Although the usage of this method apparently seems simple, the results can be highly influenced by subjective opinions of the participant in the classification (Teixeira et al., 2017). Besides, it can also be an exhaustive process due to the fact that criticality is a qualitative criterion and, in order to evaluate each material criticality level, an individual assessment has to be done.

Another methodology used in inventory classification is the XYZ analysis, which groups materials according to their demand variability, meaning that materials X are 20% of the materials and have a predictable demand and material Z are 50% of the materials and have an uncertain demand. Y materials are 30% of the SKUs which demand fluctuates. The correlation coefficient is the measure used to evaluate demand variability. One of the biggest drawbacks of the XYZ analysis is the impossibility of classifying new materials due to their lack of demand data. Often, these goods are classified as Z materials. Also, this analysis is unable to give due consideration to seasonal goods and therefore, they have to be removed before computing XYZ analysis (Dhoka and Choudary, 2013).

The aforementioned methods are all single criterion classifications and, for that reason, have the disadvantage of only using one single variable to classify materials. New methods that use multi-criteria classifications have emerged recently in order to overcome single criterion limitations. These multicriteria classification models can be cross-tabular methods, in the case of using two criteria at the same time, or much more complex models based on AHP (Analytical Hierarchical Process) techniques which attribute different priorities to each one of the criteria. The advantage of this technique is that both quantitative and qualitative criteria can be used to classify materials. Multicriteria models tend to be more time-consuming than single criteria, but the accuracy of the classification results is likely to be much higher (Praveen.M.P, 2016).

Inventory can also be classified according to its demand pattern. This technique of classification is often used to select the forecast method employed to estimate future requirements. Figure 2.4 shows a matrix divided in 4 quadrants, each one representing a class of the demand pattern.

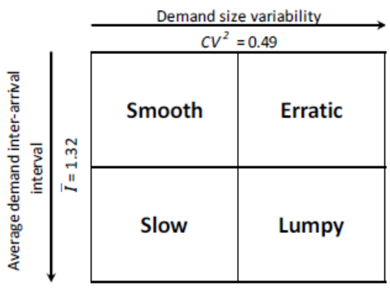

Figure 2.4: Demand pattern classification (Source: Syntetos et al. (2005))

The division of the quadrants is determined by a measure of demand variability - which is the squared root of the coefficient of variation (CV^2) - and the average demand interval ($\bar{I}$), considering the cutoff values as 0.49 and 1.32, respectively (Syntetos et al., 2005). Smooth demand is regular overtime and variability is small, whereas slow (or intermittent) demand is extremely sporadic and has no accentuated variability in terms of quantity. Erratic demand, despite being regularly distributed overtime, presents high variability of demand quantity, and lumpy demand is sporadic and has a great number of periods in which demand is zero. Figures 2.5 exemplify the behavior of an item for each category of demand classification.

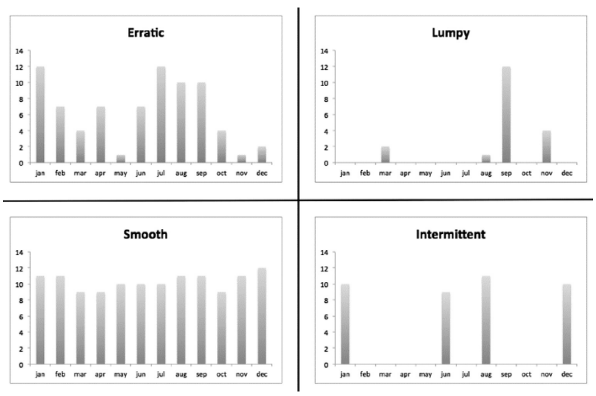

Figure 2.5: Demand Patterns (Source: Costantino et al. (2017))

2.1.5 Demand Forecast

Different forecast methods are being implemented in companies as a way to estimate future goods or materials requirements. Forecast is a tool that helps in decision making for inventory management, since it allows to understand what should be stored, how much stock of each item should be kept and in what facilities to store.

Projective forecasting methods use historical demand data to forecast future period needs, based on the analysis of a time series pattern, such as trend, seasonality and level. The most commonly used approach is the moving average, which takes the average of a given set of a specific number of periods and uses it to forecast the next period demand. This method is also usually used to detect the presence of trend in a time series. Exponential smoothing is another forecasting method that gives a higher emphasis to the most recent demand values. A smoothing factor defines the rate at which the influence of past periods exponentially impacts the results of forecast values (Makridakis et al., 2008).

For dealing with time series which evidence the present of trend, Holt (1957) has extended exponential smoothing methodology by adding a new smoothing parameter (β). The trend can evolve over time, so there is the need to smooth that evolution in order to obtain forecast results. This trend smoothing is possible with the use of Holt's linear exponential method. Additionally, to deal with data characterized by both trend and seasonality patterns, Winters (1960) extended Holt's method and added a third smoothing factor (γ) for seasonality (Makridakis et al., 2008).

The suitability of a particular forecast model for a given dataset is accessed with the calculation of standard statistical measures. These measurements will show how well the model will reproduce the data that is already known. The most commonly known forecast accuracy measures are the ME (mean error), MAE (mean absolute error), MSE (mean squared error) and MAPE (mean absolute percentual error). MAE, also known as MAD (mean absolute deviation) is an absolute error and has the advantage of being easier to interpret compared to MSE, whereas MSE is easier to handle mathematically. Mean absolute deviation measures the deviation of the forecasted demand and the current demand in units. This error was used along this dissertation and Equation 2.7 represents the most commonly used formula to calculate it where n is the number of historical periods used. Moreover, MAPE is a relative error and can be very helpful to interpret results but can only be used when the scale has meaningful origin, meaning that it cannot be used, for example, with temperature scales (Makridakis et al., 2008).

$$MAD = \frac{|\sum_{t=1}^{n} Actual\ value_t - Forecast\ value_t|}{n} \tag{2.7}$$

2.1.6 Uncertainty in Warehouse Operations

When reviewing stochastic models, literature usually mentions the component of uncertainty to which these models are attached to. This uncertainty affects the accuracy of these models and it is present in warehouse systems at strategic, tactical and operational levels. These sources of uncertainty can be unpredictable events (such as floods), predictable events like demand seasonality and internal variability such as staff absence or communication errors. Regarding sources of uncertainty that affect the operational level of the warehouse, it is present in the reception, service and issue of materials. The uncertainty in reception is usually connected to the unavailability of the ordered quantity in the supplier's warehouse or at the time of the order arrival.

In addition, uncertainty is also present in services performed inside the warehouse, such as warehouse storage. Efficient space utilization can reduce the uncertainty of replenishment shortage. Finally, uncertainty can also be associated to the issuing of the good, such as uncertainty regarding departure operations (Guo and Yu, 2018).

2.1.7 Lean Management in Warehouses

According to Heizer et al. (2016), lean inventory is a concept that refers to having the minimum level of stock necessary to keep operations running. In order to keep that desired level, tactics such as pull system to move inventory, reduce lot size, develop just-in-time delivery systems with suppliers and deliver directly to the point of use have been implemented by companies with the goal of reducing inventory costs and improving service level for the subsequent supply chain stage.

Many companies are trying to implement lean thinking methodologies to the way they manage their MRO warehouses. Some approaches emerged in the past years, many of them referring to different material classifications and respective identification of inventory control policies according to these classifications. Moreover, the lean management of warehouses is also being accomplished with the supervision of all supply chain processes that allows to tighten the control of replenishment operations, the improvement of supplier's quality and the implementation of centralized procurement. This lean methodology in spare part management is also being implemented by means of the integration of this materials management with the ERP (Enterprise Resource Planning) information systems, contributing to the standardization of procurement processes, and maintenance procedures, and allowing the exchange of information between maintenance departments, procurement departments and warehouse managers. Finally, a simpler but also effective lean warehouse management practice that has been implemented is the identification of repeated materials with different designations which allows a better control over inventory management and purchasing (Guo and Yu, 2018).

In order to get a better look at the improvement opportunities in a process, Rother (1999) introduced the idea of material and information flow diagramming. In lean manufacturing, the information flow is treated with the same level of importance as material flow. The resulting diagrams allow to have a value stream perspective, meaning that they give a viewpoint of what the big picture is like and the way the whole picture can be optimized, not only just the parts. Some companies prefer to create maps for specific sectors in order optimize local performance and, afterwards, integrate the different sectors maps to attain the complete map.

2.2 MRO warehouse

Warehouses can be classified according to the type of material they store (finish product warehouse, work in process (WIP) warehouse, etc.). Focusing on MRO warehouses (warehouses that store maintenance, repair and operations inventory), these have a particular behavior when it comes to their management. The materials that are stored in these warehouses have intermittent or slow-moving demands, yet they are of enormous importance to ensure the functioning of the operations. For this reason, factories production and maintenance departments are usually firm believers that having a relatively high volume in storage is better than having the precise needed quantity – the "Just in Case" approach (Bailey and Helms, 2007).

Identifying non-critical and critical parts of the inventory and revising stock levels and reorder points have been approaches used by some companies. Other strategies involve the reduction of the number of suppliers and the consolidation of spending in order to gain more price bargaining power. When selecting new suppliers, companies tend to place greater importance on price rather than quality; however, when measuring MRO supplier's performance, the quality of the supplied products is likely to be the most relevant factor (MSCco., 2016).

Some studies demonstrate that companies stock MRO inventory in a careless way and do not attribute the correct value to the warehouse materials, which, in turn, gives an incorrect perspective of the value of stored goods. Stocking decisions have not been economically oriented, and these costs have been perceived as necessary costs to continue operations and, for that reason, have not been questioned. Apart from this, even though most warehouses have a person assigned for the warehouse daily operations, most of the times there is no worker selected to dedicate time to controlling the long-term planning and development of the warehouse status and to reporting. Moreover, despite the fact that usually there are individuals that attempt to present solutions to the problems that concern stock control in MRO inventories, these solutions generally are not put into practice, since individuals are not eager to promote and go forward with the solutions due to the amount of work involved. These solutions cannot be carried out in isolation, meaning that there is the need to have a wider picture of the warehouse control practices and, generally, the owners of these ideas do not have that bigger picture perspective (Siponen et al., 2019).

According to Siponen et al. (2019), MRO inventory management can be divided into four perspectives: supplier management, material management, information system management and Business Process Management (BPM). This last encompassing the first three approaches. Material management comprises "part coding, part classification, demand forecasting, and establishing re-order points and quantities"; supplier management comprises "identifying network structures, strategy development for spare part logistics and supplier coordination and control"; information system management consists of "automation of ordering processes, data quality control, and supplier integration into information systems"; and, finally, the BPM allows to transit from an uncooperative management strategy to a cooperative and engaging strategy of managing warehouses.

2.3 Warehouse digitalization

The digitalization of the supply chain entails the creation of an interconnected industrial ecosystem through the use of efficient IT technologies and data architectures that support the supply chain operations. Collaborative cloud-based platforms give information access to different stakeholders and allow them to interact faster with the different supply chain stages. The level of interconnection varies depending on the adoption of "integrated planning and execution systems, logistics visibility, autonomous logistics, smart procurement and warehousing, spare parts management, and advanced analytics". Smart procurement is the integration of suppliers using big data tools so as to align planning process schedules and improve supply and collaboration. The need for suppliers to switch from traditional supply methods to digital ones and achieve the digitalization level of its customers is a big challenge of this digitalization trend (Schrauf and Berttram, 2017).

Smart warehouses are the combination of warehouse digitalization and automation. An essential step of data requirement to allow companies to put into practice inventory management models is the tracking of the material in the warehouse. Real time tracking of information is possible by using IOT technologies, such as RFID, barcode readers and smart sensors. The combination of RFID with smart shelves is being used to attain more information (e.g. material positioning).

Chapter 3

Problem Description

The goal of this section is to describe BA's current situation regarding material flow and purchasing. First of all, an introduction to the productive process is made with the aim of explaining the relationship between the functioning of the warehouses and the rest of the operations that take place at BA. The Iberian purchasing department is presented together with an organizational chart that displays the divisions that this department contains. Furthermore, the general warehouse materials are introduced and these material workflow is mentioned in detail with the support of a process map.

In addition, emphasis is placed on the process of material consumption by the User Area and on the obsolete materials that are stored in the warehouse and that have not been used for a long period of time, whose demand was incorrectly forecasted or are no longer needed due to changes in technology.

3.1 Glass Containers Production Process

The production process of glass containers has 6 stages (see Figure 3.1) that are described below.

– Composition: Raw materials are mixed according to the formulas specific for the color of the glass that is intended to be manufactured.

– Fusion: The resulting mixture of the previous stage is melted in a furnace that reaches temperatures as high as 1500°C. These furnaces are powered by natural gas and electrodes placed at the base of the furnace.

– Molding: Drops of melted glass go directly to the molds that allow the glass to gain the shape of the container that is being produced.

– Annealing and surface treatment: After exiting the molding machine, the container receives a hot surface treatment so that the glass becomes more shock-resistant. Afterwards, the container enters an annealing lehr belt and is subjected to the annealing process in order to reduce internal tensions that were generated after the molding stage. Then, the container is subjected to a cold surface treatment to make the glass surface more resistant to scratches and grooves.

– Inspection: In this stage, the container is inspected to detect any quality problems. Containers that do not meet quality standards are rejected and used for the production of cullet.

– Packaging: If the container is not rejected in the previous stage, it will go on to the packaging stage and will be palletized by automatic machines. The palletization process corresponds to the placement of the final product on top of a wooden pallet and in tiers separated by layers that can be wrapped at the end by a plastic strap.

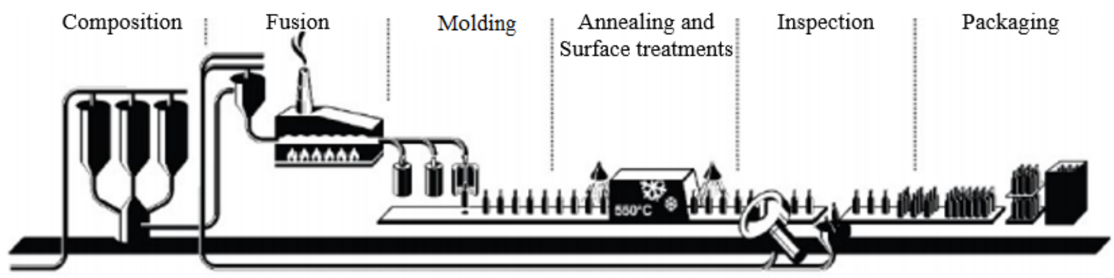

Figure 3.1: Glass containers productive process

In what concerns BA User Areas that have been referred previously, there are multiple User Areas that are dedicated to the different stages of the productive process. The main BA User Areas are displayed in Figure 3.2.

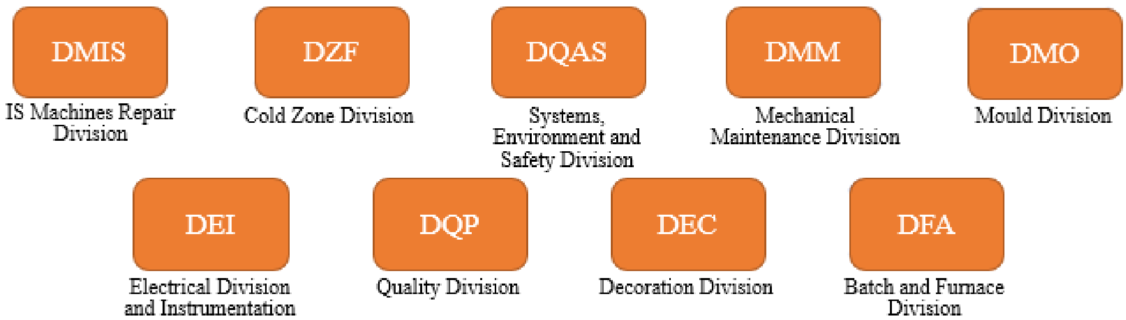

Figure 3.2: BA User Areas

3.2 BA Purchasing department

The responsibilities of BA's purchasing department are very broad, as not only is this department responsible for purchasing goods and services, but it is also responsible for ensuring the effectiveness of the procurement operations with regard to shipping and to suppliers quality verification as well as to establishing the best relation between quality, quantity, delivery time and cost.

