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Push vs Pull Production Strategy: Case Study in the Coffee Production Industry

Matilde de Sousa Leitão Gomes Xavier

Master in Management

Supervisor:
PhD Sofia Kalakou, Assistant Professor,
Iscte Business School

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Department of Marketing, Operations and Management

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Resumo

Num ambiente de globalização e onde a incerteza está mais presente, torna-se necess adaptar as cadeias de abastecimento, de forma a permitir que as empresas consigam assegurar a sua vantagem competitiva.

Deste modo, a COMPANY X Portuguesa sente a necessidade de perceber quais as vantagens associadas a uma mudança na sua estratégia de produção.

Levantadas as estratégias lean que ajudam nesta adaptação e que podem ser aplicadas ao longo de toda a cadeia, o presente estudo foca-se especificamente na implementação de uma destas estratégias na área de produção.

De entre todos os negócios existentes na empresa, foi desafiado que esta análise incidisse no negócio de cafés, uma vez que é um negócio em crescimento.

Posto isto, este estudo foca-se na análise de uma possível implementação de uma estratégia pull de produção, de modo a avaliar se os impactos sobre os custos de produção e sobre custos de posse de stock são vantajosos face aos existentes na estratégia de produção atual - estratégia de produção push.

Ao mesmo tempo, pretende-se comparar os efeitos causados perante diversos cenários de variação da procura entre a estratégia de produção atual e a estratégia em análise.

Para analisar se existiriam vantagens na implementação de uma estratégia pull na área de produção, foi utilizada uma ferramenta de simulação – Anylogic. Nesta ferramenta foi realizado um modelo que diz respeito à produção e outro modelo que diz respeito ao processo de stocks.

Palavras-Chave: Cadeia de abastecimento, Estratégias Lean de Produção, Estratéga Push de Produção, Estratégia Pull de Produção, Custos de produção, Custos de posse de Stock.

Classificação JEL: L23; L66; M11; O21

Abstract

In a globalization environment and where uncertainty is more present, it is necessary to adapt supply chains, in order to allow companies to be able to ensure their competitive advantage.

In this way, Portuguese COMPANY X feels the need to understand the advantages associated with a change in its production strategy.

Considering the lean strategies that help in this adaptation and that can be applied throughout the supply chain, this study focuses specifically on the implementation of one of these strategies in the production area.

Among all the existing businesses in the company, it was challenged that this analysis should focus on the coffee business, since it is a growing business.

Therefore, this study focuses on the analysis of a possible implementation of a production pull strategy, in order to assess whether the impacts on production costs and on holding stock costs are advantageous compared to those existing in the current production strategy - push production strategy.

At the same time, it is intended to compare the effects caused by different demand variation scenarios between the current production strategy and the strategy under analysis.

To analyze if there would be advantages in implementing a pull strategy in the production area, a simulation tool was used - Anylogic. In this tool, was made a model which represent the production process and another one that represents the stock process.

Key Words: Supply chain, Lean Production Strategies, Push Production Strategy, Pull Production Strategy, Production costs, Holding Stock costs.

JEL Classification: L23; L66; M11; O21

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Glossary

KPI - Key Performance Indicators

SC – Supply Chain

SCM – Supply Chain Management

R&G – Roast and Ground Coffee

Chapter I - Introduction

1.1 Exposition of the Context

Over the past two decades, as global competition intensifies due to globalization theory and practice of supply chain management (SCM) have received considerable attention from companies. According to Lambert (1998), “supply chain management is the integration of key business processes from end-user through original suppliers that provides products, service, and information that add value for customers and other stakeholders.” In that way, the processes of producing and distributing products and services to customers are becoming the most effective and efficient way for businesses to stay successful (Agus & Hajinoor, 2012). For that reason, the need to find lean practices becomes crucial. Lean practices at SCM impact not only the organization’s overall performance but also its competitive advantage through cost reduction, quality, delivery reliability, increased operational performance, and better financial performance.

According to Agus and Hajinoor (2012), lean production becomes one of the principal lean practices and companies should opt for several lean production techniques such as: setup time reduction, continuous improvement programs (kaizen), pull production system, shorter lead time, and small lot sizes (Arnheiter & Maleyeff, 2005). Lean production focuses on continuously improving the processes, i.e., a philosophy of eliminating all non-value-adding activities and reducing waste within an organization (Alabama Technology Network, 1998; Inman, 1999; Davis and Heineke, 2005).

The supply chain which will be analyzed in this study operates in the food and beverage sector and has been on the international market for more than 150 years. The Portuguese COMPANY X has been challenged by increased competition and therefore been forced to revise its strategies and its performance indicators to remain competitive.

In this way, I was challenged, by Portuguese COMPANY X, to measure the impact of implementing a Lean Production practices in their SC. As it will be presented, there is a wide range of Lean Production practices, however, this study will focus only on the pull production system as was asked by Portuguese Company X. The relevance of the implementation of the pull production system will be a highlight to understand if there is an advantage when compared with the current strategy implemented. Pull production strategy is the Lean Production practice most used in response to the conventional strategy – push production strategy - the one used at the moment by Portuguese COMPANY X.

To reach the goal of this thesis, a simulation model was developed and used to analyze the current scenario of the supply chain under study and the proposed scenario, through *Anylogic* software. The conclusions of this project, supported by the results of two simulation models, focus on the study of the "trade-off" between the cost of production, and the cost of holding stock. The KPIs mentioned before derive from the utmost importance that they have in assessing an organization's performance and the influence they have in defining its position in the market when compared with their main competitor (Barbosa, Musetti, & Kurumoto, 2006) as it will be seen in the literature review.

Reduction in inventories implies a reduction in working capital (holding stock costs reduction). And, production efficiency is important because the more efficient a production line is, the lower the costs are but at the same time, it is important to have an agile production line. Thus, we are facing two trade-offs, as it will be explained by Gimenez and Ventura (2011) and McIntyre et al. (1998), that are considered important pillars in this area of management when organizations must decide which strategy should adopt. The authors also mentioned Service level as an important pillar once is directly reflected in the way organizations respond to the expectations of their consumers, which has a wider range of supply and has an impact also on penalty cost for failure to satisfy the customer's order. However, this performance indicator will no be analyzed on this project.

The strategies under study (push production strategy and pull production strategy) will allow analyzing the impact they have on these two performance levels and consequently compare the levels of each in the different strategies.

1.2 General Objective

As already explained, the purpose of this thesis is to examine if the company will gain advantages on its performance after implementing a pull production strategy instead of a push production strategy, considering the following “trade-offs”: production costs and holding stock costs. To reach this objective the following process will be followed:

- Collect current data of the company to use as inputs at the simulation model in order to evaluate the current scenario;
- Develop a production and a stock simulation model using the Anylogic software to evaluate the current scenario and the hypothetical scenario, where assumptions will be used in order to facilitate the calculation of the model;
- Compare the obtained results in order to assess which scenario brings the most benefits to Portuguese COMPANY X considering the different demand scenarios and the indicators mentioned above;

1.3 Specific Objective and Research Questions

In order to meet the objective mentioned above, it’s important to enhance the understanding of each production strategy performance and the impact of each one on the indicators, so the following questions will be addressed to guide the study:

Question 1: What are the production costs and holding stock costs in a push production strategy environment?

Specific Objective: To understand how Portuguese COMPANY X's current performance is, considering the previously mentioned indicators, through data extracted from SAP-ERP as well as through the simulation model.

Question 2: What are the production costs and holding stock costs in a pull production strategy environment?

Specific Objective: Simulate a hypothetical scenario for the Portuguese COMPANY X plant, in order to evaluate production and holding stock costs.

Question 3: Which strategy has a better impact on Portuguese COMPANY X business performance considering the different demand scenarios and above-mentioned costs?

Specific Objective: Compare the results of each strategy.

1.4 Methodology

This thesis gathers the characteristics of a Company Project since the challenges/ problems are real, and the proposed improvements can be implemented. The steps developed to carry out the investigation will be the following:

1. Step I – Contextualizing the company – Portuguese COMPANY X;
2. Step II – Explanation and characterization of the study focus;
3. Step III – Description of the actual scenario;
4. Step IV – Presentation the two micro-simulation models: coffee production model and coffee stock model;
5. Step V – Applying the two simulation models in the two different strategies: push and pull production strategies;
6. Step VI – Evaluating the strategies on the two models, considering the two KPI's under study;

In order to be possible to develop the steps presented below direct observation and data extract from the ERP-SAP will be used. At the same time, it will be used a simulation model where the data mentioned before will be applied as inputs of the simulation models.

1.5 Structure

In order to meet the objectives of the investigation and to respond to the research questions the study will have the following structure:

- **Chapter 1 – Introduction -** In this chapter, the project theme is framed as well as the motivation for its development. The research problem and the objectives (general and specific) will be also defined and finally, the structure of the project will be presented.

- **Chapter 2 – Literature review -** In this chapter, concepts will be reviewed in order to support the objectives defined and assist the development of the models. Concepts such as Supply Chain, Lean Production, Push Production Strategy, Pull Production Strategy, Key Performances Indicators, and Tools to study logistics strategies as Simulation will be presented.
- **Chapter 3 – Methodology -** In this chapter, it will be described the methods that were used to obtain the data needed to develop the project as well as how they were treated in order to reach the answer for the research problem and the objectives described above.
- **Chapter 4 – Case study application and results -** Firstly, in this part, a brief presentation of COMPANY X will be made. Secondly, it will be explained which the focus of this study will be. Then it will be describing the actual process of the Portuguese COMPANY X. After that, will be present and describe the two micro-simulation models: coffee production model and coffee stock model, where will be analyzed the impact of the two strategies on the two KPI's already mentioned. Finally, the results obtained previously in the analysis of the different scenarios will be analyzed in detail.
- **Chapter 5 – Conclusion -** In this chapter, the main conclusions will be presented. A comparison between the two production strategies in terms of total costs (production costs + holding stock costs) will be made. At the same time, it will be described the limitations found during the project, as well as possible recommendations for future research.

Chapter II - Literature Review

To support this study, key elements in supply chain management will be highlighted in this chapter, such as: “Supply Chain Management”, “Lean Production strategies”, “Factor which influences the decision for pull vs push production strategy”, “Key Performance Indicators”, and the advantages obtained in the use of “Simulation Software’s” in Supply chain Analysis.

2.1 Supply Chain Management

Supply Chain Management is an area that has gained a lot of research interest and has been defined in a different way by several authors (Bechtel & Jayaram, 1997). Supply chain management is the whole sequence of the main processes of a business from the main suppliers that supply the products or services to the final consumer. The author highlights the importance of integrating the information that is exchanged throughout the chain as these add value to end customers and interested parties. (Lambert, Stock, & Ellram, 1998). Some authors also defend that the needs of end customers are only met effectively and efficiently if this information is exchanged throughout the integral parts of the chain (Childerhouse & Towill, 2002).

Lu and Swaminathan (2015) go further and says the supply chain process in addition to integrating the parts mentioned above, includes the whole process up to the final customer consuming the product and discard it. Chandra and Grabis (2016) see the supply chain as a means to develop products through the integration of suppliers, producers, warehouses, distributors, and retailers. Cavinato (1991) looks at the supply chain as a more strategic form among the various parts of the chain, arguing that this strategic integration has quite positive impacts in general in the chain.

In general, SCM's main objective is designing, organizing, and executing activities (Vonderembse, Uppal, Huang, & Dismukes, 2006) that create value for companies, customers, and stakeholders (Kazemkhanlou & Ahadi, 2014).

2.1.1 The Importance of an Efficient Supply Chain Management

According to the definitions presented before, Supply chain structures should be as efficient as possible in order to achieve responsiveness and productivity (Frazzon et al., 2018). According to Olhanger (2002), competition in the future will not be between companies but between supply chains. For that reason, the way of managing the supply chain has changed over the years.