BA's purchasing department is divided into Regional and Corporate purchasing areas. The Corporate purchasing area is responsible for managing materials for all the organization (and, at the same time, obtain economies of scale) whereas the regional areas consider a specific plant or a

Table 3.1: Purchasing Areas responsibilities

Segments	Corporate	Regional	
		Central	Local
Energy	S+N	N	R
Raw Materials	S+N+A+C	R	
Packaging	S+N+A+C	R	
Lubricants	S+N+A+C	R	
Coating	S+N+A+C	R	
Spare Parts	S+N+A+C	R	
Refractories	S+N+A+C	R	
Molds	S+N+R+A+C		
Investments	R		
Safety & EPIs		S+N+A+C	R
Big Services		S+N+A+C	R
Waste		S+N+A+C	R
Fuel		S+N+A+C	R
Subcontracts		S+N+A+C	R
Services		S	N+R+A+C
Consumables		N	N+R+A+C

group of plants and guarantee the replenishment of resources that are specific to that plant. To have a clear understanding of the responsibilities of each area, Table 3.1 summarizes what is expected of each area. Five responsibilities can be referred: strategical management (S), negotiation (N), replenishment (R), suppliers' audits management (A) and complaints management (C).

Concerning the raw materials, packaging, lubricants, coating, spare parts, refractories and molds, the negotiation with the supplier is made by BA's Corporate purchasing, due to the fact that these materials are of extreme importance to the factory and represent a large cost to BA. Their replenishment is mainly regional with the exception of molds procurement. For example, in the case of raw materials, the negotiation involves the creation of annual budgets (as it happens also with the other segments) by the Corporate section of the department which, over the course of the year, can be subject to slight adjustments that are handled by the Regional purchasing. This section of the purchasing department is responsible for the daily planning of the raw materials' delivery. Regarding the molds procurement, since the suppliers are common to all factories, all the responsibilities concern the Corporate purchasing.

Fuels, waste, services, safety equipment, consumables and subcontracts are negotiated and replenished by the Regional level, since they represent a smaller portion of BA's costs and, that way, the replenisher can be more in touch with the plant daily needs.

Focusing on BA Iberia's regional area more specifically, it is divided in to six sections, a central section and five local ones (see Figure 3.3). Each one of the five local sections (Avintes (AV), Marinha Grande (MG), Venda Nova (VN), Leon (LE) and Villafranca (VF)) is responsible for the replenishment of safety equipment, services, waste, fuel, subcontracts, consumables and energy. It is their responsibility to ensure that the orders are placed and delivered on time, to guarantee the fulfilment of the conditions negotiated with the suppliers and to guarantee the rigor in the purchasing process of the plant in question. Moreover, the Central Regional Supply section is part of the regional area and is responsible for the replenishment of raw materials, packaging materials, lubricants. coating, spare parts and refractories.

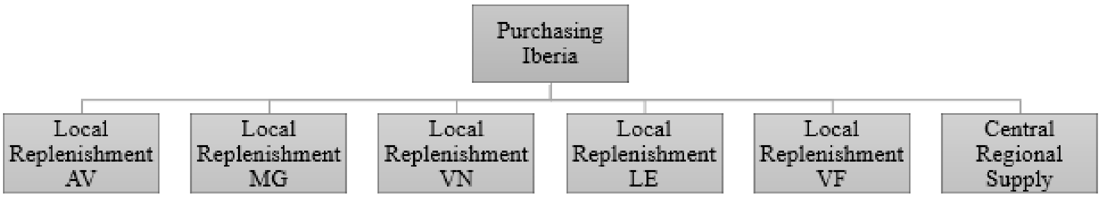

Figure 3.3: Purchasing Iberia Organizational Chart

3.3 Warehouse Materials

BA's general warehouses store materials of different types that are used to support plant operations. These material types are: consumables (CONS), fuels (COMB), spare parts (RES), refractory (REFR), office materials (ECON), forms (IMPR), hygiene and safety material (HSEG), subsidiaries (SUBS), raw materials (MP), commercial goods (MCOM), lubricants (LUB) and molds (MOLD).

In some plants, like Marinha Grande, an additional type of material - waste for recycling - is stored in the general warehouses.

This dissertation will focus on four types of materials: consumables, lubricants, refractories and spare parts, due to the fact that they are considered to be the group of materials that are in more need of an inventory restructuring. The inventory level of these materials has been reported to be inadequate and therefore a review of the inventory management policy is a necessity for BA.

Additionally, these materials can be classified according to their replenishment policy. This classification will be explored in the next section.

3.4 Warehouse Replenishment

The replenishment of the warehouse materials is planned and coordinated by SAP, which is the ERP software solution chosen by the company. SAP Warehouse Management System is the module of SAP used for these functions and it has an integrated Material Requirement Planning (MRP) system that manages inventory levels and purchasing requests. Despite the fact that SAP is able to manage and coordinate the replenishment of the warehouse, this process requires human intervention since the replenishment conditions have to be defined and all SAP replenishment requests have to go through the warehouse responsible and local replenisher in order to be validated and executed.

BA materials can be classified according to different types of MRP that are supported by SAP and that represent different replenishment policies. The selection of the MRP type will depend on whether BA wants to have stock of that material in the warehouse and whether it is allowed for the material to be purchased without having the need to be approved first by a superior. These MRP types are described below and presented in Figure 3.4.

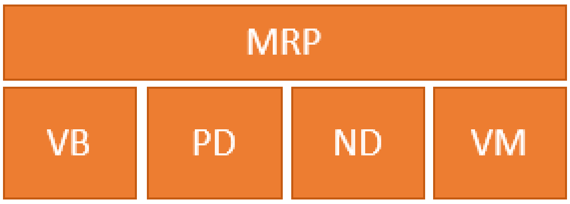

Figure 3.4: MRP types

MRP-VB: These materials have warehouse references and have a stock different than zero in order to accommodate factory needs. They are requested by User Areas by means of a reservation in SAP and their replenishment policy is the Continuous Review (s,Q) model with static reorder points. This means that, materials have a reorder point that is defined whenever the material is created in SAP and that is only updated whenever the User Area asks for an update in order to have a greater or lesser warehouse inventory on-hand. If the User Area does not request for this update, the reorder point will not be change over time. The calculation of the reorder point does not follow a formula, the technical responsible estimates what are going to be the needs of the factory for that materials in the moment the material is created (or when there is an update of the reorder point) and defines the reorder point based on his intuition and based on the factory User Areas feedback.

Whenever the reorder point is reached, a new purchase requirement is automatically generated and this needs to be manually transformed by the warehouse responsible into a purchasing requisition. So, the MRP system is not fully automated, since these requests have to be manually transformed into purchasing requisitions before being sent to the local replenisher in order for them to proceed by placing an order for the supplier.

VB materials are usually materials of extreme importance for the factory, since, if they are not available when requested, they can be responsible for the shutdown of the factory. Besides, they can also be materials that have high lead times, particularly in the case of suppliers located in geographically distant countries.

MRP-PD: Similarly to the aforementioned materials, these items also have a warehouse reference and, for that reason, are requested via reservation. However, the materials in question have a stock level equal to zero, as they are not critical materials since they do not represent a driver to a potential factory shutdown. Therefore, they are only purchased when requested. These materials as well as VB materials have permanent purchase authorization.

MRP-ND: The materials are requested by the factory through a purchase requisition. Before the local replenisher receives the information to ask suppliers to supply that good, the requisition has to be approved by a superior of the requesting User Area. They are usually materials that are at the end of their product life cycle or materials that, due to their high prices, their purchase must first be approved by a superior (no permanent purchase authorization).

MRP-VM: This MRP type, similarly to the VB MRP, follows a Continuous Review model (s,Q), meaning that a new purchasing order will be placed whenever stocks falls below the reorder point. This reorder point, contrarily to VB reorder point of static nature, is calculated based on the consumption forecast for each month. This calculation is automatic and it is performed in the beginning of each month following Equation 3.1 and 3.2 formulas. BA does not have materials with this MRP type assigned to them.

$$RP = \mu_{LT} + SS \tag{3.1}$$

$$SS = Z \cdot 1.25 \cdot MAD \cdot \sqrt{W} \tag{3.2}$$

μ_{LT} - Forecasted demand during lead time
Z – Desired service level
W – Ratio lead time/forecast days
MAD – Mean absolute deviation of the forecast
LT - Lead time

Additionally, SAP has more MRP types available then the ones presented in this section. Since BA does not make use of these MRP types and is not pretending to use them in the near future, they will not be referred along this dissertation.

Currently, a VB material MRP type is changed to a PD or ND type whenever that material stops being needed by the factory User Area and the responsible for these materials is alerted to change it. This is one of the reasons why, even though ND materials are not warehouse references, they are present in the warehouse storage. The other reason is related to the minimum order quantity that a purchase order needs to have even when less quantity is needed to satisfy the factory needs.

The number of material references that are either lubricants, consumables, refractories or spare parts present in each plant and that are classified with one of the three MRP types VB, PD and ND are show in Table 3.2.

Table 3.2: Number of CONS, LUB, REFR and RES material references by plant and according to MRP type

	AV	MG	VN	VF	LE
VB	791	1391	708	2067	1265
PD	4209	8852	2136	1416	832
ND	2185	2453	8971	1676	3054

Villafranca plant has the largest number of LUB, CONS, REFR and RES materials in VB MRP since this plant uses two different types of IS (Individual Section) machines technologies which are the machines used in the molding stage of the production process and that are composed by rows of individual but identical forming units. For this reason, twice as many spare parts references are needed to be kept in stock available in all times. Moreover, Avintes has most of the materials with the PD MRP type. Some of these materials were previously VB references, however, as they ceased to be essential materials to be kept in stock due to changes in technology, it was opted to pass these materials to the PD MRP.

Warehouse materials may or may not have one or several User Areas associated to them otherwise, the material is of common use for all User Areas. These materials are stored on shelves that are identified with the names of the User Areas that are responsible for them (see Figure 3.5).

Figure 3.5: IS machines repair User Area shelf

In the warehouse, materials are identified with a label that contains the reference, description of the material and, in some cases, a barcode with that reference. Additionally, some materials have colored stickers in their storage box as the result of a project carried out in the past with the objective of pinpointing materials whose MRP should be changed, mainly for VB materials to be transformed in ND as these were materials that are no longer consumed by the factory User Areas. Figure 3.6 is a good example of what the material label should look like.

Figure 3.6: Warehouse material label

3.4.1 Warehouse Materials Workflow

The materials workflow process starts when the User Area requests a material (see Figure 3.7). If the material is a warehouse reference, the User Area must make a reservation, whereas if the material is assigned with the ND MRP type, the User Area has to make a purchase requisition that needs to be validated by a person responsible for its approval. The person that is going to be chosen to approve the requisition will be selected based on the requisition value, the requester and the plant that is requesting the material. If the material purchase is rejected, the process ends, whereas if it is accepted, it will be ordered to the supplier by the local replenisher.

The MRP function in SAP is periodically run by the warehouse clerk in order to create purchase requisitions for warehouse materials. This happens whenever VB materials reach the reorder point or whenever PD materials are reserved, since these last materials have stock zero.

The local replenisher is responsible for making the purchasing orders to the suppliers. In order to do that, he has to consult the pending requirements in SAP, then he has to select the supplier to which he is going to make the purchase order and then he creates it.

The material will arrive after a time period (lead time) and will be delivered to the general warehouse if it has a PD or VB MRP. On the contrary, if the material has an ND MRP, the quantity requested by the User Area will be directly delivered to it and the additional order quantity that is not needed by the User Area will be stored in the warehouse. In the case of VB or PD materials, the warehouse clerk will enter the purchase orders materials in SAP, and he will verify if there is any pending reservation that needs to be fulfilled with that material. If there is a pending reservation, the material will be issued from the warehouse.

In the case of MRP VB materials have reached below the reorder point, the system will automatically generate a requisition that will be formalized by the warehouse clerk and that will be transformed in a purchase order by the local replenisher, as was previously stated. The material will arrive to the warehouse and the warehouse clerk will verify if there is a pending reservation. If this is not the case, he will simply store the material in its storage location.

The consumption of warehouse materials by the factory User Areas is triggered by means of a reservation. This means that, in order for the warehouse clerk to have the materials ready to be picked up by the plant User Areas, the latter needs to have made a previous reservation in SAP. The information that is required to be filled whenever a new reservation is made can be seen in Table 3.3.

Table 3.3: Information filled in a Reservation

Reservation
Material reference
Cost Center
Quantity
Additional information (if needed)

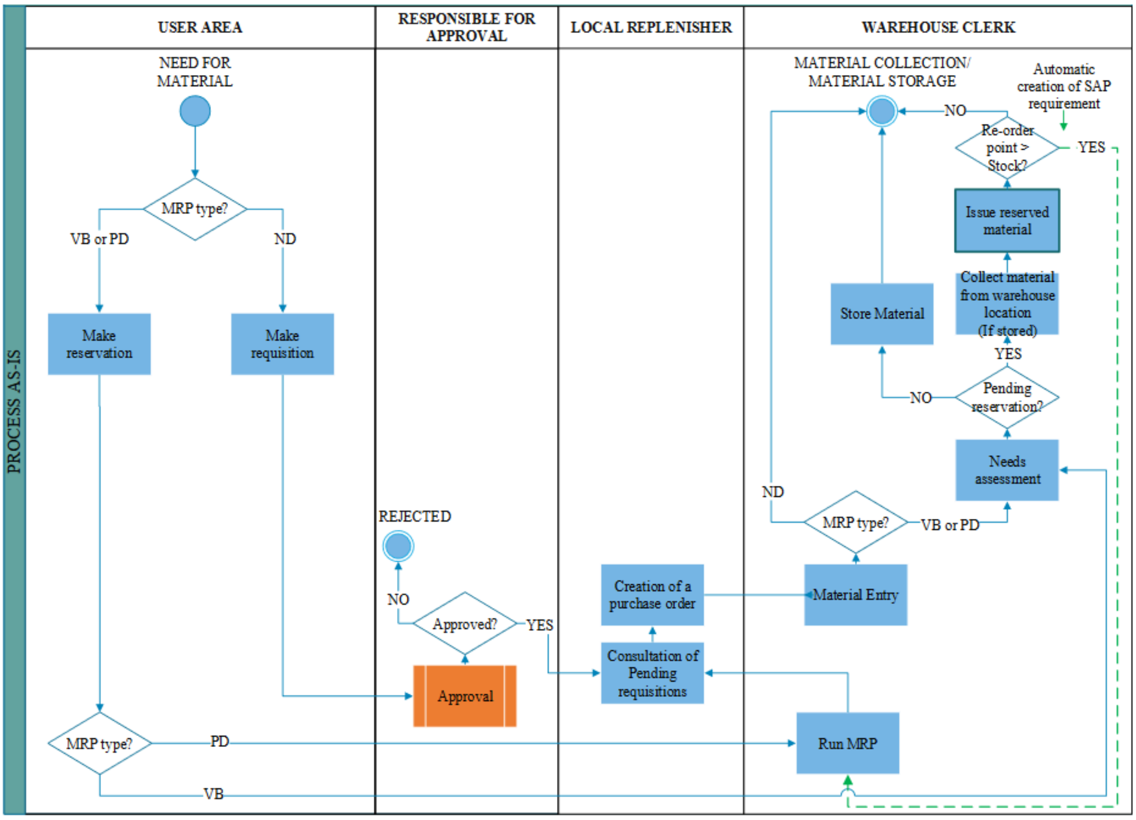

Figure 3.7: Warehoure Material Flow

Furthermore, the warehouse responsible will eventually access and validate the reservation by running the MRP transaction in SAP. If the material has a stock equal to zero, the warehouse responsible will have to transform the reservation into a purchase requisition so that the local replenisher is able to formulate a purchase order to the supplier. However, if the material has stock available in the warehouse, the warehouse responsible will access the material position, collect the material and then he issues the material in SAP.

The time spent per day by the warehouse clerk in order to perform the material issue in SAP was calculated for each plant. Table 3.4 shows the results obtained.

Table 3.4: Time spent in issuing materials in terms of FTEs per a day per plant

	AV	MG	VN	LE	VF
Time per reservation (minutes)	2,25	3,00	4,00	2,30	1,00
Average no. of issued materials per day	30,98	21,95	17,88	37,65	55,66
No. hours per day	1,16	1,10	1,19	1,44	0,93
FTES spent per day	0,15	0,14	0,15	0,18	0,12

In Table 3.4, there are some aspects that are worth mentioning. Villafranca is BA's plant that has the most optimized warehouse in terms of material movement and material storage. Materials are all identified with labels and materials are issued using a PDA (personal digital assistant). So, Villafranca is not only the plant that issues more materials per day but is also the fastest one issuing them. On the other hand, Venda Nova plant takes longer issuing materials and has the smallest number of materials issued per day.

Since the warehouse responsible has an eight hour shift a day, whenever he is absent and a User Area requests an urgent material, the shift chief is allowed to collect the material from the warehouse and register the material that was collected on a piece of paper so that the warehouse responsible is able to issue that material in the system the next day. Appendix A shows the five plants specific workflows, mentioning what information is necessary to be provided in each step.

3.5 Obsolete materials

Obsolete inventory refers to the products that are at the end of their product life cycle, meaning that they have not been used for a long period of time and are not expected to be used in the future.

In BA's warehouse one can find many of such materials, often with a high economic value. These materials are still stored mainly due to two reasons: either they have not been identified as obsolete or they have been classified as obsolete but there is no alternative use for them. Since many of these obsolete materials are specific to the glass industry, selling them is not an option most of the times. The identification of obsolete materials enables not only the freeing of space in BA's warehouse but also allows the transfer of obsolete materials from one plant to another plant that is currently using them or that will require them in future operations and consequently benefiting from these transfers.

3.6 Problem Statements

3.6.1 Problem 1 - Warehouse Material Issuing

The warehouse responsible is accountable for a variety of activities. In Avintes plant, the warehouse clerk is responsible for the posting of raw materials in SAP, the entry of packaging materials, the reception of purchasing orders coming from suppliers, the preparation of reserved materials, the issuing of materials resulting from urgent factory needs, among other tasks. This means that, during his shift, he has to focus his attention simultaneously on different activities which can have a negative impact on his performance.

Furthermore, since the warehouse has to be able to supply the factory 24 hours a day, it has to be accessible in case of emergency even when the clerk is not there. In the general store, there is only one shift a day that starts at 8h and ends at 16h30. Sometimes, after the clerk's shift, materials that were not reserved are picked up and the person that collects them from the warehouse forgets to warn the warehouse clerk about the issued material. Consequently, the physical inventory ceases to correspond to the inventory volume recorded in SAP which can have a negative impact in future reserved materials' availability.

The solution for this problem will be to identify alternative ways of issuing goods from storage in order to free some time in order for the warehouse clerk to perform other activities and improve the overall warehouse material flow efficiency, since materials that are collected out of the warehouse clerk's shift will be issued the moment they are picked from the shelves and the possibility of any mistake while registering the materials issued in SAP will be reduced.

3.6.2 Problem 2 - Warehouse inventory replenishment

In the general warehouse, the inadequate stock level is the result of many factors combined, factors that have been observed over time and different solutions have been formulated in the past in order to solve them.

The inadequate stock level can be explained by the fact that inventory volume is not assigned to materials according to their criticality or importance to the factory operations. As a result, critical materials are not the materials that have higher service level as shown when analysing the AS-IS KPIs according to ABC-VED analysis (see Table 3.5). Additionally, materials that have a low rotation have been reported to have high inventory volumes. Furthermore, obsolete materials have high inventory levels, since their reorder point is static and does not decrease with the decrease in consumption leading to a high inventory cost of obsolete materials as it is possible to be observed in Table 3.6. Obsolete materials analysis will be also explained further on.

Table 3.5: AS-IS service level according to ABC-VED matrix classification

	Service Level			Turnover Rate			Coverage in days		
	A	B	C	A	B	C	A	B	C
V	85%	77%	77%	4,06	1,48	1,27	89,9	246,6	287,4
E	85%	83%	50%	6,60	1,17	2,45	55,3	312,0	149,0
D	86%	88%	87%	9,74	3,57	1,92	37,5	102,2	190,1

Table 3.6: Percentage of obsolete materials stock

AV	**MG**	**VN**	**VF**	**LE**
3,9%	15,3%	8,3%	6,14%	2,6%

As a way to have a better understanding of the causes behind the inadequate stock level, an Ishikawa diagram is presented (Figure 3.8).

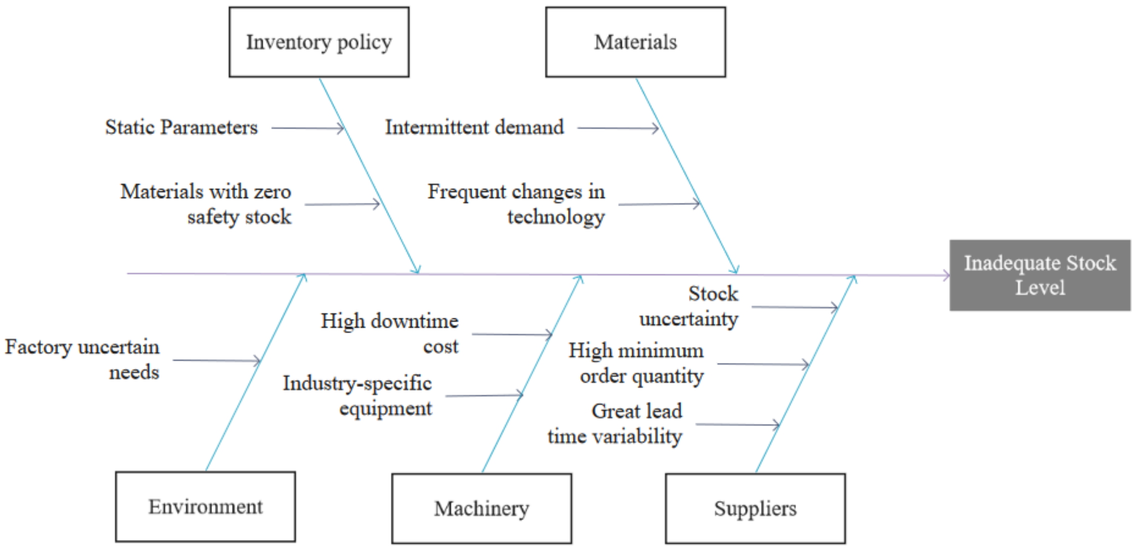

Figure 3.8: Ishikawa Diagram to identify the causes for inadequate stock level

The first cause that can be identified is related to the current inventory management policy. The inventory parameters are static in time, so they are not updated according to the material consumption behavior. Additionally, some of the information present in the material master in SAP is incorrectly defined (for example, the material lead time) and other information is missing, as is the case of safety stocks. In Avintes plant, about 23,8% of the VB warehouse references have a null safety stock and around 37,8% of the VB references that have a safety stock above zero have that safety stock set equal to the reorder point. Furthermore, 61,29% of the VB references have a lead time which is defined in SAP as being zero. In some cases, when the supplier is close to BA facilities, the lead time is possibly equal to zero; however, in the majority of the cases, this is not possible.

Moreover, the materials' nature contribute to a more difficult inventory management, since the general warehouse materials are most of the time intermittent demands goods. This makes it more difficult to predict the factory consumption needs, which consequently affects the stock level of materials. Additionally, BA is constantly trying to update and improve its equipment and, for that reason, materials become obsolete over time and, if not identified, they end up piling up.

Furthermore, the machinery used in the glass industry requires very specific materials. This means that not only is it difficult to supply them but also, whenever they stop being needed, it is difficult to get rid of them. In what concerns the down time of these machines, since stopping a machine has extremely high costs, the absence of a spare part in the warehouse can have severe consequences in the factory economic performance.

Finally, different suppliers for the same product, in general, have different geographical locations and, consequently, different lead times. This makes it difficult to manage the time of supply of these materials. These suppliers' stock availability is not certain, meaning that, whenever BA makes an order, it will have to wait until the supplier has the material available to be shipped.

Furthermore, suppliers usually have high order quantities, so BA many times ends up ordering not the amount that is needed but the suppliers minimum order quantity.

The solution for this problem will involve identifying a new stock policy or re-configuring parameters in SAP in order to have a stock level that is adjusted to the factory needs and that balances the stock level and the service level. It is expected that materials that have decreasing consumption over time will have a lower reorder point that will tend towards zero if it stops being used.

3.6.3 Problem 3 - Obsolete Materials

The general warehouse stores materials that are currently used by the factory - active references - and materials that, over time, have ceased to be used and have been in the warehouse for some time. These materials not only take up space that could be occupied by other materials that are more important to BA nowadays, but also represent money that is stuck in the warehouse. The solution to this problem will involve defining methods for identifying obsolete materials and finding alternative uses for them.

Chapter 4

Materials' Characterization and Methodology

In this chapter, the methodologies and tools used in order to solve each one of the problems presented in the previous chapter are displayed.

Firstly, for the first problem stated, the materials that were selected for this study are presented. Then, the techniques used to classify them are enumerated and the methodologies use to forecast these materials' demand are mentioned. Finally, a simulator was built in order to simulate and evaluate the performance of the implementation of different stock policies in BA general warehouse inventory management. To evaluate their performance, three KPIs were selected and calculated for each tested model. Then, the techniques used to identify obsoletes are explained.

Regarding the problem related to the warehouse materials consumption, the aspects that were taken into account for the identification of a viable solution are presented.

4.1 Materials' Characterization

In this section, the methodology used to select materials is presented. The ABC and VED analysis are performed, a target service level is defined for the different material classes and materials are classified according to the variability of their demand timing and quantity.

4.1.1 Material Selection

In the material selection process, different levels of filtering of materials were introduced. In this dissertation, an initial level of filtering was undertaken resulting in the selection of four different material groups: Lubricants, Refractories, Consumables and Spare Parts. These are usually expensive materials without which the factory could not operate and, for that reason, need to have an adequate stock management policy.

Furthermore, Avintes plant warehouse references are going to be the focus of the study, due to the lack of time and information to study all BA Iberian plants' materials. Additionally, as was previously mentioned, VB materials are the focus of this inventory management study. So, only materials with this type of MRP were included in the group of selected materials.

Besides, from the resulting VB materials, 45 obsolete material references were removed. The identification of obsolete materials will be described later on this chapter.

Additional levels of filtering were introduced, due to the absence of material consumption after the performance of the ABC analysis (167 references without rotation in the last 2 years) and, afterwards, due to the lack of the required information for the criticality analysis (114 references). These levels of filtering will be also referred along this chapter. In Figure 4.1, it is possible to observe the described filtering stages.

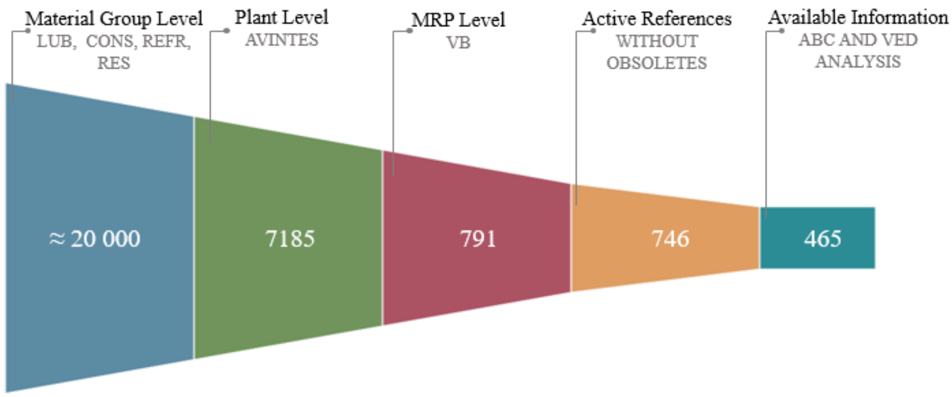

Figure 4.1: Number of material references resulting from each filtering level

4.1.2 ABC analysis

An ABC analysis was conducted in order to classify lubricants, consumables, refractories and spare parts materials according to their rotation. For this analysis, the materials' consumption value between the beginning of April 2018 and the end of March 2020 was considered. The materials' consumption volume was not considered since general warehouses store goods with different measuring units. This analysis results are presented in Table 4.1.

Table 4.1: ABC analysis results

	Cummulative SKU %	Accumulated Consumption Value (%)
A	20	87,7
B	50	98,4
C	100	100

C materials represent only 1,6% of the warehouse consumption value. These materials are a big portion of the overall warehouse references and they have an extremely low value rotation. Furthermore, A class contains 20% of these SKUs and it represents 87,7% of the overall consumption value, 7,7 p.p. more than what was expected for this class. B class materials accounts for 10,7% of these materials consumption, less than what was expected (15%), since A class materials have such a dominant impact on the warehouse value rotation.

Materials which inventory did not have any rotation in the last two years were considered D materials (167 materials). These items are not the focus of this study, since they have an extremely low rotation, but, at the same time, cannot be considered as obsolete materials.

4.1.3 Criticality Analysis

For the criticality analysis of materials, part of the materials that were classified as A, B or C materials (D materials were not considered) were classified according to the impact that their failure and the absence of a replacement in stock can have on production. This classification was possible with the help of the factory User Areas. The four impact levels are defined in Table 4.2. In order to understand if this classification is adequate for the warehouse materials, the four levels were confirmed with the responsible for the technical segment.

Table 4.2: Criticality levels description

Impact on Production	
1. No Impact	The material failure has no impact on production.
2. Quality Loss	The material failure has an impact on production quality.
3. Reduce Production	The material failure affects production performance.
4. Stop production	The material failure causes an immediate shutdown of production

The criticality assessment was analyzed for 465 materials (Table 4.3). All materials included in the lubricants and refractories material type were considered to be of extreme importance to the factory production process and, for that reason, were all assigned the highest level of impact.

Afterwards, the different impact on production levels were translated into Vital, Essential and Desirable classes. Materials whose impact in production was translated as a quality loss and a reduction of the volume of the bottles produced were included in the Essential class, whereas materials whose failure had no impact on production or whose failure stopped production were considered Desirable or Vital, respectively.

Table 4.3: Criticality by material type

	V	E	D
CONS	71	17	200
REFR	54	-	-
LUB	19	-	-
RES	98	6	-

As is possible to observe, only consumable materials were classified in the Desirable class. Within these consumables, around 69,4% of them were considered in that same class. This group of materials includes a wide variety of items, from critical to less critical ones (for example, brooms).

The fact that lubricants, refractories and 94,2% of spare parts were considered vital materials allows to emphasize the importance that these materials have for the factory User Areas and why they are of Corporate purchasing section responsibility when it comes to negotiation rather than of Regional purchasing section responsibility.

4.1.4 Target Service Level

Together with the purchase department at BA, the service level for each different quadrant of ABC-VED matrix were defined. Table 4.4 shows the matrix that reflects the desired service level for each group of materials.

Table 4.4: Service level according to ABC-VED matrix

	A	B	C
V	99%	95%	93%
E	95%	93%	90%
D	93%	90%	85%

Vital materials are expected to have a higher service level since the absence of these items in the general warehouse has profound impact in BA production process. For materials in the Desirable class, a lower service level is defined since these materials are not so critical and a low service level will represent low inventory costs.

Furthermore, the service level in the A class is expected to be higher since this class contains materials with greater value to the company. On the other hand, C materials have a lower rotation and, consequently, their presence in the warehouse will be less important.

This ABC-VED analysis will be used in the calculation of the items' safety stock further on. Higher service level will represent higher safety stocks and, consequently, higher inventory costs.

4.1.5 Demand Classification

Even though the classification of materials according to their demand pattern was not used in the selection of the forecast method, in this subsection the materials' demand classification will be presented in order to gather more information regarding the studied materials.