In the 1950s and 1960s, the most important was the mass production in order to minimize the cost per unit produced and the processes are not flexible. However, in the 1980s the way of management was forced to change due to increasing competition and companies start to be commitment to offering low cost, high quality, and reliable products with greater design flexibility which force companies to change drastically the way they manage the supply chain. In this way, nowadays a process that enables continuous improvement in the supply chain is crucial to achieve a competitive advantage and guarantee the sustainability of the business (Vonderembse et al., 2006). Thus, implementing lean practices is a good solution that enables supply chain structures to be more efficient and effective. This happens once they improve the ability to respond to demand fluctuations and reduce the costs of the chain as a whole, such as the operational and logistics costs. Lean practices impact not only the organization´s overall performance but also its competitive advantage through cost reduction, quality delivery, increased operational performance, and better financial performance (Li, Ragu-Nathan, Ragu-Nathan, & Subba Rao, 2006).

In conclusion, for the supply chain business, it is crucial to be more efficient with respect to cost, quality, delivery speed and reliability and flexibility, due to the increasing customer demand and the global competition (Sadraoui & Mchirgui, 2014).

2.2 Lean Production Strategies

The supply chain, as it was possible to understand earlier, consists of the integration of various activities, such as: distribution planning, demand forecasting, purchasing, requirement planning, production planning, warehousing, material handling, inventory, packaging, order processing, and transportation (Agus & Hajinoor, 2012) and the great objective is to reduce waste as much as possible in order to maintain a competitive advantage in the market. This waste reduction can be focused on any of the previous functions, however, according to Agus and Hajinoor (2012), the main focus of the supply chain is Lean Production processes.

Lean Production arises with the need to have a more flexible production and to reduce waste to the maximum, in this way nothing is produced until it is necessary (Davis and Heineke, 2005). The concept was originated by Frederik Taylor and was seen by many authors as an alternative to the traditional Fordism method (Krafcik, 1988; Womack & Jones, 2003). In the mid-1990s, lean production emerged as a dominant strategy for production processes (Karlsson & Hlström, 1996). Currently, this concept is dominated by a production philosophy developed by Japanese people at Toyota production systems, whose focus was "doing it right the first time", in order to reduce waste at maximum. Although this philosophy appeared in Japan, it is currently followed worldwide (Davis and Heineke, 2005).

According to Karlsson and Ahlstrom (1996), waste must be eliminated as it is something that customers are not able to pay for. Waste can be of various types: overproduction, motion, inventory, defects, waiting, transportation, extra processing, and underutilized people (2002). Thus, Arnheiter and Maleyef (2005) in the same line of thought say that all activities that do not add value to the process must be eliminated. Rizzardo and Brooks (2008) present the same definition but with the opposite thinking saying that lean production is to do only those activities that add value to the final customer. Lean production enables companies to identify waste more aggressively once the organization can adapt quickly to small variations in demand. This is also due to the greater and faster feedback directly to workers and supervisors that allows this rapid adaptation to variations (Forza, 1996). There are several lean production techniques, such as: setup time reduction, continuous improvement programs (kaizen), pull production system, shorter lead time, and small lot sizes (Arnheiter & Maleyeff, 2005).

In conclusion, Lean Production makes companies focus more on their performance and thus increase their productivity because they focus their responsibilities on the continuous improvement of these processes (Lee & Peccei, 2007). Lewis (2000) concludes by saying that productivity is improved through lean production, as it reduces waiting times. Lean production leads to greater process flexibility, which allows for quick changes in terms of products and volumes. Flexibility is seen as a very positive point in order to ensure that the production process takes place in a smoother way (Forza, 1996). In the same way, Aggarwal (1985) and Monden (1995), argue that flexibility allows solving problems in an easier way. In short, Lean production makes a company more proactive and more sensitive to the needs of the final consumer (Sohal & Egglestone, 1994).

Several authors have a positive opinion about the adoption of lean production, although slightly different. Womack and Jones (2003) argue that all companies that produce products should adopt lean production as it is the best way to do manufacturing. Hanson and Voss (1998) argue that lean production has an impact beyond production, saying it has a direct impact on the entire performance. Rizzardo and Brooks (2008) go further and argue that lean production originates the growth of the company due to the benefits it gains from reducing delivery times, increasing the quality of the products delivered, and increasing the response to the final consumer. Narasihan (2006) even says that production is lean if reduces unneeded operations, inefficient operations, or excessive buffering in operations. Alves (2012), defends that lean production gives the companies the agility needed to face the market demand and environmental change.

However, success stories and unsuccessful implementation of lean production were presented. Mekong Capital (2004) testifies that several companies that have implemented lean production have improved the waiting time for their services and products. Samson and Ramsay (1993) argue that the lean production strategies that were adopted were successful. However, according to Bhasin and Burcher (2006), only ten percent or less of the companies succeed when implementing lean production strategies.

2.2.1. Pull Production Strategy

As mentioned before, according to Arnheiter & Maleyeff (2005) pull production strategy is a lean production technique. The pull production system works in such a way that production orders are guided by the actual demand of the end consumer, where the objective is to meet its demand precisely and at the desired time (Zhou & Benton, 2007).

Thus, the sequence of processes and activities in the upstream part of the chain only starts to be processed after a consumer demand signal be triggered. Therefore, the information process starts from the downstream agent to the upstream supply chain agent, i.e in the opposite direction when compared with the traditional system (push production strategy), and in that way the material ordered, the replenishment and production are promoted taking into account the actual demand. Adopting this system along the supply chain has become crucial to improving inventory control, reducing overproduction, and thereby reducing the costs associated with this waste (Vlachos, 2015). This improvement has been possible since this system allows an organization to produce based on real consumption, with small batch sizes, and allows also to improve communication (Agus & Hajinoor, 2012).

2.2.2 Push Production Strategy

Pull production strategy appears as the opposite of push production strategy. Push production strategy according to Agus and Hajinnoor (2012) is the traditional production system where production is pushed from upstream to downstream by a production schedule.

In this strategy, the supply chain process starts at the upstream point of the chain and culminates in the downstream point of the chain, so the whole process is performed based on forecast sales. In this strategy, the production orders are triggered based on the forecast and at the end of the chain, the finished goods wait for customers' orders. Thus, is possible to conclude that the push operates in an uncertain environment in which customer demand is not yet known (Sarbjit, 2017).

John Maher and Rich Denison (2013) wrote a paper where exploring deeply the nature of pull production strategy and explain in detail what consists of the push production strategy. Accordingly to both authors, the big difference between the two strategies is in the form of planning. In the traditional push production strategy form, the plan is developed assuming that everything is constant over time. That is, sales forecast plans are made that are loaded into a system (ERP), and based on these forecasts and other factors such as unsatisfied sales, stock on hand, the master production schedule is developed, which in turn gives insight into the raw materials and packaging materials that will be accurate in the long run. Although it seems like a proactive system, the plan often becomes obsolete even before it is put into practice and is hardly changed according to the changes that have taken place in the market as it implies going back to the beginning of the process.

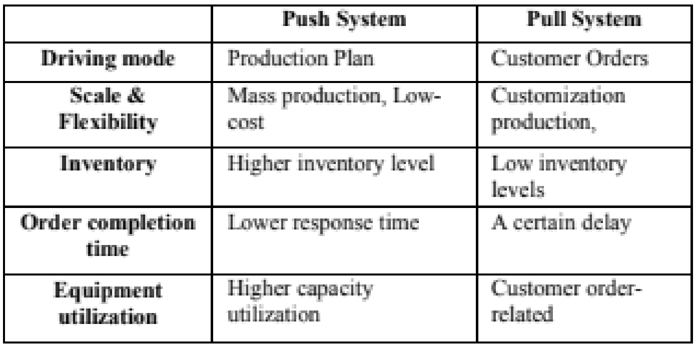
To conclude, this system often, instead of bringing flexibility, causes a negative spiral and overstocking, reducing capacity which leads to production clogging, i.e. leads to a loss of control. And today, organizations are looking for just the opposite.

2.2.3 Pull Production Strategy vs Push Production Strategy

According to Zheng and Lu (2009) push and pull production strategies are the two main production strategies. Both strategies have advantages and disadvantages and it’s crucial for an organization to opt for the right one.

Zheng and Lu (2009) describe in their article the main advantage and disadvantages of both strategies. Organizations that used push production strategy have higher occupancy costs of capital which allows to increase the effectiveness of production. However, this effectiveness is good to decrease the capital turnover but at the same time originate high levels of inventories. On the other hand, an enterprise that uses a pull production strategy could process resources efficiently and reduce cost because of its high flexibility and low inventory, but it’s impossible for the enterprise to develop economies of scale. As Zheng and Lu in 2009 said, “different enterprises should take an appropriate mode of production system according to its location in a supply chain and business goals”. They also do the association between strategy and organization located in the supply chain. They concluded the following: organizations at upstream of the supply chain should opt for a push production strategy once normally have more capacity and demand uncertainty is lower. For them reduce production costs is very important so economies of scale are indispensable. The two systems have different characteristics, and Ni Zheng and Lu

Xiaochun presented a table where is showed the main differences between the two systems:



	Push System	Pull System
Driving mode	Production Plan	Customer Orders
Scale & Flexibility	Mass production, Low-cost	Customization production,
Inventory	Higher inventory level	Low inventory levels
Order completion time	Lower response time	A certain delay
Equipment utilization	Higher capacity utilization	Customer order-related

Figure 1 - Push System vs Pull System according to Ni Zheng and Lu Xiachun

2.2.4. Factors which Influence the Decision for Pull Vs Push Production Strategy

According to Sarbjit (2017), there are some indicators that help to decide if an industry should opt for a push production strategy or for a pull production strategy. The author referred that these indicators are more appropriate for industry and services companies. Below are the factors that influenced better the decision:

- **Demand -** According to Harrison (2005), industries and services companies should opt for a push production strategy when companies have a low demand uncertainty once in that way companies will have a good indication about what to produce and what they should keep in inventory. He also adds, that in this case, companies can take advantage of economies of scale. On the other hand, he defends that when industry and services companies have a high demand uncertainty, they should opt for a pull production strategy and should manage the supply chain based on real demand to avoid producing more than needed.
- **Price of Goods -** According to Sarbjit (2017) companies should opt for a pull production strategy if the products are very costly.
- **Competition -** If the competition is intensive, the customers are not willing to wait for the product and will opt for a quicker response. So, when the competition is high, companies should opt for a push production strategy (Sarbjit, 2017).
- **Variety-** If a lot of variety is possible in the product, companies should opt for a pull production strategy (Sarbjit, 2017).

- **Perishable Products-** If the shelf-life of the products is slow, the companies should follow a pull production system, otherwise, if they can sell within the time, it would be a complete loss to the organization (Sarbjit, 2017).
- **New Product or Technology-** If it’s a new product, for example, products based on new technology, it is always advisable to have a pull production strategy. As the risk associated is high, once it is very difficult to predict the demand in advance (Sarbjit, 2017).

2.3 Key Performance Indicators

Beyond the understanding of which strategy fits better each organization, it is important to measure how the strategy impacts the performance of the company through the Key Performance indicators.

The relationship between performance indicators is essential for a structure of excellence in logistics and in today's competitive world, so it has become a focus for many organizations. Performance measures are important for improving supply chain efficiency. “Measuring SC performance can facilitate a greater understanding of the supply chain and improve its overall performance” (Charan, Shankar, & Baisya, 2008). Measurements have been used and are crucial to improving business performance (Taticchi, Tonelli, & Cagnazzo, 2010). A performance measure is defined as a metric used to quantify the efficiency and/or effectiveness of an action. ”The main goal of supply chain performance measurement models and frameworks is to support management by helping them to measure business performance, analyze and improve business operational efficiency through better decision-making processes”(Tangen, 2005). Thus, a supply chain measure is indispensable to decision-making in supply chain management, particularly in redesigning business goals and strategies, and re-engineering processes (Charan et al., 2008).