As was mentioned in Chapter 2, materials demand can be classified as Lumpy, Smooth, Erratic and Intermittent. Table 4.5 represents the number of the 465 evaluated materials whose demand was classified according to these classes. Both CV^2 (squared coefficient of variation) and ADI (average demand interval) were calculated using the daily consumption values of each material in the period of two years. The ADI was then converted to a monthly basis. The CV^2 did not include the zero demand periods, since zero demand periods are already implied in ADI computation.

Table 4.5: Number of materials of each class

Smooth	153
Lumpy	31
Intermittent	264
Erratic	17

The materials under analysis are only materials that were consumed in the last two years, meaning that they were A, B or C class materials, and materials that have been classified according to their criticality. In Table 4.5, it is possible to observe that the studied VB materials are mainly intermittent demand materials as was expected, meaning that consumption is very spaced out in time and of little varying size.

Additionally, there are some materials which the squared coefficient of variation of the demand is equal to zero. These are materials which, when consumed, are only consumed one unit at a time.

To see how the materials are distributed by these demand classes, Figure 4.2 is presented. To be able to have a better visualization, the vertical axis, corresponding to the coefficient of variation, was limited to one and the horizontal axis, corresponding to the average demand interval, was limited to 6 months.

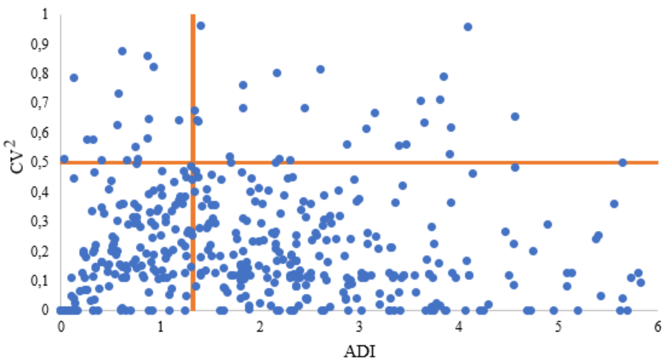

Figure 4.2: Scatter plot of materials according to their variability in demand timing and quantity

4.2 Demand Forecast

Having the ability to forecast demand for a given material and for a given time period is essential for an effective operations performance. This section presents the forecast application that was developed in R programming language and which goal is to replicate SAP forecast methodology. The forecast data was not obtained directly from SAP, because it was not available - changes to the master material records of all materials would have to be done in order to obtain such information.

Five different forecast methods were used in order to forecast materials' demand. These methods were (see formulas in Appendix C): Exponential Smoothing, Adaptive Exponential Smoothing (Trigg and Leach), Second order exponential smoothing, Linear Holt and Holt Winters.

The historical data used as input corresponded to the individual consumption of the materials, from April 2017 until March 2020. This time interval can be divided in two periods: one that was used for parameterization (April 2017 until March 2019) and another (April 2019 and March 2020) that was used for testing the model.

Subsequently, models were compared and the selected model was the one that presented the smallest Mean Absolute Deviation. Once again, this forecast error measure was chosen taking into account the SAP method selection process.

4.2.1 Naïve Method

To evaluate the performance of the forecast results, they were compared to a Naïve method in which all forecasted values are set to be the values of the last observation. This method usually has a good performance when data follows a random walk.

$$Forecast\ value_t = Actual\ value_{t-1} \tag{4.1}$$

The MAD average that was obtained with the Naïve method is compared with the results obtained with the other 5 methods mentioned above. Results are presented in Chapter 5.

4.3 Replenishment Models

In this section, the developed simulator is presented. This simulator was built with the goal of replicating SAP inventory management behavior and to evaluate the performance of the implementation of different stock policies in the replenishment of the selected materials.

4.3.1 SAP MRP-VM model - Automatic reorder point MRP

The MRP-VM type is assigned to all materials and SAP automatically calculates reorder point (RP) and safety stock (SS). These formulas do not include lead time variability and, in some cases, can be considered limiting/too simplistic. Despite this, the fact that the system automatically updates the stock policy parameters can be a big advantage, since, by doing so, the need for human intervention is much smaller. This model is a Continuous Review model, meaning that the stock level is controlled in each moment.

The formula used by SAP to calculate the reorder point (RP) is the following:

$$RP = \mu_{LT} + SS \tag{4.2}$$

$$SS = Z \cdot 1.25 \cdot MAD \cdot \sqrt{W} \tag{4.3}$$

μ_{LT} – Expected demand during lead time

Z – Safety factor for the desired service level
W – Ratio lead time/forecast days
MAD – Mean absolute deviation of the forecast
LT – Lead time

It is important to mention that SAP uses the lead time that was defined in the material master which, in some cases, has not been updated since the moment of creation of the material. In order to use this model, the lead time has to be updated. The multiplication factor $1.25 \cdot MAD$ corresponds to an estimation of the standard deviation of the forecast error (Hill, 2012).

4.3.2 MRP VB with approximation of demand to a normal distribution

In this model, materials maintain their MRP VB type and the RP and the SS are recalculated considering lead time variability. In this case, it is necessary to define a parameters revision/update period, since these parameters are static in SAP. Equation 4.4 and 4.5 are the ones used to calculate the RP and SS (Jin, 2019). The VB MRP, as it was mentioned previously, follows a Continuous Review model.

$$RP = \mu_{LT} + SS \tag{4.4}$$

$$SS = Z \cdot \sqrt{LT \cdot \sigma_D^2 + \sigma_{LT}^2 \cdot \mu_D^2} \tag{4.5}$$

μ_{LT} - Expected demand during lead time
σ_{LT} - Lead time standard deviation
σ_D - Demand standard deviation
LT - Lead time
Z – Safety factor for the desired service level

4.3.3 Min/Max model

The Min/Max policy is simulated with this model. Whenever stock falls below the min stock level in the review moment, a new order will be placed to the supplier with a quantity that will allow to reach the maximum stock level.

This model was only tested for materials which the lot size could be possibly negotiated with the supplier. In the case of lubricants, since it is not possible to purchase a specific volume from the supplier (only fixed capacity containers can be usually purchased), this model was not applied. The formulas used in order to calculate reorder point and safety stock are described below according to Silver et al. (2009). This is the only Periodic Review model tested with the simulator.

$$\frac{\mu_X}{\mu_{LT}} = \mu_\tau + LT \tag{4.6}$$

$$\frac{\sigma_X}{\mu_{LT}} = \sqrt{[\mu_\tau + LT] \cdot CV^2 + \sigma_\tau^2} \tag{4.7}$$

$$\frac{s}{\mu_{LT}} = \frac{\mu_X}{\mu_{LT}} \cdot Z + \frac{\sigma_X}{\mu_{LT}} \tag{4.8}$$

$$\frac{S}{\mu_{LT}} = \frac{s}{\mu_{LT}} + n - \mu_\tau \tag{4.9}$$

X - Total demand

τ - Time interval between the moment stock falls below reorder point and the next review instant

μ_{LT} - Average demand during lead time

LT - Lead times (in terms of review periods)

s - Reorder point

S - Order-up-to-level

CV - Standard deviation divided by the mean of the demand

Z - Safety factor for the desired service level

n - Desired average time between consecutive replenishment

The formulas used to calculate μ_X and σ_τ^2 are presented in Appendix E.

4.3.4 MRP VB - approximation of demand to a Poisson distribution

Model 4 is similar to Model 2 except for the demand distribution is not approximated to a Normal distribution but to a Poisson distribution. In this case, the expected demand variability is equal to the squared root of the expected demand (see Equation 4.10). This policy is commonly used for slow moving goods (Jin, 2019) and this model is also a Continuous Review model.

$$\sigma_D = \sqrt{\mu_D} \tag{4.10}$$

4.3.5 Simulation Inputs, Assumptions and Functioning

The simulation inputs per material were: unit price, initial stock (end of March 2019), required service level (according to ABC-VED analysis), replenishment quantity (Fixed Lot Size), replenishment lead time (April 2017 – March 2019), variability of replenishment lead time (April 2017 – March 2019), demand forecast (April 2019 - March 2020), demand variability (April 2019 - March 2020), material reservations (April 2019 - March 2020).

Furthermore, three assumptions were made during the data preparation:

– the price used was the standard price defined in SAP, which means that price variations were not taken into consideration.

– transfers from plants and returns to the warehouse were not considered in the simulation, since the decision to make one of these movements depends on other factors such as the User Areas decisions to return or the planners' decision to transfer material from one warehouse to another depending on the actual stock level of a specific moment.

– regarding replenishment lead time, this was obtained by calculating the average difference in days between the date of creation of a purchasing order and the date of reception of the order in the general warehouse. Some purchasing orders were incorrect or incomplete, meaning that they only had one of the two previously mentioned dates. In those cases, the lead time defined by SAP was used and the lead time variability was equal to the variability of materials of the same group.

For each month, the simulation ran as illustrated in Figure 4.3 with the final monthly stock equal to that month initial stock, plus materials purchasing and minus material's consumption during that month, as can be observed in Figure 4.4. In this last figure, Si corresponds to the month initial stock and Sf corresponds to the month final stock. Figure 4.3 is adjusted to the functioning of a Continuous Review model. In the case of the studied model being a Periodic Review one, this diagram will present some differences: the stock policy parameters calculated in the first stage of the diagram are the reorder point (RP), the safety stock (SS) and the order-up-to level (S), the reception of the supplied material will correspond to the second stage of the diagram (and will happen at the beginning of each review period) and the order quantity will depend on the stock level at the review moment and on the order-up-to level (S).

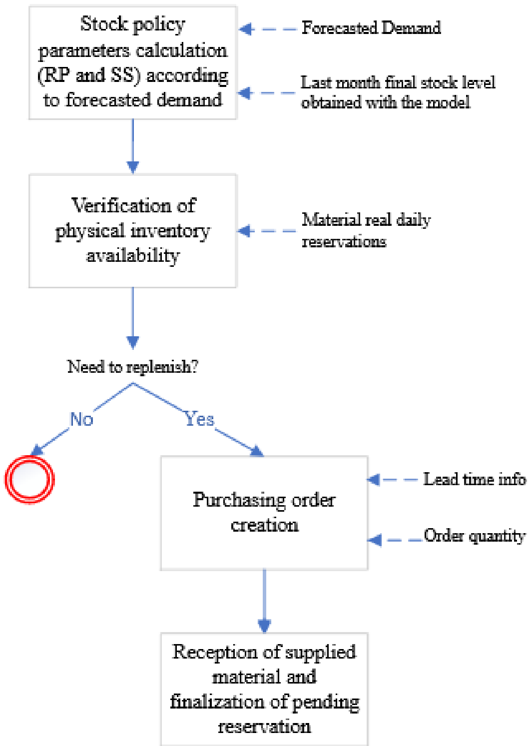

Figure 4.3: Diagram of the functioning of the simulator

In order to understand if the simulation is working as close to reality as possible, instead of simulating purchasing orders, the real orders to suppliers were initially used as inputs for the simulator. These real orders corresponded to purchase decisions that were not transferred between plants or subjected to other movements other than purchase from suppliers and consumption by User Areas. Figure 4.5 shows the comparison between the real turnover rate of these materials that was obtained with SAP and the one that was obtained with the simulator, which proves the suitability of the simulator to test alternative models.

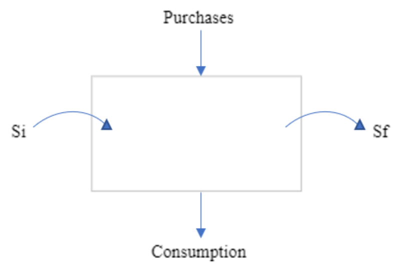

Figure 4.4: Movement of materials during the simulation

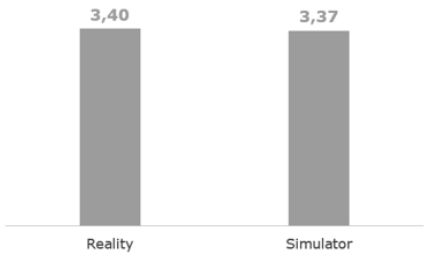

Figure 4.5: Turnover rate AS-IS vs Simulation

4.3.6 Key Performance Indicators

The KPIs used to measure the different simulated models were stock coverage, stockout rate and turnover rate. These KPIs were measured for each simulated month and they were also aggregated and measured for the whole simulated year.

4.3.6.1 Stock Coverage in days

The stock coverage in days provides an estimated stock holding duration and is calculated as the ratio of the average invested capital in stock and its annual consumption. This KPI can also be presented as a percentage of given time period if the ratio is multiplied by 100%.

$$Stock\ coverage\ (days) = \frac{Average\ Value\ of\ inventory\ on\ hand}{Annual\ consumption\ Value} \cdot 365 \tag{4.11}$$

4.3.6.2 Alpha Service Level

The Alpha service level is calculated as a rate of the number of satisfied reservations on time in relation to the number of the total number of reservations of warehouse materials made by the factory. This indicator can be estimated either in terms of financial value or quantity and it is an event-oriented measure.

$$Alpha\ Service\ Level\ (\%) = \frac{No.\ of\ reservations\ satisfied\ on\ time}{No.\ of\ reservations} \cdot 100 \tag{4.12}$$

4.3.6.3 Turnover rate

Turnover rate corresponds to the quotient between annual consumption and the average stock level in stock. The higher the turnover rate, the lower the warehousing expenses will be and the more efficient the warehouse management policy is.

$$Turnover\ rate = \frac{Annual\ consumption\ Value}{Average\ Value\ of\ inventory\ on\ hand} \tag{4.13}$$

Both stock coverage and turnover rate can be calculated based on economic value and volume. However, due to the fact that the warehouse stores materials with different measuring units (Kg, m, L, etc.), the calculation of these KPIs based on materials economic value was the selected option.

4.4 Obsolete materials identification

The identification of obsolete materials is key not only to free storage space that will be used for new materials required for factory operations, but also to post-pone the need to order these same materials for other plants, since these materials can be transferred from one plant to another.

Two ways of identifying potential obsolete materials were used: the first was by defining for each material group a time period of rotation in which a material is considered obsolete when its rotation is below the defined time period; and the second was done through the identification by workers of the materials that were no longer needed for the factory operations.

After the identification of obsolete materials and its approval by the plant's production chiefs, alternative plants where the references could be transferred to were pointed out. An EXCEL spreadsheet containing, for each material, each Iberian plant consumption in the last two years (from April 2019 to March 2020), last consumption date of those plants and current stock volume was made so as to serve as a guide. Finally, materials that could be transferred were pointed out to the "receiving" factories so that they could prepare them to be shipped whenever a new truck had free shipping space.

4.5 Warehouse consumption methodology

To facilitate the consumption of the warehouse materials, it was necessary to identify a SAP-compatible solution that allows the materials to be removed by scanning a bar code without the need of creating a prior reservation of the material. This solution had to be compatible with a smartphone or a tablet. Though it could also be compatible with a barcode scanner, it would represent a greater cost to the project, since the the plants do not have one of these gadgets available to be used in the general warehouse. In addition, since many of the warehouse materials are not identified with a barcode, the selection of a software that allows to create these codes was also critical so that the warehouse clerk could print them.

Chapter 5

Results

The results obtained with the development of this project are described in this chapter. For each problem stated, there will be quantitative and qualitative information following the methodology expressed in Chapter 4. The information presented in this section is complemented with the appendixes that are going to be mentioned throughout this chapter.

5.1 Digitalization of warehouse materials' issuing

A solution for this problem lies in identifying an alternative method for controlling the consumption of warehouse goods in a more efficient and effective way. One viable solution is the issuing of the warehouse goods through barcode scanning.

In order to issue the material, there must be a reading device, a barcode and a software present in the reading device that establishes the connection between SAP system and the material issuing.

For the reading device, the chosen gadget is a smartphone with a camera capable of reading the barcode. This device was chosen because it is easier to handle and more intuitive to use than a barcode scanner. Furthermore, this smartphone has to contain a software that is able to connect to the SAP system and make the direct material issuing. The application Movilizer for smartphone allows a factory operator that requires a material from the warehouse to issue it without no longer using a prior reservation of the material. The operator simply needs to go to the warehouse, collect the material, read the barcode of that material that is displayed in the storage box of the material and register in the smartphone screen the number of collected units and his/her cost center (the accounting unit that will incur the cost). Additionally, the software Movilizer allows to issue materials by registering the material's reference in the smartphone screen; consequently, the use of this software does not imply that all the materials have to be identified with their barcode, although having the barcode label makes the task of issuing materials easier and faster.