The concern about performance measurement increased about 20 years ago (Taticchi et al., 2010). Companies have understood that for competing in a continuously changing environment, it is necessary to monitor and understand firm performances.

According to Barbosa, Musetti, and Kurumoto (Barbosa, Musetti, & Kurumoto, 2006), consumers are increasingly demanding in terms, prices and services and it is in this last factor that logistics emerges as strategic value creation, improving delivery reliability, reducing lead times and maintaining low stock levels, increased production efficiency, among others. These values are perceived by customers as a result of the benefits they incorporate into the product and the value that the consumer acquires the product. Thus, optimization of the logistics function has been the focus of many organizations, and a crucial point of this optimization lies in the logistics performance measurement systems, or rather the definition of an organization's logistics performance indicators. According to Barbosa et al. (2006), as mentioned above, the main key performance indicators are stock, production efficiency, service level

2.3.1 Stock

The stock analysis, according to Jacobs and Chase (2013), is the definition of the exact moment when it must be replaced and what is the respective quantity. Dooley (2005) adds that effective stock management is directly related to cost reduction and, in turn, has a positive impact on the service level provided.

According to Muller (2003), all stored stock of raw materials, products under development, or even finished products, always have associated costs. Ballou (1993), states that all costs that are not being optimized in stock management are capital losses that could be being invested in other projects of the company. Muller (2003) ends by saying that it is therefore extremely relevant to have a rigorous analysis of the holding stock costs.

Holding Stock Costs

According to Carvalho et al (2012) the holding stock costs corresponds to costs directly related to storage, being defined by the cost of storage, the opportunity cost of capital, and the cost of obsolescence, these being represented by a rate. By multiplying this rate by the value of the stock and by the respective quantity stored, the holding stock costs are obtained.

- **Storage Cost -** Corresponds to the cost associated with salary charges, charges for physical facilities and equipment, their amortization, taxes, insurance, among others.
- **Capital opportunity cost -** Represents the cost of storing an amount in stock, instead of being invested in another application.
- **Obsolescence cost** – This corresponds to the cost that the company incurs when an item in stock becomes obsolete.

2.3.2 Production Efficiency

The increase in competitiveness has made companies increasingly concerned about producing quality products at a low level of cost (Womack, 1990). According to Pinto (2009), production costs are calculated by adding the fixed costs of production with the variable costs of production.

$$Production\ costs = Fixed\ costs + Variable\ costs \qquad (1)$$

The fixed costs are all the costs that do not change by the total quantity produced. These are the costs related to workers, the costs with machinery and facilities. On the other hand, variable costs are all costs that can change depending on the quantities produced, which can be associated with electricity, the cost of raw materials, the waste associated with each production process, among others. For Pinto (2009) waste is a variable cost that is very relevant to production costs. The author defines waste as all kinds of activities that consume time and resources and that later make the product more expensive, forcing the company to market it at an unfair price. For the author there are two types of waste:

- **Pure waste -** These are all operations that are not necessary for the activity of a company, and that must be eliminated.
- **Necessary waste -** These are activities that must exist, but that do not add value. Examples of these activities are machine changes and stops associated with cleaning them. Although, as already mentioned, these operations cannot be avoided, according to the author they must be reduced to the maximum in order to decrease the costs of the operations.

2.3.3 Service Level

The increase in competitiveness also causes companies to increasingly seek to differentiate the service offered. This makes Logistics play an important role in maintaining customers (Christohper, 1997).

For Bowersox and Closs (1996), time and place are essential factors in the impact of the service level. For the authors, the product has no value if it is not available to the customer at the desired time and place. For these two authors, customer service consists of three dimensions:

- **Availability -** refers to the ability to have stock when the product is desired by the customer. This capacity is measured by the level of stockout - a term used in logistics to designate a lack of stock. The stockout level is calculated by dividing the orders delivered completely by the total orders ordered;
- **Operational performance -** covers the idea of punctual delivery, that is, cycle time consistency, operational flexibility, and recovery from failures;
- **Reliability -** ability to meet the combined service level.

All three of these indicators are associated with disruption costs. These costs result when demand cannot be met due to the lack of stock. According to Reis (2010), rupture implies two types of costs:

- Loss of sale of the item (opportunity cost);
- Loss of company image, where the cost is impossible to determine.

By assessing the stockout rate present in the stocks, it is possible to determine whether the cost plus a safety stock for this stockout is less than the cost of stockout itself. Once again, this represents a trade-off that needs to be evaluated. In this way, the service level indicator is associated with the stockout rate. The higher the service level, the lower the stockout rate, and vice versa.

While it is important to achieve all these KPIs, it is important to note that the logistics system is composed of several trade-offs and to achieve some KPIs in the best way it is necessary to leave others lower. A typical example is, the more the company cuts transportation costs, the more storage costs will have, hence it is important to analyzing the integrated functions with others in order to avoid serious errors in the logistics structure (Giménez Thomsen & Ventura, 2011). From what was presented above, by the author Reis (2010) it was also possible to verify the existing trade-off between the stockout cost and the costs of having security stocks.

Mc Intyre et al. (1998), comment on the issue of trade-offs, stating that these make logistic measurement difficult, due to the impossibility of incorporating criteria such as robustness, compatibility, and integration into a metric.

It is possible to conclude that the performance indicators represent a means of verifying compliance with the objectives that were defined in the strategic planning, extremely relevant in today's dynamic and competitive environment. So, performance indicators are tools used in pursuit of high logistics performance. However, it is difficult to obtain them all at the same time because to acquire one is necessary to abdicate others.

2.4 Tools to Study Different Strategies in Logistic

Increasingly, the supply chain is a challenging area due to the complexity and uncertainty linked to this whole area. Therefore, it is necessary to use tools that help to make the right decisions (Liu, Liu, & Liu, 2013). However, these tools can only be used in very simple scenarios (Frazzon et al., 2018). With the development of theory and technology in logistics, an increase in unknown factors, diffuse factors and complex causal relationships emerged, which made it difficult to solve these problems through mathematics. Thus, computer simulation is now one of the most used practices in the study of these areas (Zheng & Lu, 2009). This tool allows for a more realistic study of the problem while at the same time assessing the consequences of different decisions (Pirard, Iassinovski, & Riane, 2011). According to Li (2015) and Selim (2017), simulation allowing to act in dynamic and complex environments.

2.4.1 Simulation

Simulation is used to optimize a process and allows to find the best solution among all possibilities. Simulation uses the minimum resources while analyzing the maximum information and, in that way, allows to find the near best solution. The system evaluates the data by running the simulation model for a specific period and presents the outputs (Hung & Liker 2007).

Logistics have been developed among over the years and because of that research and analysis have become more complex mainly because of the complex relationship between variables. Due to this complexity, it is difficult or impossible to analyze and solve these logistics problems by mathematics, that’s why simulation has become so popular in this area (Zheng & Lu, 2009). Yolanda and Anu (1997) also agree that simulation software is crucial nowadays due to the need to find the optimal and near-optimal solutions in minutes, instead of performing an exhaustive examination of relevant alternatives in days or months.

Many authors have used simulation as a tool for their research in Supply chain management: Kuo-Ting Hung and Jeffrey K.Liker (2007) applied simulation to study the batch size effect on production lead-time. E.jack Chen (2002) uses chemical manufacturing to determine the required capacity of logistics operation to allow continuous operation. Li Jia-bin (2006) used the software to improve the reliability of the inventory in a pull-type supply chain. Han (2004) analyses the order process of the Pull type system. Finally, Ni Zheng and LU Xiaochun (2009) also used simulation in their paper to analyze the principle of the two main modes of production system- “push” and “pull” system and compare the inventory levels of these two systems. It is possible to conclude based on the information above that the area of simulation optimization is growing and are very useful. Through that tool, it’s possible to analyze in a faster way what is the impact if companies change some constraints and variables in specific processes and analyze what will be the output in different scenarios. This method helps organizations to challenge the current scenarios and simulate new ones what is crucial to a continuous improvement environment which is so important nowadays when competition in this area is so intensive (Selim, 2017).

2.5 Conclusion

According to Bechtel and Jayaram (1997), Lambert, Stock, and Ellram (1998), Childerhouse and Towill (2002), Lu and Swaminathan (2015), Chandra and Grabis (2016), Cavinato (1991), Vonderembse, Uppal, Huang, and Dismukes (2006), Kazemkhanlou and Ahadi (2014), it is possible to realize that there are some definitions for the supply chain, however, all conclude that these are defined by a set of activities that create value for the final consumer.

According to Sadraoui & Mchirgui (2014), due to globalization, supply chains have become a concern for companies with the aim of becoming more competitive and more efficient in terms of costs. Vonderembse (2006) argues that between 1950 and 1960 the objective was mass production, but in 1980 that thought was forced to change due to the globalization mentioned above and the increase in competitiveness. Companies start to be commitment to offering low cost, high quality, and reliable products with greater design flexibility. Olhanger (2002) argues that competition in the future will not be between companies but between supply chains. For that reason, the way of managing the supply chain has changed over the years.
According to Agus and Hajinoor (2012) to waste reduction Lean strategies could be implemented in any part of the Supply Chain, however, for him, the main focus of the supply chain is Lean Production. Several authors have a good opinion about the adoption of lean production, although slightly different. Womack and Jones (2003), Voss (1998), Rizzardo and Brooks (2008), Mekong Capital (2004), Samson and Ramsay (1993) agree that Lean Production strategies have a good impact on companies, however, they defend that they have an impact on different aspects. On the other hand, Sohal (1993) presented evidence that the adoption of lean production strategies fails.

According to Arnheiter and Maleyeff (2005), there are several lean production techniques, such as: setup time reduction, continuous improvement programs (kaizen), pull production system, shorter lead time, and small lot sizes. However, they defend that the most used nowadays is the pull production system.

The pull production system appears as the opposite of the push production system. According to Sarbjit (2017), there are some indicators that help in deciding which strategy companies should adopt. Harrison (2005) defend that demand is the main factor that influences the decision and Sarbjit (2017) defends the Price of Goods, Competition, Variety, Perishable Products, New Products, or Technology are all factors that influence decision.

Beyond the importance of deciding which strategy companies should adopt companies should also measure the impact of those decisions on their KPI’s. Authors like Charan, Shankar, and Baisya (2008), Taticchi, Tonelli, and Cagnazzo (2010), Tangen (2005), (Barbosa, Musetti, and Kurumoto (2006), and McIntyr (1998) describe how important It is to define the key performance indicators, in order to meet the customer’s expectations. They defend that the most key performance indicator used by companies are: Stock, Service Level and Production Efficiency.

Liu (2013), Frazzon (2018), Zheng & Lu (2009), Pirard, Iassinovski and Riane (2011), Li (2015) and Selim (2017) argued that the supply chain is becoming a challenging area due to the complexity and uncertainty linked to this whole area. Therefore, it is necessary to use tools that help to make the right decisions, and linear programming, it is no longer considered a method that alone can solve these complex problems. So, computer simulation appears as a method to solve these complex problems in the supply chain management area.

Zheng and Xiaochun (2009), Berger et al. (2019), Frazzon and Danielli (2018), Tortella and Frazzon (2018) explained the advantages of using computer simulation to analyze these type of problems and gave examples that have been analyzed through this method. To better understand what the main scope of these studies and there conclusions were, the following summary was constructed:

Author: Zheng and Xiaochun (2009)

Study Scope: Established a model based on Anylogic to analyze both inventory levels and order completion time of both strategies (push production strategy and pull production strategy) under different production capacity and demand conditions.

Conclusion:

When production capacity is greater than customer demand:

- push-type production system shows high inventory volume and low-cost advantages because of mass production. Moreover, has less time to complete a customer order, with almost no delay.
- pull-type production system the company could maintain low levels of inventory and the time to complete could fluctuate depending upon the order quantity.

When production capacity and customer demand are basically balance:

- pull-type production: low inventory and fluctuant order completion time.
- push-type production: inventory level is low (slightly higher than the pull-type production) and order completion time is good (slightly less than the pull-type system).