In short, with this solution, the warehouse clerk will not be responsible for issuing the materials in SAP, since the individual that collects these will issue them the moment they are collected. As a result, not only is it expected that the difference between the physical inventory level and the SAP inventory volume will be reduced but also the warehouse clerk will gain time to perform other activities that are of his responsibility. The inventory level error was not able to be calculated, since that would require the physical inventory counting of all warehouse goods.

In order to understand whether the application is of interest to BA, the number of hours that could be saved with the application needs to be multiplied by the warehouse worker's hourly wage and an estimate of the application's viability in economic terms has to be made. Since all the information regarding Movilizer utilization price was not obtained in time to be evaluated and inserted in this dissertation, the values will not be indicated and an economic analysis will have to be carried out by BA afterwards.

Moreover, issuing the materials with a barcode scanning application implies that these are identified with a barcode so that the person carrying the reading device is able to read the code. Some BA plants already have a portion of their materials identified with a barcode. For those materials that are not identified, the creation of a barcode using the material reference will be done through a free software called Apli (see Appendix D). This software allows to select a database facilitating the creation of multiple barcodes. This software is not connected to SAP, the creation of the barcodes will have to be done externally to the SAP system.

Figure 5.1 shows the new workflow for material consumption that will be obtained if BA decided to implement this software. Firstly, the factory will have a material need. Then, the User Area worker will check the material availability in SAP. If the material is available, the worker will go to the warehouse, he will scan the material barcode with the warehouse smartphone and he will enter his cost center and the quantity he is going to issue in the smartphone screen. However, if the material is not available in the warehouse, the worker will simply have to wait until the material is replenished.

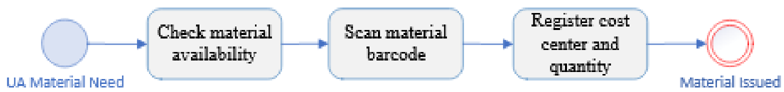

Figure 5.1: New Consumption Process

5.2 Obsolete materials' identification

In order to identify obsolete stock based on SAP material records, for Lubricants and Refractories, it was necessary to compare the time that the material is without movement with a predefined comparison period. For lubricants, that comparison period corresponded to 1 year whereas for refractories, the comparison period corresponded to 3 years. In total, 24 lubricants and 89 refractories were classified as obsoletes. Consumables and spare parts were not assigned a comparison period since these two material groups comprehend goods with variable product life cycle length.

In addition, obsoletes were also identified by factory workers in two moments: when the criticality analysis was made and when the warehouse clerk in Villafranca was asked to free space so that important materials could be stored. The criticality analysis allowed to identify materials that were no longer needed in Avintes due to the fact that one of BA ovens - AV5 - is going to be reconstructed in the near future and new spare parts and consumables will be needed. In total, 13 consumable materials and spare parts were identified during the criticality analysis. In Villafranca, a total of 564 material references were identified as obsolete references.

The number of materials' references that were classified as obsolete according to both methods can be viewed in Table 5.1.

Table 5.1: No. of obsolete and potential obsolete material references

	AV	MG	VN	VF	LE
RES	11	-	-	489	-
CONS	2	-	-	50	-
REFR	29	15	25	33	12
LUB	3	4	4	11	2

Figure 5.2 shows the obsolete materials piled up until a decision is made about their future. Table 5.2 has the number of material references and the number of units of these references that were transferred to other plants. Only Villafranca materials were transferred.

Figure 5.2: Obsolete material in Villafranca plant

Table 5.2: Material transfered from Villafranca plant

Receiving plant	No. of material references	Volume transfered (Units)
AV	7	49
VN	14	97
LE	3	29

The identification of alternative plants where these materials could be transferred to was based on the consumption of other plants in the previous year. In Appendix B, a sample of the EXCEL file that was developed identifying the different fields that were taken into account in this analysis is presented. Many of the materials were not transferred due to the fact that they are materials for equipment that is specific to the "supplying" plant.

5.3 Replenishment Models Results

Regarding the models tested in the simulator, scenarios were built in order to draw conclusions as to the model or models that best fit the warehouse materials. Additional information regarding these scenarios is presented in Appendix E.

5.3.1 Forecast Results

In this subsection, the forecast results that were used to define the replenishment models parameters are presented. For what concerns, the Naive methods, the mean of the absolute size of the error obtained with the more robust methods was smaller than the one obtained with the Naïve method. The average percentual difference of the MAD obtained with the Naïve methods and the MAD obtained with the more robust methods was of 31,0%. Table 5.3 summarizes this percentual difference for each one of the forecast methods. As it is possible to visualize, when the exponential smoothing method is selected, the percentual difference between the MAD obtained with the Naïve method and the exponential smoothing method is much lower than when the Naïve method results are compared to the other forecast methods.

Table 5.3: Percentual difference between Naïve method and robust methods

Forecast Method	Average % difference from Naive method
Exponential Smoothing	37,3%
Trigg & Leach	30,7%
Second Order Exponential Smoothing	16,6%
Linear Holt	24,1%
Holt Winters'	28,3%

In Figure 5.3, an example of the forecast of a consumable material demand can be visualized.

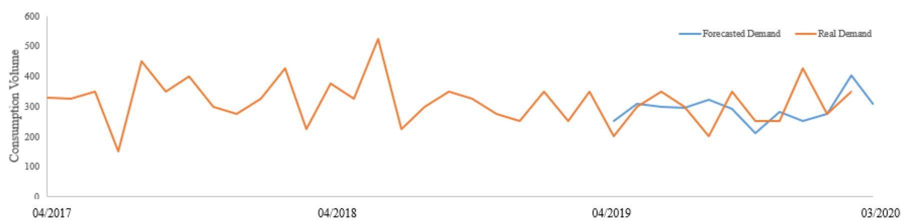

Figure 5.3: Demand Forecast of a Consumable

5.3.2 Scenarios Results

Firstly, the AS-IS KPIs were obtained. Turnover rate and coverage in days were extracted directly from SAP, whereas the service level, due to the absence of a SAP transaction that computes the warehouse stockouts, was calculated with the approximation of the number of stockouts to the number of times stock reached zero. Table 5.4 shows theses KPIs and Table 5.5 demonstrates the service level, the turnover rate and coverage in days by ABC-VED class. Lubricants are the materials that have the highest service level (96%). These materials and refractories are all critical for the factory functioning and, for that reason, have to be available all the time. However, refractories group have a very low service level (83%), since according to the ABC-VED matrix, these materials should have a service level equal to or higher then 93%. Spare parts are materials that have the smallest service level (70%) and consumables have a service level of 87%. This can be somehow worrying due to the fact that around only 70% of the times that a spare part reference is reserved it is available. The overall service level of the studied materials is 84,95% and the inventory is able to cover 98,3 days of materials' needs.

Table 5.4: AS-IS KPIs

Turnover Rate	Service Level	Coverage in days
3,71	84,95%	98,3

Table 5.5: AS-IS KPIs according to ABC-VED matrix classification

	Service Level			Turnover Rate			Coverage in days		
	A	B	C	A	B	C	A	B	C
V	85%	77%	77%	4,06	1,48	1,27	89,9	246,6	287,4
E	85%	83%	50%	6,60	1,17	2,45	55,3	312,0	149,0
D	86%	88%	87%	9,74	3,57	1,92	37,5	102,2	190,1

As was previously mentioned, different scenarios were built with the models that were presented in Chapter 4. These scenarios are described below. For all the scenarios, the parameters are updated at the beginning of each month.

The first scenario that was tested used the model that replicates SAP MRP VM behavior to calculate the reorder point and the safety stock and continuously monitors stock level. As far as the second scenario is concerned, the reorder point and the safety stock are calculated with Equations 4.4 and 4.5 and the stock level is reviewed continuously. This model would require that the MRP type of the materials be kept as VB, since the reorder point and the safety stock would be defined externally to SAP and introduced manually each month in the material master record. Moreover, a third scenario that uses the previous Continuous Review model and calculates the reorder point and the safety stock using the same equations was built in which the stock level is limited by a maximum stock calculated according to the Equation 5.1.

$$S_{max} = RP + Lot\ Size - (Min\ consumption \cdot Min\ lead\ time) \tag{5.1}$$

In Equation 5.1, the minimum consumption is the smallest consumed quantity in past consumptions and the minimum lead time is the shortest period of time that took for the supplier to deliver the ordered quantity in past deliveries.

The fourth scenario is very similar to the second one, although in this one, the refractories are not considered in the analysis.

In the fifth scenario, for slow movers (materials whose turnover rate is smaller than 2) the calculation of the reorder point and of the safety stock is done with the approximation of demand to a Poisson distribution. The reorder point and the safety stock of the materials that are considered fast movers are calculated following model 2 equations that approximate demand to a normal distribution. This model is still of Continuous Review and the MRP type used is still the VB.

In the sixth scenario, the Min/Max policy was implemented in spare parts, refractories and consumables whose CV was smaller than 0,5. This model was not tested in lubricants since they are bought in cans that have specific lot sizes. In this scenario, the desired number of periods between two consecutive replenishments (n) was considered to be 2 and afterwards 3. For the rest of the materials, the Continuous Review model used in scenario 2 was implemented.

After obtaining the results of the sixth scenario, a new scenario was built in which the Min/Max model with n equal to 2 was implemented only in a group of 51 consumables of low price (price smaller than 20€) and with CV smaller than 0,5. The rest of the materials maintained the VB MRP type and the model parameters were calculated based on the second model equations.

Finally, the two last scenarios were built combining the most positive aspects of the previously mentioned scenarios. For the first one of those two scenarios, the Min/Max model was implemented for the previously mentioned 51 consumables. Furthermore, for slow movers, the parameters were calculated with the approximation of demand to a Poisson distribution and their stock was continuously reviewed over time. For the rest of the materials, their stock was also continuously reviewed over time and these materials parameters were calculated with the second model equations. For the second scenario, the same methodology used in the previous scenario was adopted with the exception of the refractories that were not included in this scenario.

Table 5.6 summarizes the results obtained with the scenarios mentioned above.

Table 5.6: Results Summary

Scenario	Turnover rate	Service Level	Coverage
MRP VM	2,87	89,7%	127,2
MRP VB Normal Distribution	2,39	91,7%	152,7
MRP VB Normal Distribution with Smáx	2,54	90,6%	143,7
MRP VB Normal Distribution without REFR	3,06	91,5%	120,6
MRP VB Poisson Distribution	2,66	91,4%	137,4
Min/Max (n=2)	2,37	92,6%	153,8
Min/Max (n=3)	1,17	94,5%	311,7
Min/Max (n=2) for 51 CONS	2,36	92,6%	154,7
Min/Max, Poisson and Normal	2,64	92,0%	138,3
Min/Max, Poisson and Normal without REFR	3,49	92,2%	104,3

With the first scenario, the warehouse overall service level improved, reaching 89,7% of service level, and the turnover rate became smaller as expected (decreased from 3,71 to 2,87). Compared to BA AS-IS, this increase in service level and decrease in turnover rate make sense, due to the fact that in the AS-IS the reorder point was not updated with changes in the demand pattern over time and due to the fact that materials in the warehouse are usually not assigned a safety stock even though reorder points are set slightly above the expected demand during lead time to smooth demand variability. Lubricants service level was 96%, refractories service level was 95% consumables and spare parts service level reached 89%.

This model does not take into consideration lead time variability and demand variability is calculated as 1.25·MAD which can be a poor estimation of demand fluctuation. Despite this, this model corresponds to a practical solution since the reorder point and the safety stock are updated automatically at the beginning of each month, eliminating the need for someone to update the values. So, this is one factor that should be taken into consideration while deciding the best stock management policy. For obsolete materials that are one of the main focus of BA, this model will work as expected when the material stops being consumed, meaning that the reorder point and the safety stock in time will tend to zero. Table 5.7 shows the service level, the turnover rate and the coverage in days obtained for each ABC-VED matrix quadrant.

Table 5.7: First Scenario Results

	Service Level			Turnover Rate			Coverage in days		
	A	B	C	A	B	C	A	B	C
V	93%	85%	89%	3,01	1,08	1,21	121,3	338,0	301,7
E	89%	93%	75%	4,85	0,67	1,72	75,3	544,8	212,2
D	90%	91%	83%	7,62	3,50	1,99	47,9	104,3	183,4

As far as the second scenario is concerned, due to the fact that this model uses standard deviation of the forecast error and takes into consideration the lead time variability, as expected the inventory turnover decrease from 3,71 to 2,39. Speaking in terms of days in stock, the inventory volume with this model covers 54,4 additional days. Despite this, the service level reached 91,74%, improving spare parts service level in about 18 p.p., lubricants in 1 p.p., refractories in 14 p.p. and consumables in 4 p.p.. This scenario can be used as a basis of comparison for the rest of the scenarios since the goal is to regulate the service level and the turnover rate, allowing to obtain a good service level at the same time as reducing the cost of inventory.

With this last scenario and the ones that are going to be mentioned ahead, the stock parameters will have to be defined externally to SAP and have to be updated manually in the beginning of each month. So, a clear drawback of these models is the time that it will take for the person responsible for this task to update them.

As a way to understand the impact that the definition of a maximum stock level has in the second scenario, a third scenario was built in which the stock level is limited by a maximum stock. With this scenario, the service level decreased in more than 1 p.p. in comparison to model 2. On the other hand, the obtained turnover rate was of 2,54. A more significant decrease in inventory costs was observed in the Refractories and Consumables (12,5% and 9,0%). This scenario had a poor performance there was a big decrease in service level that implied a not so significant stock value decrease.

The reason for eliminating refractories in the fourth scenario is that refractories are materials that the User Areas are capable to predict their demand, meaning that, according to the plant maintenance schedule, the User Area responsible is able to give an estimation of how many materials it will need. Additionally, these materials have a big cost and a significant lead time variability. In order to compare this model to the second one, the KPI for the second model were recalculated without the refractories. The overall service level increased from 85,03% (service level AS-IS without refractories) to 91,47% and the days of inventory increased in 34,55 days. With this scenario, even though the service level decreased slightly compared to the second scenario, the number of days of inventory decreased in 19,87 days compared to the AS-IS scenario that the model is being compared to.

Moreover, with the fifth scenario, the turnover rate was of 2,66 and the service level of 91,37%. An increase of 39,11 days in inventory stock level was observed compared to the AS-IS model. Compared to the second scenario, this scenario has less 15,31 days of inventory, which can be seen as an improvement, even though the service level decreased in 0,38 p.p..

An additional sixth scenario was built in order to evaluate the Periodic Review model with order up to level. Since the equations that support this model make the approximation of the demand distribution to a normal distribution, for materials that have a high coefficient of variation, the Equation E.2 may produce an error, as the calculation inside the square root may generate a negative value. So, for materials whose coefficient of variation was superior to 0.5, the simulation model 2 was used. Since lubricants are materials which need to be bought in cans with a fixed lot size, the replenishment policy used for these materials was the one corresponding to model 2. The bigger the n, the smaller the turnover rate is. This is due to the fact that, by ordering for bigger periods of time, the average inventory level is expected to be greater than when ordering for the amount needed during lead time. An advantage that comes with this review policy, that is not so obvious when looking at these figures, is the reduction of ordering costs by concentrating the quantity ordered in one order instead of multiple ones. In addition, suppliers generally prefer larger and less frequent orders to smaller orders which are more frequently posted, since they have greater cost associated to packaging and other order related costs.

With this last scenario, when n equals to 2, it was observed that there was a material group which had a better performance in terms of service level when using the Periodic Review system instead of the Continuous one. This group is made up of the consumables materials that have a coefficient of variation smaller than 0.5 and that had a small price (smaller than 20€ per unit). For these materials, the Periodic Review has a good performance due to the fact that consumables are the group of materials with the smallest cost on average and the Min/Max model usually presents good results when applied to materials that have low costs. For these materials, an increase in service level was verified with a small decrease in turnover rate.

For this reason, a seventh scenario was constructed in which s Continuous Review model was applied to all materials except the group of consumables with coefficient of variation smaller than 0.5. For these 51 materials, the selected model was the periodic review with order up to level. For the selected consumables, the obtained service level was 2,71 p.p. greater when subjected to the periodic review compared to the Continuous Review and the coverage in days also increased in 1,9 day.

Finally, the last scenarios were simulated that combine Continuous Review with normal and Poisson distribution approximation for slow movers and periodic review for the 51 mentioned consumables. The first one considers refractories whereas the second one presented does not.

Looking at the first scenario and by comparing it to the AS-IS, the inventory level increased in 40,2 days. However, this increase in inventory costs was accompanied by an increase in overall service level (92,0%). Consumables service level increased in 3 p.p., lubricants in 3 p.p., refractories in 13 p.p. and spare parts in 23 p.p.. The use of the periodic review in the 51 materials allowed to increase the service level without implying a big increase in inventory costs, due to the fact that these materials were of low cost. Additionally, the Poisson distribution allowed a better fit of the stock level for materials that were slow movers without resulting in a significant loss of service level. With the normal distribution, these materials were being assign an excess inventory level that was reduced with the approximation of their demand to a Poisson distribution. Now, looking at the second scenario, the elimination of refractories allowed to increase the service level from 85,03% (AS-IS service level without refractories) to 92,16% and the coverage in days 18,29 days (from 86,05 to 104,34 days). With the last scenarios (the Min/Max, Poisson and Normal and the Min/Max, Poisson and Normal without REFR), the obtained service level, the turnover rate and the coverage in days are presented in Table 5.8 and 5.9.

Table 5.8: Final Scenario Results (with Refractories)

	Service Level			Turnover Rate			Coverage in days		
	A	B	C	A	B	C	A	B	C
V	97%	92%	90%	2,88	1,11	1,14	129,9	326,5	247,6
E	93%	91%	75%	4,76	0,75	1,74	76,7	486,7	209,8
D	93%	91%	83%	5,04	3,28	2,13	72,4	111,3	171,4

Table 5.9: Final Scenario Results (without Refractories)

	Service Level			Turnover Rate			Coverage in days		
	A	B	C	A	B	C	A	B	C
V	97%	94%	90%	3,24	1,41	1,19	112,7	258,9	306,7
E	93%	91%	75%	4,76	0,75	1,74	76,7	486,7	209,8
D	93%	91%	83%	5,04	3,28	2,13	72,4	111,3	171,4

It is important to mention that the obtained service level for class CE is much lower than the service level that was desired for this class. This class only contains four materials and these four materials were only consumed in eight different moments. Since there was a stockout in 2 moments, the service level immediately decreased for 75%. Drawing conclusions for this class can be somehow misleading.

One of the main reasons why the scenarios' results were not as disparate as expected is the fact that the lot sizes were fixed and, in some cases, they are not set as being the minimum quantity possible to order to the supplier.

Furthermore, since 135 of 465 materials were classified in the C and D classes and the desirable service level for this group of materials is 85%, it makes sense that the overall service level will be close to the 92%.

To conclude, the last scenarios were those that presented a more satisfactory service level/ turnover rate trade-off. This shows that having a replenishment policy adapted to the type of material allows to obtain inventory levels appropriate to the consumption behavior of the material. Nevertheless, this model has a disadvantage which is the need to update the reorder point and the security stock of all the materials studied every month. The exclusion of the materials in the final model allows for more satisfactory results since, as can be seen in Appendix E, inventory costs do not grow as abruptly. However, by not including these materials, it will be necessary for the User Areas to indicate when it is necessary to update the parameters for this type of materials. As it has been observed, the updating of the parameters is not something that recurs in the BA frequently, so the adoption or not of this last scenario will have to be well considered.

Using the new MRP type VM is also advantageous compared to BA AS-IS in the sense that it is not necessary to update the inventory parameters since SAP does this automatically. Although the service level is not as high as in the last scenario, using this MRP type will allow BA to offer a higher level of service to the plant than it does at present without the inventory costs increasing exponentially.

To conclude, BA decided to opt for the implementation of the new MRP VM for all tested materials. The practicability of the solution and the improvement in terms of service level ended up being the deciding factors for BA. In order to implement this replenishment policy, BA has to: update the lead time of all the materials master record and perform the VED analysis for the materials that were not studied due to the lack of information and, consequently, assign them a service level.

Chapter 6

Discussion

The project presented has as a line of work the identification of opportunities for improvement in the processes of the general warehouse of BA regarding the materials' replenishment, their consumption and the identification of obsolete references. The results of the project were positive and showed to bring added value to BA's operations, namely a more efficient warehouse materials' issuing, a reduction in the level of stock of materials without rotation at Villafranca plant and the presentation of procurement policies which are different from those currently used by BA and that can be advantageous for refractories, spare parts, consumables and lubricants references.

To start with, the need to understand which type of materials BA has in its warehouse was important in order to understand their behavior and how their shortage could affect the operations of the factory. Regarding the stock management policy, 465 material references of the lubricants, refractories, spare parts and consumables groups were assessed concerning the best policy use. With the construction of a simulator, BA had quantitative basis to support its decision making regarding the best inventory policy that fits its materials. The selection of the best inventory policy involved the identification and analysis of the different trade-off: service level, inventory costs and practicability of implementation. When it comes to inventory costs and practicability of implementation, the first model (VM MRP) is the model that makes the most sense to implement (with 89,7% service level) since the stock policy parameters are calculated automatically by SAP. However, if the service level is the most important factor in the model selection, then the final scenarios with 92,0% (with refractories) and 92,2% (without refractories) in service level will be the best solution, since they are customized models for the different types of materials that the warehouse stores. BA end up opting for the solution that was more practical which is the implementation of MRP VM for all studied materials.

Concerning the consumption of the warehouse materials, the research presented in this dissertation was important for BA in order for the company to have an idea of what the digitalization of the warehouse consumption represents in terms of savings and how this digitalization could be carried out. The implementation of this digital solution will represent savings of 0,15 FTEs on average for each plant. Nevertheless, the biggest benefit is related with the possibility of improving the inventory level accuracy, meaning that the difference between the physical stock and SAP stock will be reduced. This is possible since, with the digitalization of the materials' consumption, materials will be issued the moment they are collected from the warehouse and this action will be performed by the person that requested the material, so the warehouse clerk will not need to be present when it happens.

As far as obsolete materials are concerned, their identification and transfer for other plants will allow to postpone the purchase of new materials and also the freeing of space in the warehouse. For those materials that did not have an alternative use, their removal from the warehouse will be suggested. This is an ongoing process, since every year there are materials that become obsolete especially those that result from changes in technology that BA is constantly making.

Regarding future work related to this topic, some points can be explored, such as the incorporation of shortage cost according to material criticality in the simulation. This will allow decisions to be taken taking into account the economic impact of the shortage of material which, in turn, will give a more realistic perspective to the simulator. Furthermore, while in the topic of material criticality, the calculation of this feature of the material can incorporate other parameters such as the number of supplier and the lead time which, in turn, will upscale this classification. Another way to analyze the criticality of the material is to link it to the production process and measure the impact of its failure on sales volume. This will require linking the material to the BOM of a final product or to the equipment BOM that intervenes in the production process.

While in the topic of material classification, in order to have a more accurate attribution of the service level to the different ABC-VED matrix quadrants, a sensibility analysis could be performed in the future. This way, the selection of the service level for each one of these quadrants would be based on the inventory costs obtained with the simulator for the different safety factors.

In addition, the analysis of obsolete materials that are either consumables or spare parts is another subject that can be explored in future works. In this paper, these obsolete materials were not considered due to the fact that these groups are made up of very different materials and, for that reason, further individual material analysis is required.

Besides, in this paper, the selected forecast models were the ones that SAP uses for the forecast of future requirements. For future work other forecast methods could be studied, namely the Croston method which is commonly used in the forecast of intermittent materials needs, to assess the impact of using more accurate forecasting methods.

Additionally, different inventory management policies were simulated for Avintes plant warehouse. Since BA has another four plants in the Iberian Peninsula, the materials present in the warehouses of these plants could be the object of study of other dissertation/papers.

Finally, in this paper, the digitalization of the issuing of warehouse goods process is studied. The digitalization of the process of warehouse goods receipt was not analyzed although it may be the subject of study for other work. This last process has also improvement opportunities which may represent savings for BA in terms of time and hence money.

In conclusion, despite all the work that still needs to be performed and despite the difficulties encountered, I feel an enormous satisfaction in the work carried out and I am grateful for all the knowledge that this experience has given me.