When the production capacity is less than customer demand:

- The inventory levels and order completion time of both production systems are similar. Production capacity on both systems is unable to meet customer demand, so there is no more inventory to meet new customer orders and order completion time will increase.

Author: Berger et al. (2018)

Study Scope: This study reported a simulation-based optimization approach for the implementation of pull-production to practice in a lean supply chain to improve operational performance.

Conclusion:

For the current scenario, push-production, the author concluded that allows to achieve an efficiency of 0,046. The author concluded that the current strategy used in the supply chain under study does not generate a good performance for the system. This is justified by the fact that in this scenario the company produced a fixed monthly quantity, so this results in ruptures in the level of service to the customers.

For the proposed scenario, pull-production, allowed to achieve an efficiency of 0,107.

Author: Tortella and Frazzon (2018)

Study Scope: Analyze four different strategies of inventory management for finished goods in a supplier-customer relationship in a Lean supply chain management environment. The results were measured using the lead time and service level.

Conclusion:

After simulated the different inventory strategies, the author could conclude about what scenarios allows to achieve the best lead time and at the same time the best service level.

Chapter III - Methodology

This thesis gathers the characteristics of a Company Project since the challenges/problems are real, once it was proposed to analyze the impact in a real company and in a specific business if the current strategy was changed to a new one. The goal is to understand which strategy fits better the company. This developed work is also a descriptive and causal study. It is descriptive because it will describe all the processes related to the business under study and this will be possible due to the data that will be collected. It will use qualitative data obtained through direct observation of the processes and quantitative data which will be obtained through the ERP system. At the same time is a causal study once the main goal of the project is understanding the effect that the change of production strategy will have on the KPI's under study.

3.1 Case Study Steps

As mentioned earlier, the aim is to answer the three main questions already presented, always considering the production costs and holding stock costs as these are important factors to achieve a competitive advantage nowadays and to respond to market requirements, as it was possible to conclude in the literature review.
Here, it will be describing all the steps that will be done in order to achieve the answer to the three research questions.

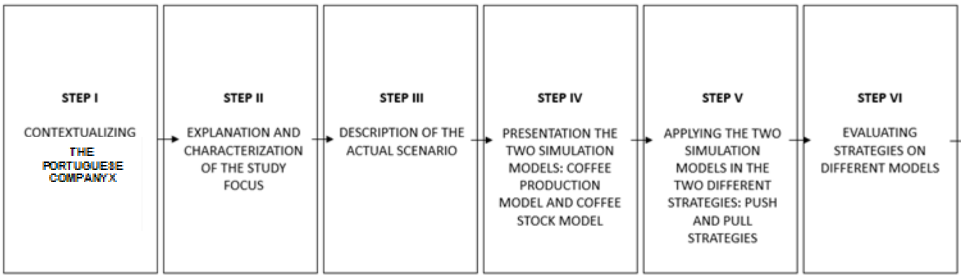


Figure 2 - Research Steps

3.1.1. Step I – Contextualizing the Portuguese COMPANY X

Initially, it will be presented an introduction of the Portuguese COMPANY X, with a description of all the businesses that exist in the company and understand the main processes. The main goal is to contextualize the problem that will be analyzed in this case study, that is, the study of the push production strategy and pull production strategy.

3.1.2. Step II – Explanation and Characterization of The Study Focus

After company contextualization, it is crucial to explain which business and processes of the company will be analyzed and why. Among all the existing businesses in Portuguese COMPANY X, previously presented, the theme of the proposed thesis focuses on the coffee business, since it is a business in considerable growth, and it is necessary to give more attention.

Once this is a very complex business and with a great diversity of products, there is a need to choose one of the sales channels of this business - Retail or Out of Home. For this choice, the objective is to extract data directly from the SAP-ERP software in relation to the sales forecasts made during the year 2019 in each of these two types of channels.

At the end of the analysis, the objective is to understand which of these two businesses has a less accurate demand forecast and focus only on that channel. Once according to what was presented in the literature review chapter, demand is one of the most important factors and could have more influence on the decision about what strategy companies should opt for. Thus, if that channel business has a less accurate demand it will be a good chance to evaluate if it will gain advantages if change the production strategy. Harrison (2005) defends, industries and services companies should opt for a push production strategy when companies have a low demand uncertainty and defends that when industry and services companies have a high demand uncertainty should opt for a pull production strategy.

3.1.3. Step III – Description of the Actual Scenario

Based on the business focus defined in the previous step it will be described how that business works nowadays in Portuguese COMPANY X – “as is” process in Coffee business. To obtain this information will be used direct observation and data extract from SAP- ERP.

The main objective of this step is to understand how Portuguese COMPANY X does its planning nowadays, in order to better understand what is the logic behind the model that will be simulated to represent the current scenario. At the same time, it is also important to understand how the planning of the companies changes when implemented a pull production strategy.

3.1.4. Step IV- Presentation the Two Simulation Models: Coffee Production Model and Coffee Stock Model

After clarifying the focus of the analysis and following the explanation of the "as is" process, the two simulation models that will be created to accomplish this study will be present. The first one represents the Coffee Production process and the second one represents the Coffee Stock process.

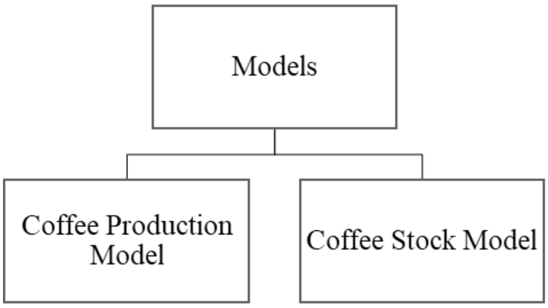


Figure 3 - Simulation Models

To help to develop these two models, direct observation will be used in order to understand better the coffee production and stock processes. At the same time, it will be used SAP-ERP to extract important data for the inputs of the models.

3.1.5 Step V – Applying the Two Simulation Models in the Two Different Strategies: Push and Pull Production Strategies

Finally, the two different strategies (push production strategy and pull production strategy) that are being studied will be analyzed through the two different models that will be created. The objective is to compare the models in each strategy taking into account the KPI's already mentioned in this document. In this part, some inputs will be changed according to the strategy that will be studied at that time, to reflect the differences of each strategy in the original model and thus give different outputs. At the same time, some premises will be taken into account in the study, in order to achieve the feasibility of the hypothetical scenario.

To improve the analysis of this study, different types of demand will be analyzed to understand also the impact that demand has on the choice of the production strategy measured by the KPIs in question. As was possible to conclude on one topic of the literature review, demand has a big impact on the decision of which strategy a company should use.

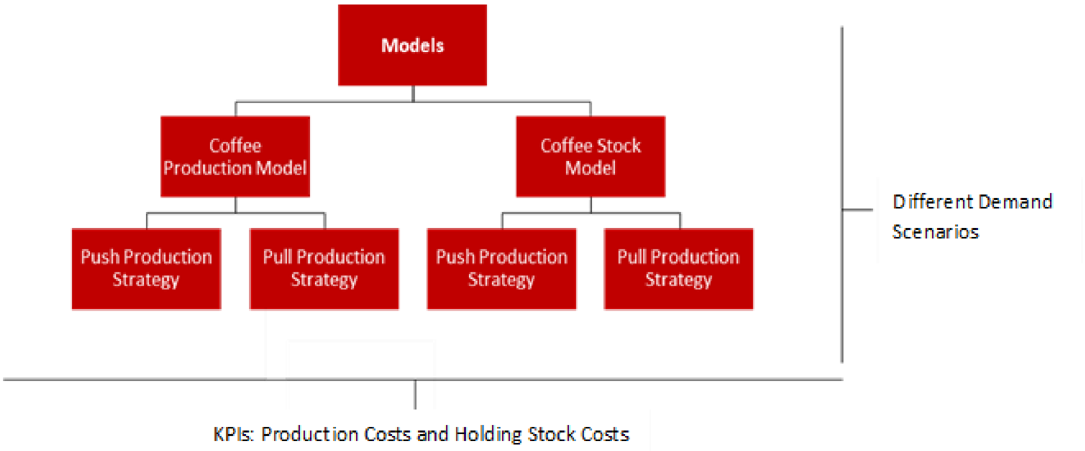


Figure 4 - Simulation Model Structure

On both models, different types of demand will be studied to understand the impact on the two different KPIs and then realize what is the most advantageous strategy, with everything else on the model remaining constant.

The reference point will be the current demand but then analyzes will be added until the demand decreases by half and until the demand increases by double compared to the current demand. The big objective as already mentioned is to understand the impact on the two different KPIs if the strategy used by Portuguese COMPANY X on production changed but at the same time to understand how the forecast change influence the choice of the strategy and understand if there is a point on forecast where it starts to be advantageous to use one strategy or another one.

3.1.6. Step VI – Evaluating the Strategies on the Two Models

After analyzing the outputs of each model, conclusions about the two models will be made in order to understand which strategy fits better in Portuguese COMPANY X at the moment. The conclusions will be made taking into account the current forecast but at the same on the scenarios where demand started to have big changes. The proposed scenarios, as already mentioned, will be evaluated based on two KPI’s, production cost and holding stock costs.

Chapter IV – Case Study Description

4.1. Step I – Contextualizing the Portuguese Company X

The Portuguese COMPANY X currently operates in several categories.The company headquarters are in Lisbon where 1.113 workers currently work. In addition to the headquarters, this company has two factories. One factory exclusively produces coffee and the other factory produces other type of products.

4.1.1.1. Coffee Business - Factory

Nowadays, Portuguese COMPANY X is increasingly focused on the Coffee Business, which is the main reason for the theme of this thesis to be developed within this business. At Portuguese COMPANY X there are two types of coffee - Roast & Ground Coffee (R&G) and capsules. In Portugal, only R&G coffees are produced and all the capsules formats are imported from other countries.

The Portuguese COMPANY X factory produces several different brands of coffee.The factory has eight production lines and each one is responsible to produce specific formats. The factory has also two Roasters which are the main bottlenecks of the factory at the moment, once they do not have enough capacity for the final volumes, so sometimes the lines have spare capacity but it’s not possible to produce more, once the Roaster has not capacity. The images below were provided by the Portuguese COMPANY X and give the possibility to demonstrate the eight production lines and the two Roasters, as well as their respective product portfolio.

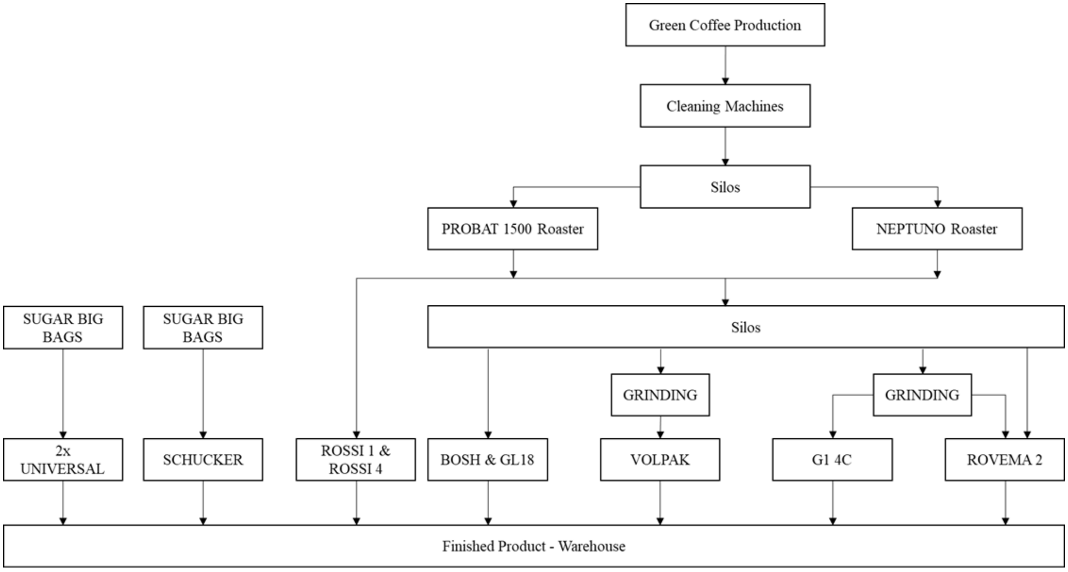


Figure 5 - Factory Resources

The coffee Business is divided into two channels: the retail channel as know as in-home coffee and the Professional channel as know as out-of- home coffee. Rovema 2, G14, Rossi lines produce the Retail formats, where Rossi produce Office Retail format. The other ones, Bosh, GL18, Volpack produce for Out ofHome channel. Based on the production volumes of 2019 about 70% of the volumes produced were for the Out-of-Home channel.

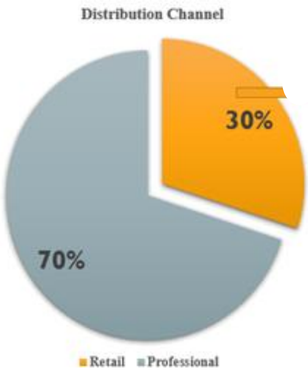


Figure 6- Distribution Channel: Retail vs Professional

The export volumes have been growing in the last few years since 2017, however National volumes still have a major impact on volumes produced which represent 64% of volumes produced in 2019, as shown in the chart below.

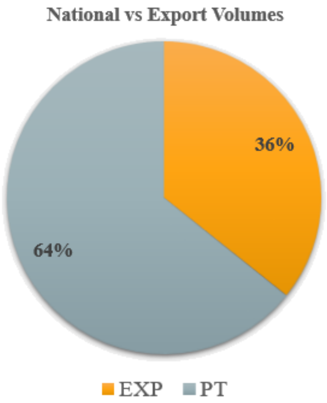


Figure 7 - National vs Export Production Volumes

Overall, the volumes produced in the Portuguese COMPANY X factory has been growing over the years as it is possible to see in the following graph:

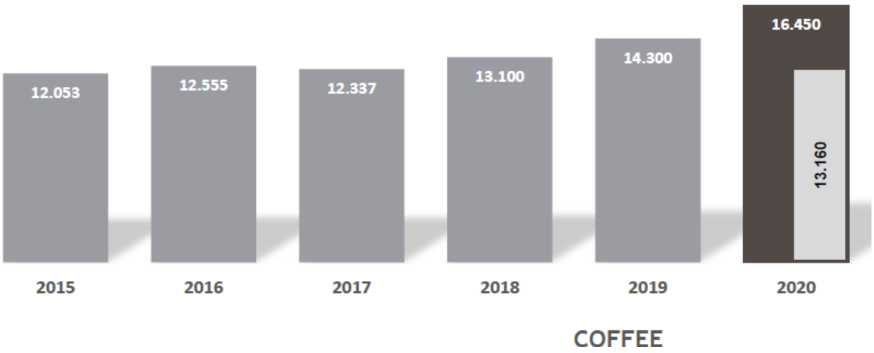


Figure 8 - Factory production volumes

The expectation is that it will continue to increase a year mainly due to a new brand growth forecast which is expected to grow by 3,5% a year, also due to the growing of the other products which is expected to grow 2,5% a year and finally due to the expectation of penetration of new products. With these volumes' growth forecasts, the plant may face major capacity constraints, mainly in the Roasting capacity.

4.2. Step II – Explanation and Characterization of the Study Focus

As previously presented, Portuguese COMPANY X has a wide range of businesses. However, the thesis topic that was proposed, focuses only on the coffee business. As it was also possible to understand, the coffee business is quite complex, since is composed by two different sales channels that work in a completely different way and, in addition, have a great diversity of products. Therefore, to facilitate this analysis, it was necessary to reduce the range of products to be analyzed. Thus, it was decided to focus the study on one of the sales channels. In order to make this decision, it was evaluated which would be the best channel to be analyzed – Retail channel or Out-of Home-channel.

As referred before according to Harrison (2005) demand is an important factor which helps to define which strategy fits better at the company. Therefore, an analysis was made based on the history of monthly forecasts during 2019 to understand which of the channels has a less accurate forecast. Through this analysis, it was possible to conclude that the

Out -of-Home channel had a demand accuracy of 93% during the year 2019 and the Retail channel presented a demand accuracy of 79% in 2019, as it is possible to observe in Appendix A. Thus, this case study will focus exclusively on the coffee portfolio of Portuguese COMPANY X that are sold exclusively in the retail channel, once the demand accuracy of this channel is less accurate than in Out-of-Home channel and then a pull production strategy may be more advantageous. Beyond this restriction, the case study will focus only on the national market. Considering this analysis restriction, only two of the eight machines existing in the factory will be analyzed (G14 machine and ROVEMA machine) and only one of the Roasters that exist in the factory as is possible to see in figure 6.

4.3 Step III – Description of the Actual Scenario at Portuguese COMPANY X

Portuguese COMPANY X works in a push production environment which is supported by SAP - ERP. All the process begins based on high-level strategic goals. The Business Plan establishes budgets and identifies resources required to execute the plan, then the plan is handed off to the Sales, and then Operations and Supply Chain teams (Demand and Supply Planning) validate the goals and determine how they will be met. All the process in this area works based on a weekly cycle which is all developed based on forecast considering historical data of previous years. Demand Planners are responsible to put demand on the products and in a specific plant that represents a specific country/area of COMPANY X.

On a weekly basis, the Forecast versus the Actuals sales of the last week should be revised. By reviewing the gaps, the demand planner decides if the future demand plan needs to be adjusted or not. Demand planners are also responsible to provide information about new or discontinued articles and main promotions. Overall, demand planners must ensure that all the information is passed in the most accurate way in order nothing fails in the future, this information is crucial for the entire plan to be done in the most correct way possible. Once the forecast plans are completed the data is loaded into the ERP system and a rough-cut capacity plan is created to verify if it will be possible to produce the desired results.

The production plan is developed based on the net requirements that were generated by a heuristic triggered by the SAP-ERP considering the forecasts that were loaded on the system by demand planners and are made for the next forty-eight weeks.

The main challenge on the production plan is to adjust the requirements according to the capacity available on the roaster and consecutively on the machines. When the production plan is completed, based on the demand that was loaded on the system, it runs again a heuristic in the ERP system, which is responsible to trigger the needs of the procurement team of raw materials and packaging materials that will be needed in the following weeks. Beyond this action, the supply planners assigned to this area of the business, with the support of the ERP-SAP, distribute the stock among all warehouses in order to meet customer service objectives and to ensure that optimal stock covers are maintained. Usually, the production plans are made according to the needs that are generated in the system according to the demand that was loaded in the system. However, the planning is always done so that there is production of the same type of product as long as possible, while respecting stock levels and capacity limitations and the product mix to be produced.

In short, all steps are done based on forecasts, and there may be two associated risks: not be able to sell all the products or do not have enough products to sell. Normally, Portuguese COMPANY X produces according to the needs, but one or two weeks in advance, in order to be able to respond at that time to the customers' orders. The main disadvantage of this scenario is that, if the requirements increase or decrease in the meanwhile, it is very difficult to react.

According to John Maher and Rich Denison (2013) the main problem of this push scenario is *"while seemingly proactive, the plan often becomes obsolete before it is executed as it cannot easily accommodate changes in market conditions or adjust to variations inherent in manufacturing environments".* It was precise because of these problems that Portuguese COMPANY X wanted to study the possibility of implementing a pull strategy, in order to understand its ability to react to changes in customer needs and, consequently, what are the impacts on production and maintaining stock levels.

4.4. Step IV – Presentation the Two Simulation Models: Coffee Production Model and Coffee Stock Model

To reach the goal of this project, two general scenarios of the supply chain under study were modeled: Coffee Production Model and Coffee Stock Model. For that, the models were implemented and simulated in *Anylogic* software in order to best reflect the reality. In *Anylogic*, there are two types of simulation models: dynamics models and discrete models. In the dynamics models the model status changes continuously with time, on the other hand in the discrete models the status only changes when an event occurs, for all other time periods, nothing changes in the system. Ihis project was develop a discrete event model (Grigoryev,2012).

The main objective is to study in each model the push production strategy and pull production strategy and evaluate the impact on the KPI’s under study but at the same time considering different demand scenarios. The reference point will be the current demand but then scenarios will be made until the demand decreases by half and until the demand increases by double compared to the current demand.

4.4.1 Coffee Production Model

Below is presented the logic of the Coffee Production Model:

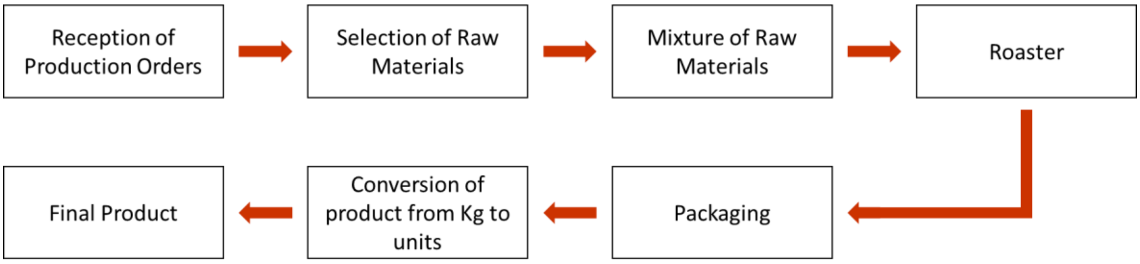


Figure 9 - Coffee Production Model

- **Reception of Production orders -** The first part of the process corresponds to the indication of the quantities that will be needed to produce. Historical data of Portuguese Company X's production plans for the year 2019 were analyzed. Based on all production plans for the year 2019, the quantities produced on average (in kilograms) per week for each type of product were used to serve as input for production orders for the model developed. These quantities will be fixed when the push production strategy be analyzed but will change in the pull production model depending on the actual demand.

- **Selection of Raw Materials -** In this phase, the necessary raw materials and respective quantities are defined to produce the products in question. The management of raw materials will not be a topic discussed in this project, so it will always be considered that there is no shortage of raw materials to produce.
- **Mixture of Raw Materials -** In this third phase, the mixing of the previously selected raw materials takes place.
- **Roaster -** The roaster is where the roast from the mixture of raw materials made previously occurs.
- **Packaging -** In this phase the packaging of the mixture of roasted raw materials takes place.
- **Conversion of product from Kg to units -** After the product is packaged, the final product is ready. Therefore, it is necessary to convert, on the simulation model, kilograms to units of the final product which represents the boxes.
- **Final product** – At this stage, it is possible to analyze the process output, that is, the total quantities produced in units (boxes) during the week.

4.4.1.2. Model Description

In order to compare the cost of production in each strategy, a simulation model of Coffee Factory was created in *Anylogic* software, as figure 11 shows.