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Appendix A

Plants Workflow

A.1 Avintes Warehouse Material Flow

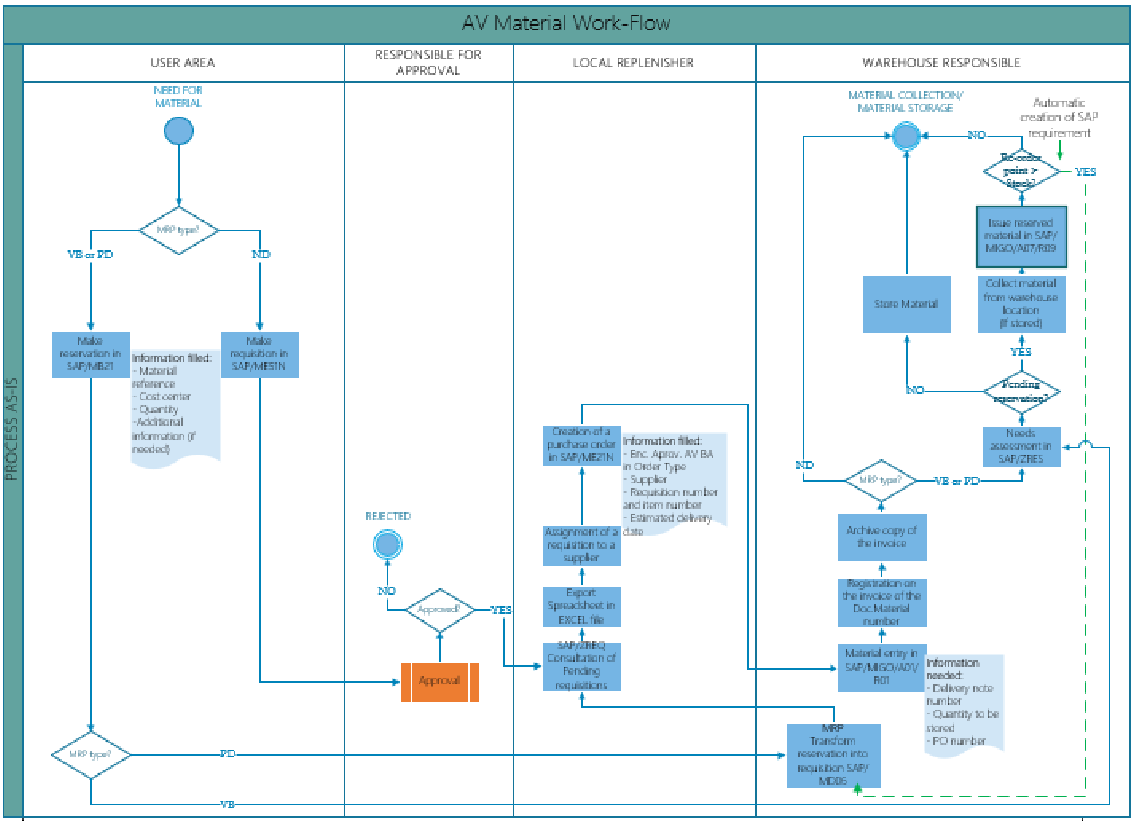

Figure A.1: Avintes Warehouse Material Flow

A.2 Marinha Grande Warehouse Material Flow

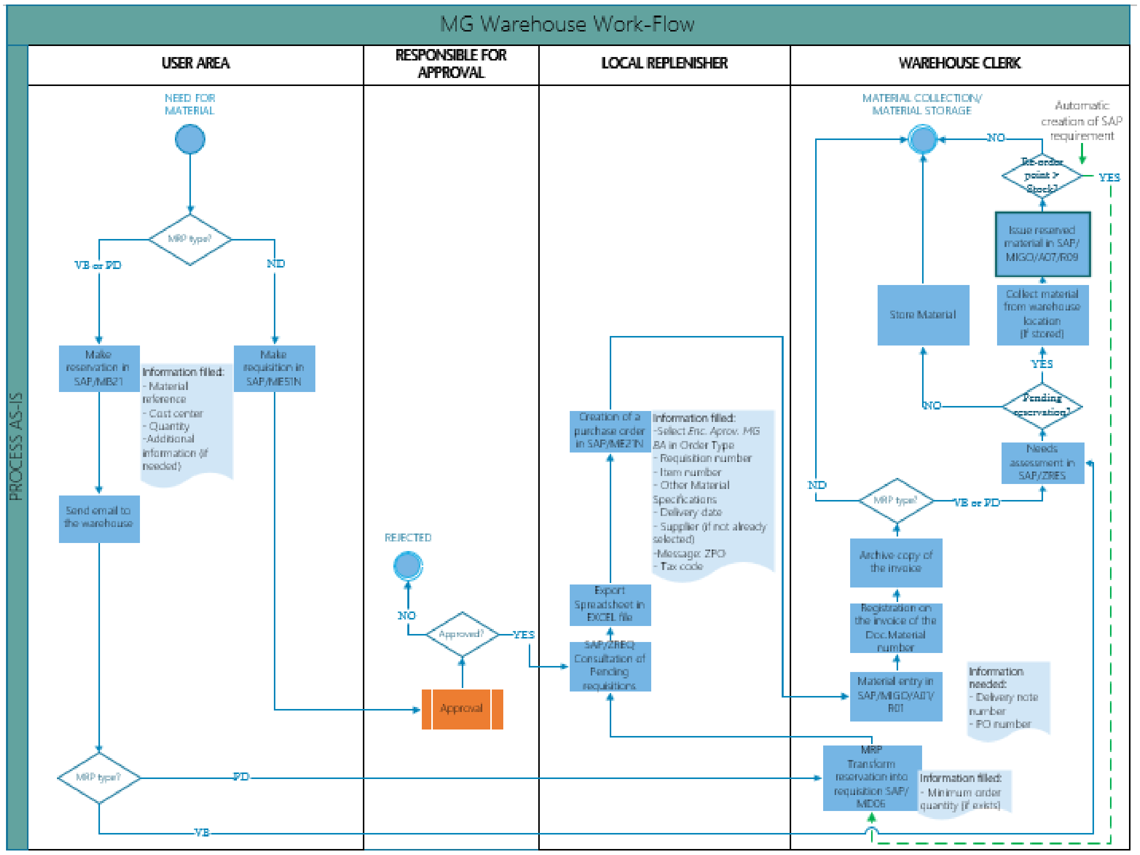

Figure A.2: Marinha Grande Warehouse Material Flow

A.3 Venda Nova Warehouse Material Flow

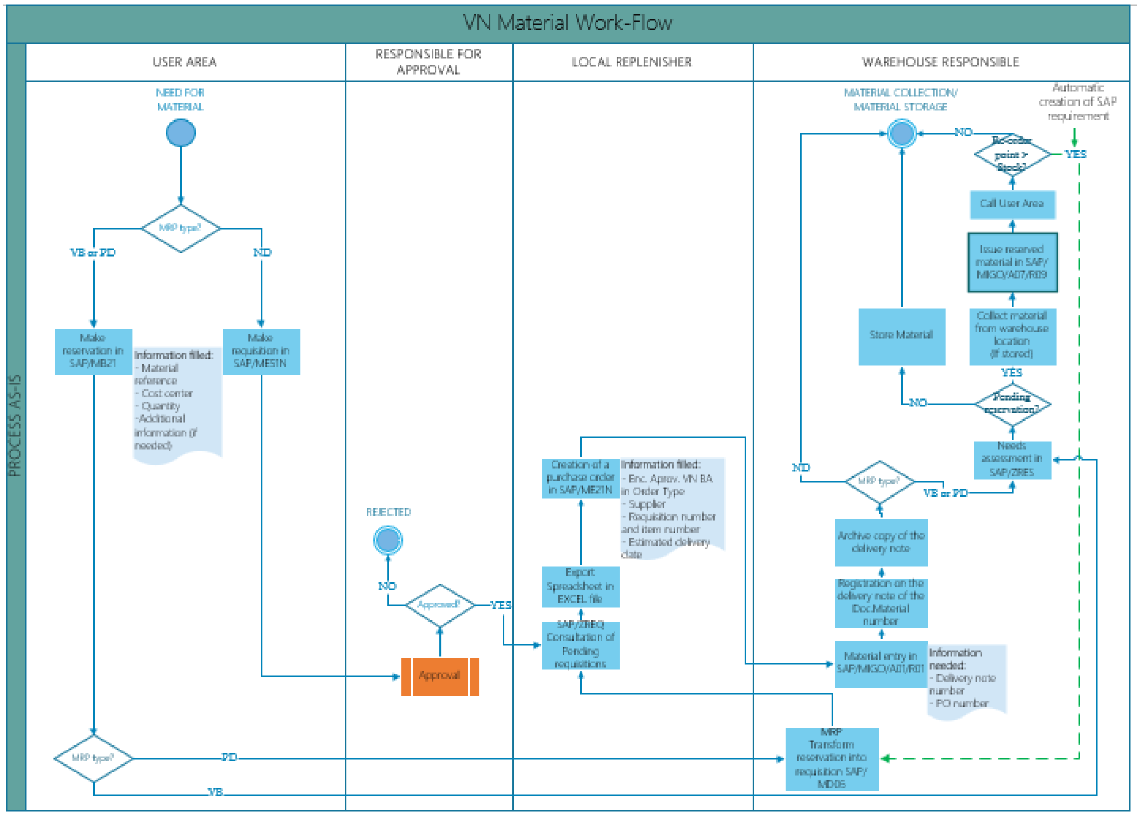

Figure A.3: Venda Nova Warehouse Material Flow

A.4 Leon Warehouse Material Flow

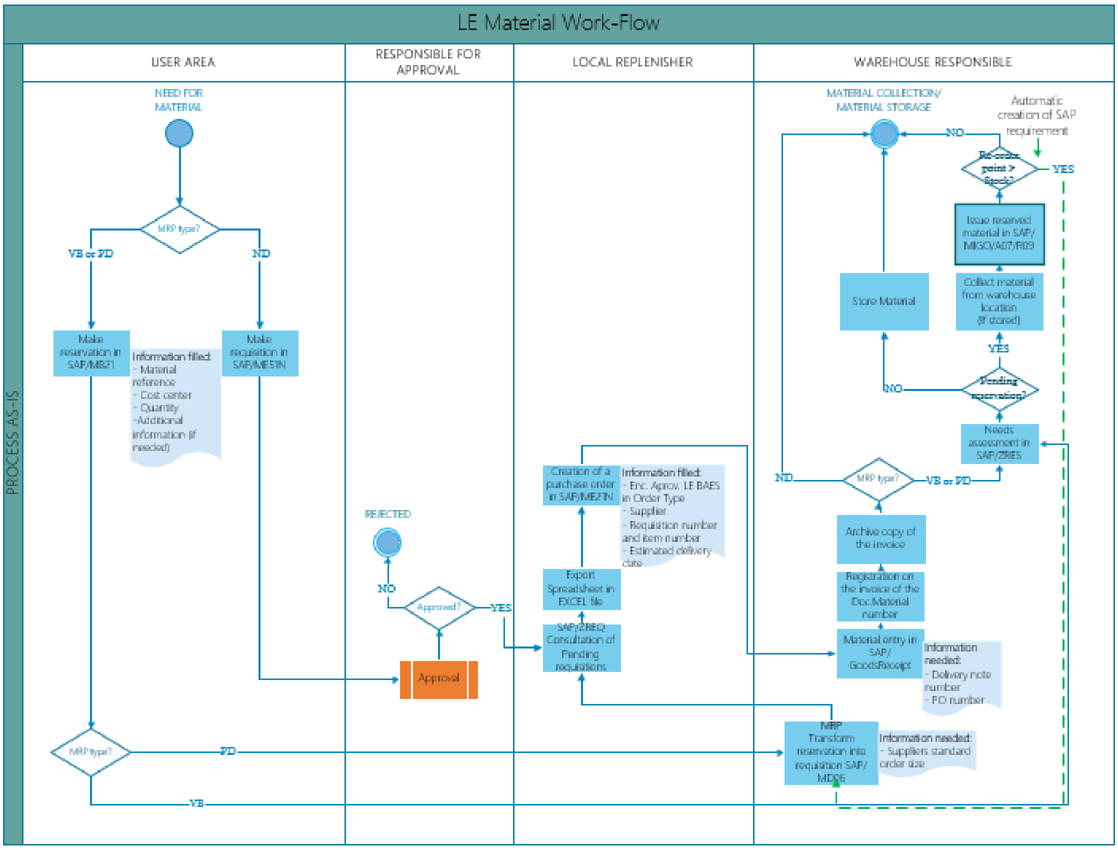

Figure A.4: Leon Warehouse Material Flow

A.5 Villafranca Warehouse Material Flow

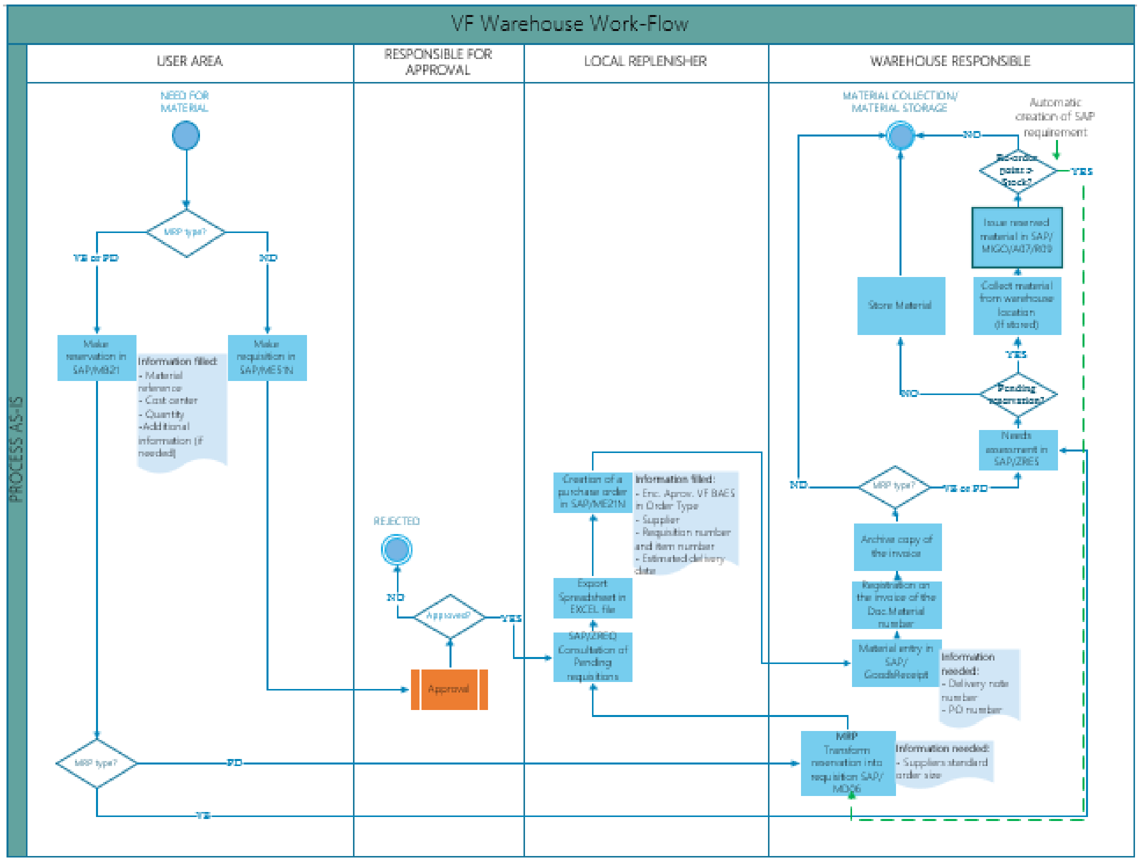

Figure A.5: Villafranca Warehouse Material Flow

Table A.1: Table with times of main activities of the work-flow

Plant	Material Entry	Material Issue	Run MRP	Order to Supplier
AV	1h	1,16h	0,08h	1h
MG	0,66h	1,10h	0,29h	1h
VN	1h	1,19h	0,25h	0,5h
LE	1,5h	1,44h	0,25h	-
VF	1,5h	0,92h	0,25h	-

Table A.1 shows the timings of the main activities related to the warehouse material workflow. Some of the obtained values are approximation, since timing them was not an option.

Appendix B

Obsolete Materials spread sheet

	Fábricas que consumiram no último ano											
	AV			MG			VN			LE		
Material	Data último consumo	Volume Anual Consumido	Stock Atual	Data último consumo	Volume Anual Consumido	Stock Atual	Data último consumo	Volume Anual Consumido	Stock Atual	Data último consumo	Volume Anual Consumido	Stock Atual
4440799							07.04.2020	12	3			
4456762	20.03.2020	19	0	27.03.2020	14	6						
4459621	03.10.2019	2	3				15.01.2019	5	3			
4459625							18.07.2019	3	5			
4459626							28.01.2019	2	3			
4402136	02.09.2019	5	0				03.09.2019	1	5			
4402137												
4416195							12.05.2020	12	0			
4416196							08.05.2020	13	2			
4416221							02.05.2019	5	5			
4440634							08.05.2020	21	15	24.12.2019	10	9
4440660												
4440737							23.07.2019	3	8			
4451636							23.10.2019	4	9			
4440635										24.12.2019	5	7
4440734							02.04.2020	10	0	29.11.2019	4	1
4470094							28.11.2019	14	5			
4420989	21.01.2020	12	4				01.07.2019	4	10			
4420995	27.12.2019	2	6							29.11.2019	4	3
4421037							13.11.2019	10	10	13.03.2020	4	4
4421551												
4440636							04.06.2019	3	7	21.05.2020	7	3
4448237												

Figure B.1: Obsolete Materials - Other Plants Consumption

Figure B.2: Villafranca obsoletes ready to be shipped to other plants

Appendix C

Forecast Methods

C.1 Exponential Smoothing

$$\hat{Z}_t = \alpha \cdot Z_t + (1-\alpha) \cdot \hat{Z}_{t-1} \tag{C.1}$$

α - smoothing factor
$\hat{Z}_t$ - forecasted value
Z_t - historical value
$\hat{Z}_{t-1}$ - previous period forecast

Source: Makridakis et al. (2008).

C.2 Trigg and Leach

$$\hat{Z}_{t+1} = \alpha_t \cdot Z_t + (1-\alpha_t) \cdot \hat{Z}_t \tag{C.2}$$

$$\alpha_{t+1} = |\frac{A_t}{M_t}| \tag{C.3}$$

$$A_t = \beta \cdot E_t + (1-\beta) \cdot A_{t-1} \tag{C.4}$$

$$M_t = \beta \cdot |E_t| + (1-\beta) \cdot M_{t-1} \tag{C.5}$$

$$E_t = Z_t - \hat{Z}_t \tag{C.6}$$

β - α smoothing parameter
A_t - smoothed estimate of forecast error
M_t - smoothed estimate of absolute forecast error
Z_t - historical value
E_t - forecast error
$\hat{Z}_{t+1}$ - forecast value

Source: Makridakis et al. (2008).

C.3 Second order exponential smoothing

$$\hat{Z}_t^{(1)} = \alpha \cdot Z_t + (1-\alpha) \cdot \hat{Z}_{t-1} \tag{C.7}$$

$$\hat{Z}_t^{(2)} = \alpha \cdot \hat{Z}_t^{(1)} + (1-\alpha) \cdot \hat{Z}_{t-1} \tag{C.8}$$

α - smoothing factor
$\hat{Z}_t^{(1)}$ - Simple smooth forecasted value
$\hat{Z}_t^{(2)}$ - Double smooth forecasted value
Z_t - historical value

Source: SAP (2016).

C.4 Holt's linear Method

$$L_t = \alpha \cdot Z_t + (1-\alpha) \cdot (L_{t-1} + b_{t-1}) \tag{C.9}$$

$$b_t = \beta \cdot (L_t - L_{t-1}) + (1-\beta) \cdot b_{t-1} \tag{C.10}$$

$$\hat{Z}_{t+m} = L_t + b_t \cdot m \tag{C.11}$$

L_t - estimate of the level of the time series
b_t - estimate of the slope of the time series
Z_t - historical value
$\hat{Z}_{t+m}$ - forecast for m periods ahead

Source: Makridakis et al. (2008).

C.5 Holt-Winters' (Multiplicative Method)

$$L_t = \alpha \cdot \frac{Z_t}{S_{t-s}} + (1-\alpha) \cdot (L_{t-1} + b_{t-1}) \tag{C.12}$$

$$b_t = \beta \cdot (L_t - L_{t-1}) + (1-\beta) \cdot b_{t-1} \tag{C.13}$$

$$S_t = \gamma \cdot \frac{Z_t}{L_t} + (1-\gamma) \cdot S_{t-s} \tag{C.14}$$

$$\hat{Z}_{t+m} = (L_t + b_t \cdot m) \cdot S_{t-s+m} \tag{C.15}$$

L_t - represents the level of the series
b_t - denotes the trend
S_t - seasonal component
Z_t - historical value
$\hat{Z}_{t+m}$ - forecast for m periods ahead

Source: Makridakis et al. (2008).

Appendix D

Digitalization of warehouse consumption

The label template that is going to be used to create the materials tags so that the warehouse materials are properly identified can be observed in Figure D.1.

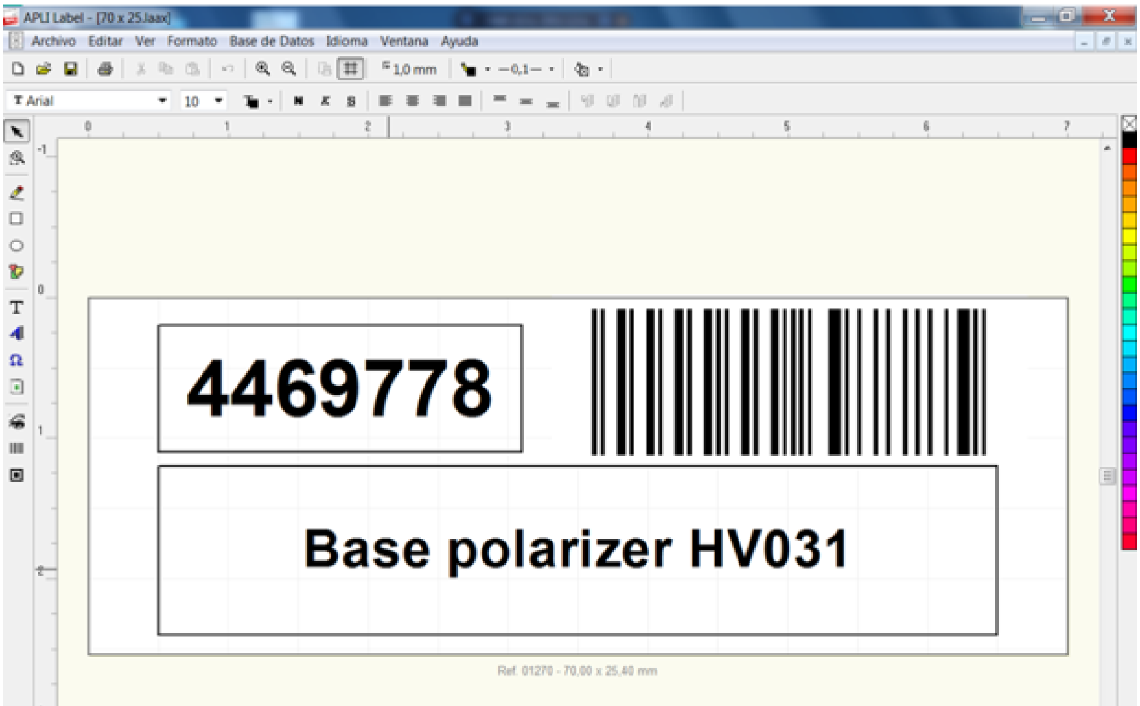

Figure D.1: Template in Label software to create material label

The barcode type that is being already used in some plants is the EAN-13. This type of barcode requires that references have 12 digits and BA warehouse references only have 7 digits. In order to complete the barcode, 5 zeros will need to be added to the beginning of the material reference.