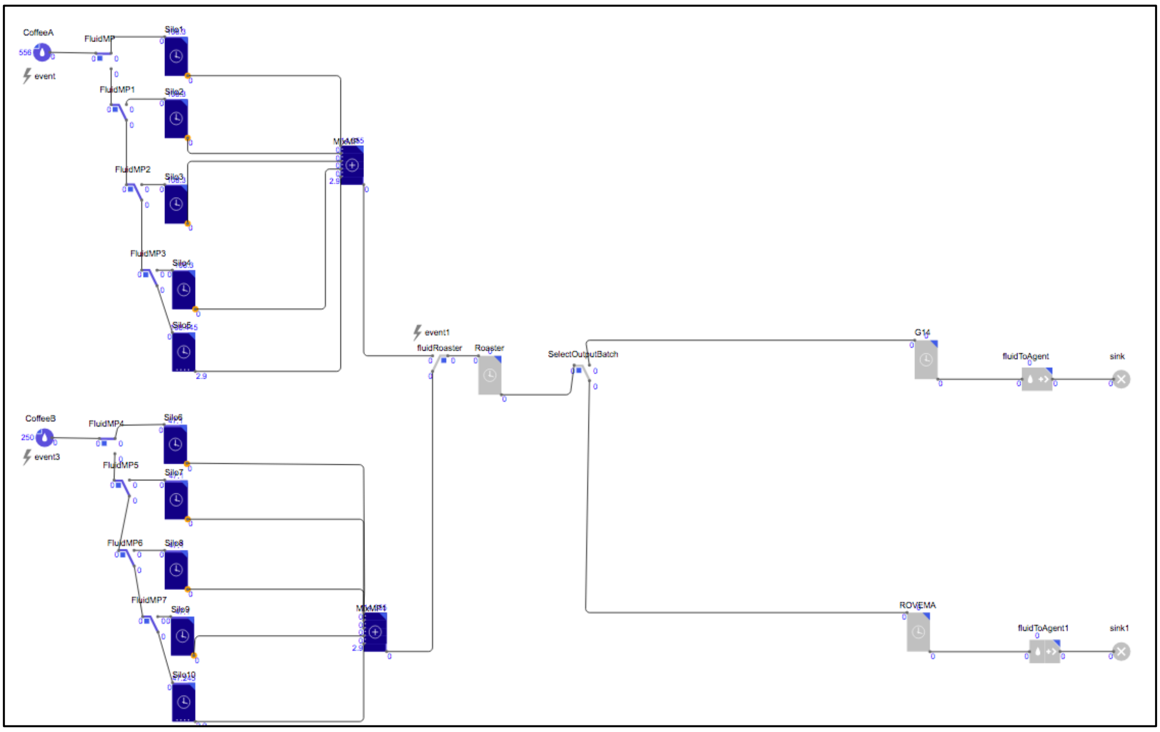


Figure 10 - Simulation Model of Coffee Production

In Anylogic Software, each problem is represented by a model, and each model is composed by a set of blocks responsible for representing the agents which are interconnected in order to represent the logic of the simulation model. The visual presentation of the model is illustrated in figure 11 and its function are described in the following section:

The model has two different sources, “Coffee A” and “Coffee B”, which are responsible to generate production. Each source triggered different flows which generate different products and the flow is measured in Kilograms. The products that flow out from the first source are produced in “G14” resource and the ones that flow out from the second source are produced in “ROVEMA” resource. These are the resources responsible to produce retail products, as explained in Step I. After the two first sources ten silos are created, five per each source. Each silo contains different raw materials, known as green coffees, once to produce Coffee A and Coffee B is needed the combination of some green coffees. After the silos are represented the two blocks were called “MIXMP” and “MIXMP1”. In those blocks, the mix of previous green coffees is made. When the mix is ready the fluid moves to the “Roaster” where the coffee will be roasted. After the “Roaster” the fluid will be packed on the two resources – “G14” and “ROVEMA”. The block named “fluidToAgent” and “fluidToAgent1” transform the flow in kilograms into units, in order to have the visibility of how many cases were produced during the simulation time. Each block has capacities and the fluid which is in the block only moves to the next block when the blocks are completely empty and the block only starts to process only when they are full. The block also has defined the capacity of the fluid that flows out each time according to the capacity of the next block.

The main objective of this simulation model is to compare the process costs, mainly in the “Roaster” block, since it is in this block that the costs can vary, depending on the strategy under analysis. As explained in the literature review, the production costs are calculated based on the fixed costs and variable costs. However, this project will focus only on the variable costs related to the waste, once are the only values which can vary on each strategy. In this case, the variable costs are related with the setup of the product on the production process and stoppages associated with the machine’s cleaning.

In the push production strategy, it will always be producing “in mass” while in the pull production strategy it will always be varying the type of product being produced according to the order of the customers. In order to compare the two strategies, the model will be run twice, on the different scenarios, with different inputs according to the logic of the strategy under study. The principal information about the model is reflected in the table below.

Inputs	Outputs
Production Order - Product A	Indicates the quantities that must be produced of product A by the end of the week, which were defined in the preparation of the production plan made according to the forecast loaded in the system.
Production Order - Product B	Indicates the quantities that must be produced of product B by the end of the week, which were defined in the preparation of the production plan made according to the forecast loaded in the system.
Process Roaster Time	Allows collecting the processing time of the Roaster, including the stoppage time for cleaning if the type of product being produced has changed.

Total Boxes Produced - Product A	Allows collecting the number of boxes that have already been produced of product A each time that the process ends.
Total Boxes Produced - Product B	Allows collecting the number of boxes that have already been produced of product B each time that the process ends.
Processing Roaster Cost	Indicates the fixed cost of the Roaster process.
Processing Cost - Product A	It gives the cost of the Roaster process relative to the total quantities produced bythe product A. This value is given by multiplying the total number of boxes produced, the processing time of the Roaster relative to the same quantities and the fixed cost of the Roaster process.
Processing Cost - Product B	It gives the cost of the Roaster process relative to the total quantities produced by the product B. This value is given by multiplying the total number of boxes produced, the processing time of the Roaster relative to the same quantities and the fixed cost of the Roaster process.
Total Processing Cost	That is, it adds the process cost of product A to the process cost of product B.

Table 1 – Important Data of Coffee Production Model

To understand how these inputs give the outputs mention above it was necessary to create some variables on the model which is possible to see in appendix B.

4.4.1.3. Blocks Description

In Anylogic there are several libraries that could be used for simulating models, such as: *Process Modeling Library, Material Handling Library, Pedestrian Library, Rail Library, Road Trafic Library* and *Fluid Library*. For this model it was used the *Fluid Library*, exclusively.

On *Anylogic* simulation software java type codes can be placed to create actions which then are linked by the user, using programming in java. In Fluid Library, these codes can be defined in three different fields:

- ***On Full*** **–** Action executed when the fluid has reached the Capacity level and the input of the tank gets closed.
- ***On Ready*** **–** Action executed when the fluid has spent the required time in the tank (if any), just before it can flow out.
- ***On Empty*** **–** Action executed when the fluid has completely flowed out of the tank, just before the new cycle starts.
- ***On Rate Change*** **-** Action executed when any of the flow rates (input or output) changes.

Below, it will be explain the function of each block on the model and whenever a java code was used to complement the action of one of the blocks in order to best represent the reality, the attachment where it is possible to see it will be indicated.

Block *Fluid Source* – The Fluid Source block is responsible for generating the fluid in the model, normally it is placed at the beginning of the Fluid models. In these blocks it is possible to define the rate at which the needs are generated and how often we want them to be generated. In the model there are two blocks of this type called: "CoffeeA" and "CoffeeB":

The “CoffeeA” block is responsible for triggering the production needs of product A, which is produced in resource “G14”.

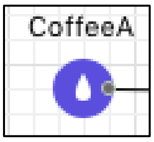


Figure 11 - Coffee A Block

The “CoffeeB” block has the function of generating the production needs of product B, which is produced in the “ROVEMA” resource.

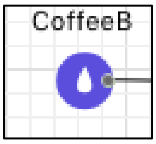


Figure 12 - Coffee B Block

Block *Fluid Select Output* – This block is responsible for routes the fluid from the previous block to another block, however, this block has two possible outputs and is possible to choose if the fluid goes to one output or to another one. In the model, nine blocks of this type are represented: “FluidMP”, “FluidMP1”, “FluidMP2”, “FluidMP3”, “FluidMP4”, “FluidMP5”, “FluidMP6”, “FluidMP7” and “SelectOutputBatch”.

The first eight Fluid Select Output are responsible for routing the Fluid Source "CoffeeA" and "CoffeeB" to "Silos1", ..., "Silos10". And as previously indicated, it is possible to choose whether the fluid comes out in the first output or in the second output. In the model it is defined that the fluid always comes out by the first output but whenever the block after that first output (called "Silo ...") reaches its maximum capacity the fluid is sent to the second output and so on.

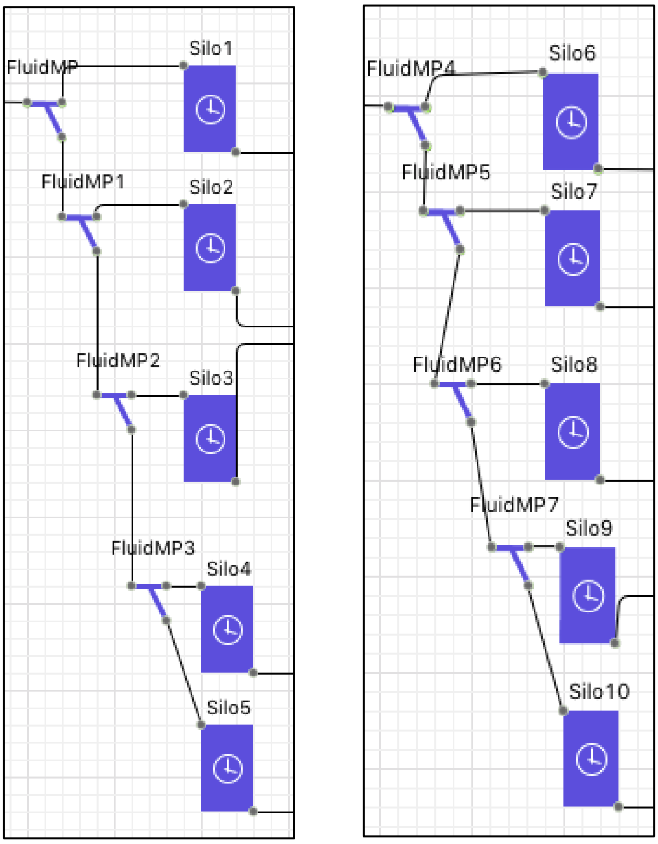


Figure 13 - FluidMP (...) FluidMP7 Blocks

The other Fluid Select Output present in the model is “SelectOutputBatch. This block is responsible for forwarding the fluid from the “Roaster” block to the appropriate resource. That is, if we are producing product A, it must be sent to the first output to be further processed in the block called “G14”. In the case of product B, the fluid must exit through output two in order to be directed to the “ROVEMA” block. For this to be reflected in the model it was necessary to use a java code (appendix C).

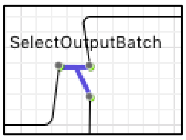


Figure 14 - SelectOutputBatch Block

Block *Process Tank* - Accumulates the fluid up to the capacity level, optionally delays it for a given amount of time, and lets it flow out. Therefore, for this type of block, the capacity of the block and the maximum quantity that can leave this block each time can be defined. In the model there are thirteen blocks of this type:

Ten of them have been previously presented: "Silo1", "Silo2", "Silo3", "Silo4", "Silo5", "Silo6", "Silo7", "Silo8", "Silo9" and "Silo10". These blocks serve to accumulate each type of raw material necessary to produce product A or product B. The first five silos ("Silo1" ... "Silo5") have the five different raw materials necessaries to produce product A, the remaining five have the raw materials necessaries to produce product B. Each block has defined a maximum capacity and whenever one of them reaches the maximum capacity the fluid enters in the next “Silo…”. In order for this to be accomplished and for the Fluid Select Output mentioned above redirect the fluid to the next “Silo…” block as soon as the previous one has reached its maximum capacity, a code has been defined in the *On Full* field for all the first ten blocks, as it is possible to observe in appendix D. These ten Process Tank have no associated process time. The fluid remains inside the block until the next block of the model has the capacity to receive it.

The other Process Tank present in the model was called “Roaster”. This block has the function of roasting the mixture of the five different raw materials present in the ten blocks named "Silos ..." mentioned above. This block has a total capacity defined and a time required to perform the roasting. The roasting time is always the same, but sometimes a cleaning time can be added to this block if the type of product to be produced changes (product A or product B). That is, as explained before: if Product A is being produced and then the factory starts to produce Product B at the time of the roasting process will be added the cleaning time. In order for this action to be reflected in the simulation model, a code was used in the field *On Full* (Appendix E). In this block, were also placed codes relates with the variables mentioned above about process time which will be used to measure the process cost (Appendix F)

Finally, the last two Process Tank present in the model, represent the two resources where each type of product is packaged. In these two blocks, the capacity of the block itself and the maximum amount that can leave this block at each time for the next block were defined.

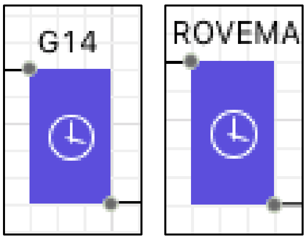


Figure 15 - G14 and Rovema Blocks

Block *Mix Tank* - Makes a mix of fluids coming in from up to five different sources and can delay a given amount of time until the fluid flows out. The proportion of components in the mix can be defined by giving the amount of each component. In the model we have two blocks of this type called “MixMP” and “MixMP1”. These blocks receive the fluid from the five silos that contain the raw materials needed to produce each type of product. A delay time has also been defined, which is associated with the stopping time required for cleaning the block whenever a new set of raw materials enters.

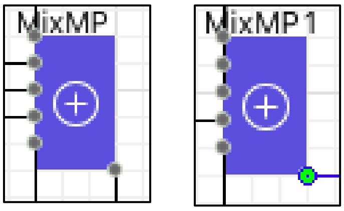


Figure 16 - MixMP and MixMP1 Blocks

Block *Fluid Select Input* – This block does exactly the opposite of block *Fluid Select Output*. *Fluid Select Input* is responsible to routes the flow from two inputs to the output. In the model, this block is present only once. This is responsible for directing the fluid from the two blocks “MixMP” and “MixMP1” to the roaster.

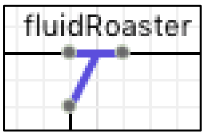


Figure 17 - FluidRoaster Block

Block *Fluid to Agent* – This block is responsible for converting the fluid into units, once it allows to define how much fluid corresponds to a unit. *Fluid to Agent* allows to define how much kilograms are needed to produce one unit. In the simulation model created, there are two blocks of this type whose function is only to convert the fluid into units. It is placed after the blocks “G14” and “ROVEMA” because after they are packed, they are converted into units.

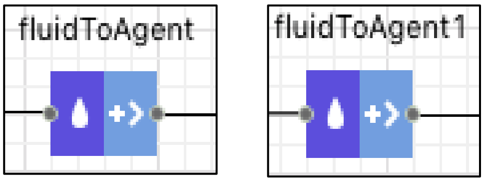


Figure 18 - FluidToAgent and FluidToAgent1 Blocks

Fluid Dispose – It is a typical end block of a Fluid Library flowchart. In the model created, two blocks of this type are present: “sink” and “sink1”. The block “sink” finalized the line of production of product A and “sink1” of product B.

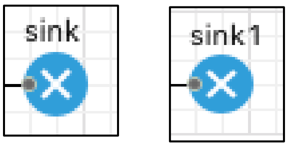


Figure 19 - Sink and Sink1 Blocks

Below is a table summarizing the most important designations of the resources created in the model to represent reality:

Model Resources	Description
Coffee A	This designation represents the blcock which is responsible to inject te prodction in orders of product A
Coffee B	This designation represents the blcock which is responsible to inject te prodction in orders of product B
Silo 1, Silo 2, Silo 3, Silo 4, Silo 5, Silo 6, Silo 7, Silo 8, Silo 9, Silo 10	These designation represents Silos where the quantities of raw material is needed to produce products A and B are in storage.
MIXMP, MIXMP1	These designation represents the machines where the raw materials are mixed.
Roaster	This designation represents the roaster where the mix of raw materials are roasted.
G14	This designation represents the machine where products A are produced.
Rovema	This designation represents the machine where products B are produced.
fluidToAgent, fluidToAgent1	These designation represent the block responsible in the model to vonvert the fluid from Kg to boxes.
Sink	This process symbolizes the end of the production process of product A and gives the tota quantities produced of that product.
Sink1	This process symbolizes the end of the production process of product B and gives the tota quantities produced of that product.

Table 2- Coffee Production Model Blocks Description

4.4.1.4. Blocks Capacity

To make the computational simulation process possible, some data related to the capacity of the resources provided by Portuguese COMPANY X was consolidated and adapt from reality.

1. As it is possible to analyze in the table below the “Roaster”, considering the downtimes, has the capacity to roast 125.712 Kg per week. This, considering that the factory works at a nominal speed of 900 with an efficiency of 97%.

Roaster Capacity and Downtimes	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Nominal Speed	950	950	950	950	950	950
Eficiency	97%	97%	97%	97%	97%	97%
Available Hours	24	24	24	24	24	24
Clean Downtime - Roaster				4		
Clean Downtime- Raw Materials Mix		3,5				

Total Production Time	24	21	24	20	24	24
Total Capacity/Day	22.116	18.891	22.116	18.430	22.116	22.116
Total Capacity/Week	**125.712**					

Table 3- Roaster Capacity and Downtimes

1.1. In the simulation model this capacity is equivalent to 873 Kg, as we can see in the calculation below:

$$\frac{125.712\ Kg}{144\ hours\ (6\ days\ x\ 24\ hours)} = 873 \text{ Kg/week} \qquad (2)$$

1.2. The capacity of the block called “Roaster” is 14,5 Kg per time, this value was defined as follows:

$$\frac{873\ Kg\ (Roaster\ capacity\ on\ the\ simultion\ model)}{60\ Seconds\ (roasting\ time\ process)} = 14{,}5 \text{ Kg} \qquad (3)$$

This means that in the model is possible to roast 14,5 Kg at each time in the roaster. The roaster capacity for each time was calculated by dividing the roaster capacity in one typical hour by the required roasting process time which will be explained in the below chapter - Assumptions.

2. The capacity of the block called “MixMP” and “MixMP1” was defined considering the capacity of the “Roaster” block. The capacity of the two blocks is also 14,5 Kg in order this block can send all the quantity for the next block (Roaster block) and at the same time to “Roaster” block has the required quantity to start the roasting process. This was defined in this way, since the bottleneck of capacity existing in the factory is in the roaster and not in the other blocks, in this way the capacity of all blocks was defined according to the capacity of the roaster.

3. The capacity of blocks called “Silo1”, ..., ”Silo10” varies depending on the quantities to be produced and is defined with the following calculation:

$$\frac{Quantity\ defined\ to\ produce - Product\ A\ or\ Product\ B}{5\ Silos\ (number\ of\ silos\ for\ each\ type\ of\ product)} \qquad (4)$$

= = Kg per Silo

This capacity only changes because if the quantities to be produced decreased and were not enough to fill these silos, the model would stop once some blocks only start the process when the maximum capacity is reached. In this way, it was defined that this capacity was going to be dynamic but also because it is not a capacity restriction in the factory.

And, the fluid that leaves each block each time is 2,9 Kg:

$$\frac{14{,}5\ Kg\ (capacity\ of\ next\ block - \text{MixMP})}{5\ Silos\ (number\ of\ silos\ for\ each\ type\ of\ product)} = 2{,}9 \text{ Kg per Silo} \qquad (5)$$

Thus, it was assumed that it’s required the same amount of each of the five raw materials to produce Product A and Product B.

4. The blocks designated by “G14” and “ROVEMA” have a capacity of 14,5 Kg, in order to absorb all the fluid that is roasted each time by the “Roaster” block, with the following difference:
   - The G14 block has a maximum output rate of 1,2 Kg per second;
   - The “ROVEMA” block has a maximum output rate of 2.4 Kg per second;

   This difference represents the different formats of the Product A and B , i.e., the kilograms needed to produce one unit of each product as it will be present on the assumption topic below.

5. After running the production model during the time under analysis and taking into account all the capacity restrictions presented above, it is possible to conclude that the maximum production capacity for these types of products is 561 units which is equivalent to 806 Kg. This is in line with what is currently happening at Portuguese COMPANY X, since it usually uses every available production capacity per week.

6. It was assumed that there are no capacity constraints related with th raw material needed to produce these two types of products.

4.4.1.5. Assumptions

To facilitate the computational simulation process, some information was consolidated and simplified considering real information acquired from the SAP-ERP. But consider that the simulation student version *Anylogic* only runs for an hour and the goal is to have a week as a basis of analysis, all the real quantities were reduced to an hour of simulation. Thus, the model is based on the assumptions present below but the real values must be converted always to the equivalent values in one hour.

Assumption A

The following table shows production times and downtimes in a production week:

Roaster Cleaning Downtime	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Nominal Speed	950	950	950	950	950	950
Eficiency	97%	97%	97%	97%	97%	97%
Available Hours	24	24	24	24	24	24
Clean Downtime - Roaster				4		
Clean Downtime- Raw Materials Mix		3,5				
Total Production Time	**24**	**20,5**	**24**	**20**	**24**	**24**

Table 4- Roaster Cleaning Downtime

A.1. The factory works six days a week and three shifts a day, that is, 24 hours a day. In this way, six days will be analyzed, which in the simulation model it will correspond to one typical hour;

A.2. In addition to the process time, the cleaning time shown above must be considered:

- 4 hours represent the hours of stoppage per week to clean the "Roaster" when the type of product to be produced changed. In the table is present in a specif day but is only a way to show how this impact the real process time. In the model, this cleaning stoppage is represented when the production product type changes. For example, when the factory is producing Product A, and then starts to produce a new product, in the simulation model is Product B. This stoppage in the model is represented by 100 seconds:

$$\frac{4\ hours}{144\ hours} = 0{,}027 \text{ hours} \tag{6}$$

$$0{,}027\ \times\ 3600 \cong 100\ seconds \tag{7}$$

In the total of the week there is a cleaning stop that corresponds approximately to 100 seconds but, since this downtime, as mentioned above, occurs whenever it's needed roast the mix of raw materials, the stop was calculated each time that happens:

$$\frac{556\ KG+250\ KG}{14{,}5\ Kg} = 56 \text{ times that Roster works during an hour of simulation.} \tag{8}$$

That is, each downtime in "Roaster" block takes 1,8 seconds, as showed below:

$$\frac{100\ \ seconds}{56\ times} \cong 1{,}8 \text{ seconds} \tag{9}$$

The time was calculated based on the typical quantities produced in one week (556 Kg + 250 Kg) at Portuguese COMPANY X divided by the maximum capacity of the "Roaster" (14,5 Kg). Then, dividing the total time of roaster cleaning (100 seconds) per week by the times that the fluid needs to pass on the "Roaster" block (56 times).

- 3,5 hours represents the cleaning time in the mixing silos throughout the week. It's also assigned to a specif day of the week but happens everytime that mix of raw materials occurs. In the simulation model this stoppage is reflected whenever a new fluid enters in the silos called "MIXMP" and "MIXMP1". In that way, in the model this stop corresponds to the following:

$$\frac{3{,}5\ hours}{144\ hours} = 0{,}024 \text{ hours} \tag{10}$$

$$0{,}024 \times 3600 \cong 86{,}4\ seconds \tag{11}$$

In the total of the week there is a cleaning stop that corresponds to 86,4 seconds but, since this dowtime, as mentioned above, occurs whenever a new mixture of raw materials enters the “MixMP” and “MixMP1” blocks, the stop was calculated each time that happens:

$$\frac{556\ KG+250\ KG}{14{,}5\ Kg} = 56 \text{ times that mixing takes place during an hour of simulation.} \tag{12}$$

That is, each downtime in “MixMP” and “MixMP1” blocks take 1.6 seconds, as showed below:

$$\frac{86{,}4\ seconds}{56\ times} \cong 1{,}6 \text{ seconds} \tag{13}$$

One more time, the time was calculated based on the typical quantities produced in one week (556 Kg + 250 Kg) at Portuguese COMPANY X divided by the maximum capacity of the “MixMP” and “MixMP1” blocks (14,5 Kg). Then, dividing the total time of roaster cleaning (86,4 seconds) per week by the times that the fluid needs to pass on the “MixMP” and “MixMP1” blocks (56 times).