Adding zeros to the warehouse reference will not be an issue when reading the barcode, since the mobile application used to read the code is capable of detecting the correct material reference by eliminating the initial zeros.

Appendix E

Replenishment models additional information

E.1 Periodic Review model (T,s,S) - Min/Max

$$\frac{\mu_X}{\mu_{LT}} = \mu_\tau + LT \tag{E.1}$$

$$\frac{\sigma_X}{\mu_{LT}} = \sqrt{[\mu_\tau + LT] \cdot CV^2 + \sigma_\tau^2} \tag{E.2}$$

$$\frac{s}{\mu_{LT}} = \frac{\mu_X}{\mu_{LT}} \cdot Z + \frac{\sigma_X}{\mu_{LT}} \tag{E.3}$$

$$\frac{S}{\mu_{LT}} = \frac{s}{\mu_{LT}} + n - \mu_\tau \tag{E.4}$$

X - Total demand

τ - Time interval between the moment stock falls below reorder point and the next review instant

μ_{LT} - Average demand during lead time

LT - Lead times (in terms of review periods)

s - Reorder point

S - Order-up-to-level

CV - Standard deviation divided by the mean of the demand

Z - Safety factor for the desired service level

n - Desired average time between consecutive replenishment

The formulas used to calculate μ_X and σ_τ^2 are presented in Appendix

Table E.1: Fractional polynomial approximations of μ_τ as a function of CV for selected values of n

n	Approximation (note C $\equiv$ CV)
2	$0.53608 + 0.44271 \cdot (C^{-1} - 3.333) + 1.7634 \cdot (C^{-1/2} - 1.826) + 1.0508 \cdot (C^{-1/2} \cdot ln(C) + 2.198)$
3	$0.51211 + 1.8652 \cdot (C - 0.3) - 1.1430 \cdot (C^2 - 0.09) + 3.1367 \cdot (C^2 \cdot ln(C) + 0.1084)$

Table E.2: Fractional polynomial approximations of σ_{τ}^{2} as a function of CV for selected values of n

n	Approximation (note C ≡ CV)
2	$0.07401 + 0.53380 \cdot (C - 0.3) - 0.58217 \cdot (C^2 - 0.09)$
3	$0.08283 + 0.36794 \cdot (C^{1/2} - 0.5477) - 0.35809 \cdot (C^{1/2} \cdot ln(C) + 0.6594)$

E.2 Results

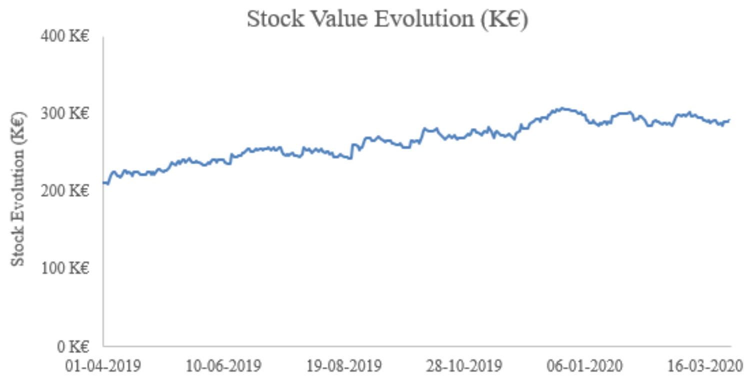

Figure E.1: Scenario 1 - Stock value evolution

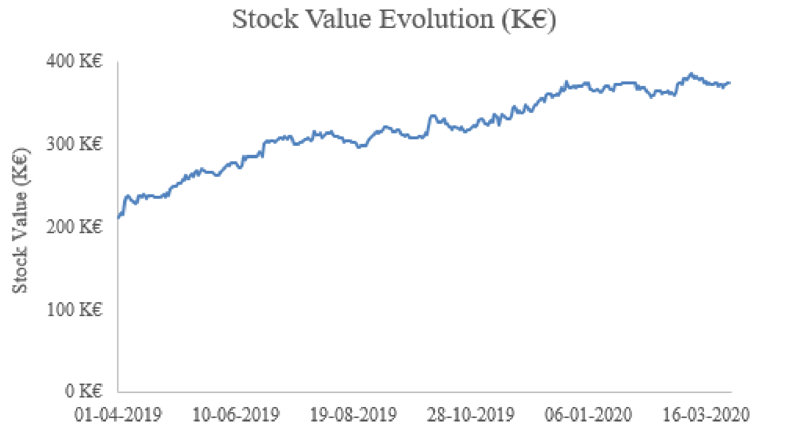

Figure E.2: Scenario 2 - Stock value evolution

Table E.3: Second Scenario KPIs

	Service Level			Turnover Rate			Coverage in days		
	A	B	C	A	B	C	A	B	C
V	97%	92%	89%	2,82	1,14	1,03	129,4	320,2	354,4
E	93%	90%	75%	4,79	0,76	1,74	76,5	480,3	209,8
D	93%	91%	82%	5,16	3,22	2,14	70,7	113,4	170,6

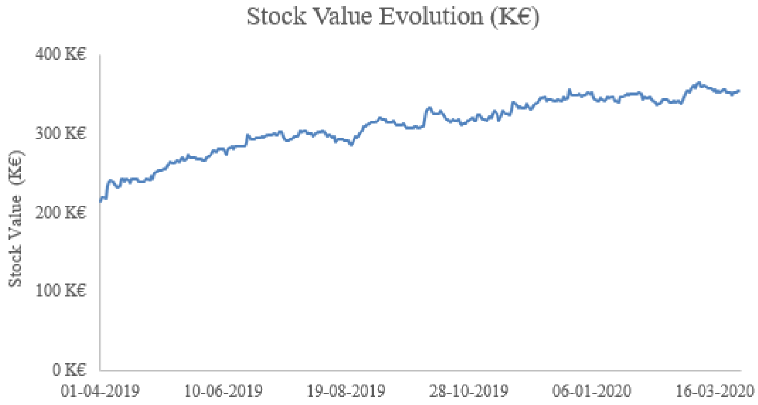

Figure E.3: Scenario 3 - Stock value evolution

Table E.4: Third Scenario KPIs

	Service Level			Turnover Rate			Coverage in days		
	A	B	C	A	B	C	A	B	C
V	96%	90%	87%	2,96	1,16	1,51	123,3	314,7	241,7
E	91%	88%	75%	5,02	0,80	1,75	72,8	456,3	209,1
D	93%	91%	82%	6,64	3,22	2,25	55,0	113,35	162,2

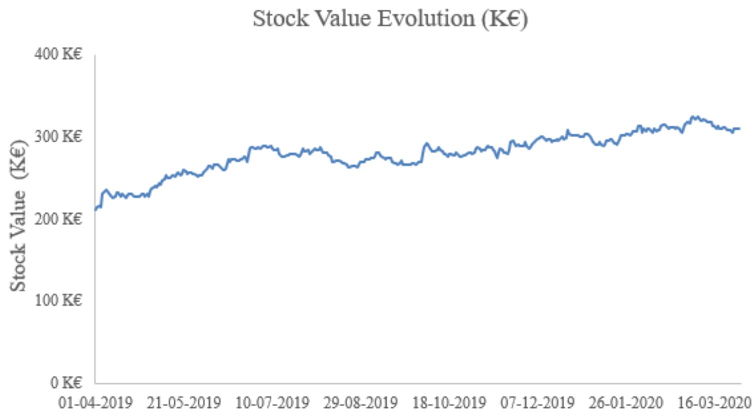

Figure E.4: Scenario 4 - Stock value evolution

Table E.5: Fourth Scenario KPIs

	Service Level			Turnover Rate			Coverage in days		
	A	B	C	A	B	C	A	B	C
V	97%	93%	90%	3,15	1,36	1,82	115,9	268,4	200,5
E	93%	90%	75%	4,79	0,76	1,74	76,2	480,3	209,8
D	93%	91%	82%	5,16	3,22	2,14	70,7	113,4	170,6

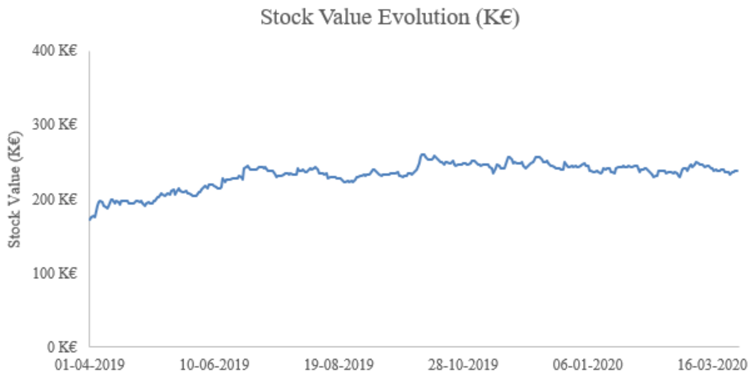

Figure E.5: Scenario 5 - Stock value evolution

Table E.6: Fifth Scenario KPIs

	Service Level			Turnover Rate			Coverage in days		
	A	B	C	A	B	C	A	B	C
V	97%	91%	88%	2,88	1,22	1,63	127,7	299,2	223,9
E	93%	90%	75%	4,79	0,76	1,75	76,2	480,3	208,6
D	93%	91%	82%	5,16	3,35	2,25	70,7	109,0	162,2

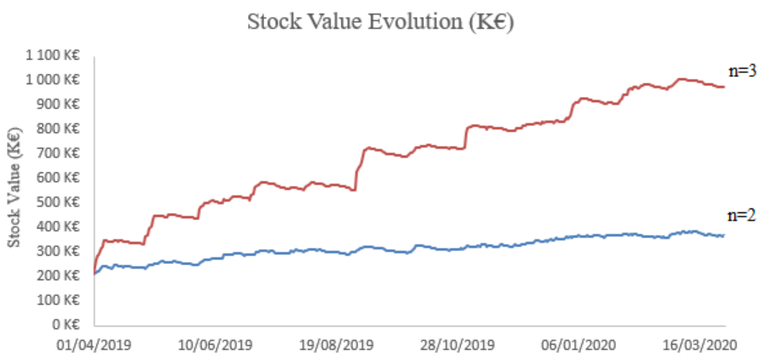

Figure E.6: Scenario 6 - Stock value evolution

Table E.7: Sixth Scenario KPIs (n=2)

	Service Level			Turnover Rate			Coverage in days		
	A	B	C	A	B	C	A	B	C
V	97%	93%	93%	2,82	0,97	1,38	129,4	376,3	264,5
E	93%	92%	75%	4,62	0,73	1,32	79,0	500,0	276,5
D	93%	91%	85%	5,16	3,40	2,02	70,7	107,4	180,7

Table E.8: Sixth Scenario KPIs (n=3)

	Service Level			Turnover Rate			Coverage in days		
	A	B	C	A	B	C	A	B	C
V	97%	95%	94%	2,69	0,65	1,02	135,7	561,5	357,8
E	94%	95%	75%	2,87	0,41	1,03	127,2	890,2	354,4
D	94%	92%	87%	4,98	3,41	0,98	73,3	107,4	372,4

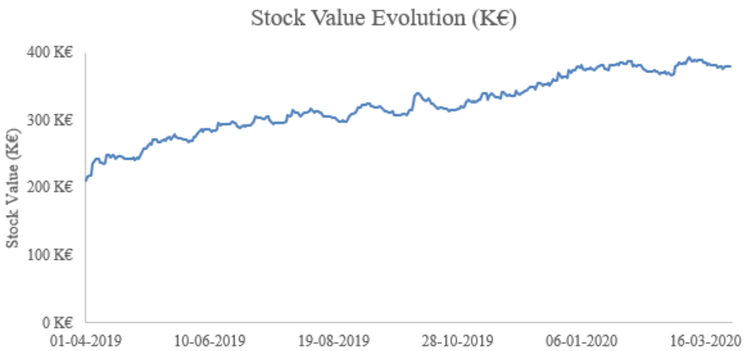

Figure E.7: Scenario 7 - Stock value evolution

Table E.9: Seventh Scenario KPIs

	Service Level			Turnover Rate			Coverage in days		
	A	B	C	A	B	C	A	B	C
V	97%	93%	93%	2,82	0,97	1,38	129,4	376,3	264,5
E	93%	92%	75%	4,62	0,73	1,74	79,0	500,0	209,8
D	93%	91%	86%	5,16	3,40	1,98	70,7	107,4	180,7

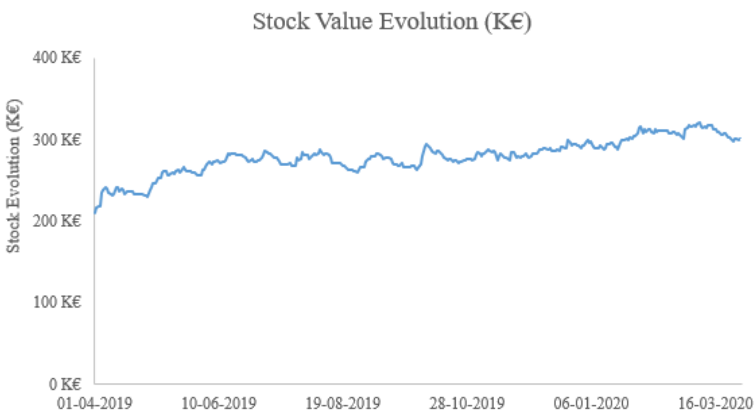

Figure E.8: Final scenario with Refractories - Stock value evolution

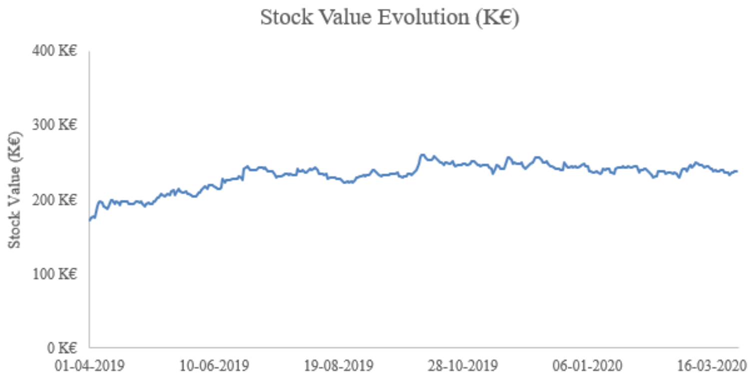

Figure E.9: Final scenario without Refractories - Stock value evolution

E.3 Material Information Input

	A	B	C	D	E	F	G	H	I	J
1	material_ref	unit_price	initial_stock	material_type	ABC	VED	fixed_lot_size	sap_leadtime	SAP_RP	RP_SS
2	4400360	2,78	20	RES	B	V	20	0	12	12
3	4400370	100	5	RES	A	V	5	0	5	5
4	4400406	41,66	5	RES	B	V	5	0	5	5
5	4400417	172,21	1	CONS	B	V	1	0	1	1
6	4400462	42,15	2	RES	A	V	2	0	2	2
7	4400511	51,93	21	RES	A	V	10	15	12	6
8	4400581	19,08	20	RES	B	V	20	30	15	10
9	4400585	4,584	6	RES	B	V	5	0	3	2
10	4400637	2,52	5	RES	C	V	5	0	5	5
11	4400640	22,64	10	RES	A	V	10	0	10	5

Figure E.10: Material information used as input for the simulator

Note that columns 8, 9 and 10 were not used in the scenarios presented in chapter 5.