Assumption B

In the simulation model it is considered that only one type of product is produced on each machine. On resource “G14” is produced only Product A and in “ROVEMA” resource is produced only Product B;

Assumption C

Based on reality it was defined that the "Roaster" takes 2,5 hours to roast all the coffee when reach out its maximum capacity. And it was also defined that the Roaster only starts to roast the coffee when it reaches its maximum capacity, so it is roast always the same quantity. So it's possible to know how much time the roast process takes as below formula shows. This process on the simulation model corresponds to 60 seconds.

$$\frac{2{,}5\ hours}{144\ hours} = 0{,}017 \text{ hours} \tag{14}$$

$$0{,}017\ \times\ 3600 \cong 60\ seconds \tag{15}$$

C.1 It is also important to highlight that whenever the type of production product change occurs, to the 2,5 hours of roasting process are added the 4 hours of cleaning stop but per each roast process:

$$60\ seconds +\ 1{,}8\ seconds = 61{,}8\ seconds \tag{16}$$

Assumption D

In the resources "G14" and "ROVEMA", it was defined that is produced one box per second. For this, the real formats of the products produced in each type of machine were considered: in "ROVEMA" it was considered that 1,2 KG (format 6 x 200gr) corresponds a one box, and in "G14" a box corresponds to 2,4 Kg (format 12 x 200gr);

Assumption E

The model's time unit is in seconds;

Assumption F

Color blue represents the fluid of Product A and the fluid of Product B is represented by green.

Assumptions Summary

Below is a table that summarizes all inputs used in this model. The table is divided into two parts:

- One part corresponds to values that have been converted from reality to the simulation time of one hour since they are values that are influenced by time.
- The other part corresponds to values that have not been converted since the simulation time does not influence them.

Time and Capacity Constraints - Coffee Production Model		**Input Description**	**Real**	**Simulation Model**
Converted Inputs	Time Constraints	Production Time	6 days	1h
		Total Clean Downtime - Roaster	4h	100 sec.
		Clean Downtime- Roaster each time	0,071h	1,8 sec.
		Total Clean Downtime - Raw Materials Mix	3,5h	86,4 sec.
		Clean Downtime- Raw Materials Mix each time	0,063h	1,6 sec.
		Roasting Time	2,5h	60 sec.
		Packing Time	144 sec.	1 sec.
	Capacity Constraints	MIXMP and MIXMP1 Capacity	50.285 Kg	14,5 Kg
		ROVEMA and G14 Capacity	50.285 Kg	14,5 Kg
		Total Roaster Capacity	125.712 Kg	873 Kg
		Roaster Capacity per time	50.285 Kg	14,5 Kg
		Total Production Capacity - Kg	116.000 Kg	806 Kg
		Total Factory Production Capacity - units	80.740 units	561 units
Unconverted Inputs	Others	Product A - Box unity	2,4 Kg / box	
		Product B- Box Unitity	1,2 Kg / box	

Table 5 - Time and Capacity Constraints - Coffee Production Model

4.4.2 Coffee Stock Model

4.4.2.1. Contextualization

In order to compare the impact of each strategy on holding stock costs, below is present the logic of the Coffee Stock Model:

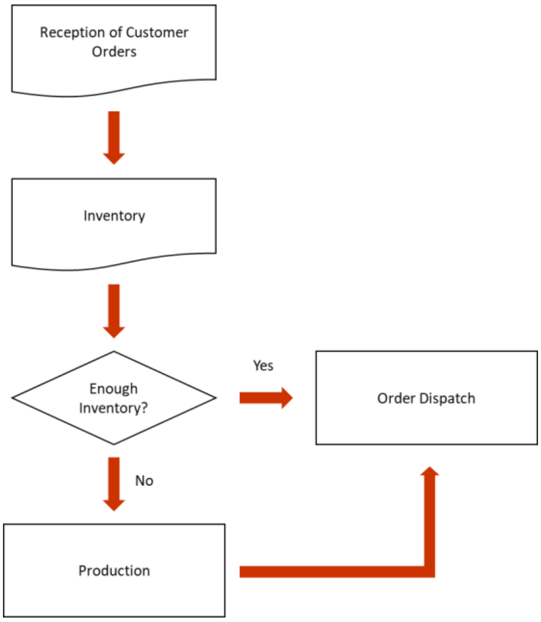


Figure 20 - Coffee Stock Model

- **Reception of Customers orders** – In the first part of the process the customers orders are received.
- **Inventory** – At this stage it is analyzed whether there is enough stock to satisfy the customer's order. If there is enough stock, the order is satisfied and passes automatically to the fourth stage. Otherwise, a production order is generated, and it is at this stage that it is waiting to be produced.
- **Production** – If in the previous step it was verified that there is not enough stock to satisfy the order, it is in this third phase that the production of the quantities ordered by the customer occurs. Orders are produced one at a time and the production time of a unit was established according to the production time of a unit in the Coffee production model. Moreover, the orders are produced according to the order in which they are placed. After the production of the ordered quantity, this quantity is added to the existing stock.
- **Order Dispatch** – In this last stage of the process, the order is satisfied, and the quantity of the customer order is removed from the existing stock.

4.4.2.2. Model Description

To reach the second goal of the study and evaluate the holding stocks costs, a model was developed as showed below, which reflect the process described above:

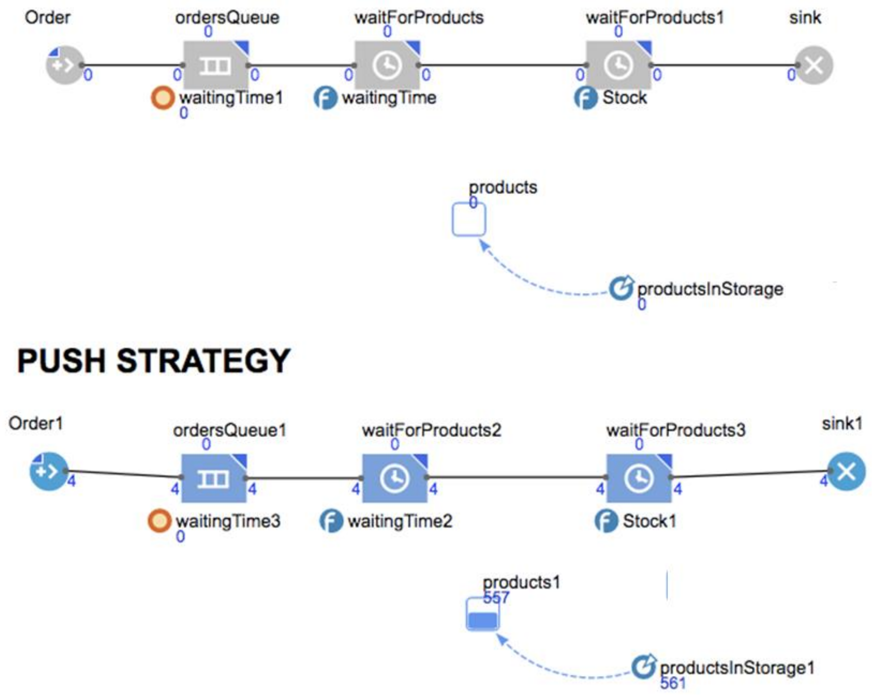


Figure 21 - Simulation Coffee Stcok Model

In this model, two different processes are present: one where will be applied the pull production strategy and another one where will be applied the push production strategy. Both processes have the same logic but the first one does not have stock at the beginning and the second one has.

The first blocks of the processes “Order” and “Order1” are the ones that receives the customers orders. Then if there is stock available, the time on the “waitForProducts” or “waitForProducts2” is zero otherwise will takes “X” time to be produced. The “ordersQueue”and “ordersQueue1” blocks are used when the orders have to wait to move for the next block. In the “waitForProducts” and “waitForProducts2” blocks, if the order is bigger than the stock available it must be produced and at the final the quantity produced is added to the stock – “products” and “products1” blocks. If the quantity ordered is lower than the quantity in stock, the “products” and “products1” remain with the same quantity at that stage. After the product is added or not, it will be possible to move for the next block "waitForProducts1" and "waitForproducts3"and here it is when occuring the dispatch of the product to the customer and the quantities of the stock available are reduced.

In this model, the objective is to compare the holding stock costs according to the type of strategy being analyzed. To complement this analysis, different forecast scenarios will be considered.

Below are present the main inputs and outputs of the model. In appendix G is possible to see all the variables created on the simulation model in order to achieve the desired outputs.

Inputs	Outputs
Costumer Order	Gives the quantity ordered by each costumer
Products in storage	Gives the total quantity in stock at certain time.
Holding Stock Costs	Indicates the fixed cost per unit of having holding stock.
Total Holding Stock Costs	Give the cost by day of having holding stock. This value is obtained by multiplying the quantity present in stock at the end of the day with the unit production cost and the holding stock rate.

Table 6 - Inputs and outputs of Coffee Stock Model

4.4.2.3. Blocks Description

As previously mentioned, in Anylogic there are several libraries that can be used. In this simulation model, the *Process Modeling Library* was used, once this type of models is a sequence of operations that typically involving queues, delays and resource utilization. In these blocks of the *Process Modeling Library* type *java* codes can be placed to create actions. These codes can be defined in three different fields:

- ***On Enter*** **–** Code executed when the agent enters the block.
- ***On at Exit*** **–** Code executed when the agent is ready to exit the block.
- ***On Exit*** **–** Code executed when the agent exits the block.
- ***On Remove*** **-** Code executed when the agent is intentionally removed from this block.

The following blocks were used for this model. Whenever, java codes were used to complement the action of the block, the attachment where it is possible to check it will be indicated.

Block *Source* – This block is responsible for generating agents. In this model there are two blocks of this type: "Order" and "Order1". The block called "Order" is responsible for generating the orders in the model that will be studying the pull production strategy and the block called "Order1" will generate the orders for the model where the push production strategy will be simulated.

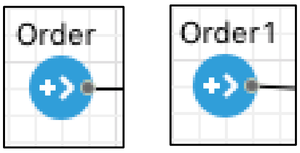


Figure 22 - Order and Order1 Blocks

In this block, a java code was used, in the *On at Exit* field (appendix H).

Block *Queue* – The block *Queue* is used for the agents waiting to be accepted by the next block in the process flow. In the simulation model, two of these blocks are used, one for each type of strategy: "ordersQueue" and "ordersQueue1". These blocks in this simulation model are used to store customer orders in the order they were requested, at least, until the next block has the capacity to produce it.

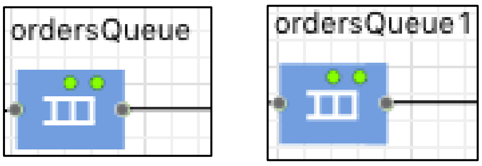


Figure 23 - OrdersQueue and ordersQueue1 Blocks

Block *Delay* – Delay block is used to Delays agents by a specified time. In this model, four blocks of this type are used, two in each process.

The first two blocks of this type (“waitForProducts” and “waitForProducts2”) were used to represent the production time, if required. So that the delay would only happen when it was necessary to produce the products, it was used a java code in the *On Enter* field (appendix I) .

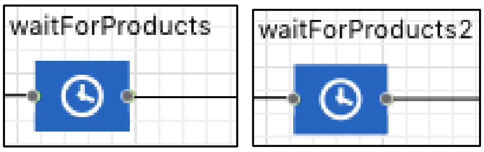


Figure 24 - WaitForProducts and waitForProducts2 Blocks

The last two ("waitForProducts1" and "waitForProducts3") were used to represent the dispatch of the products to the customer, however, the delay as it will be explained in the assumptions chapter, will be zero. The java code presented before was also used for the second process but with the name of the blocks present in that same process.

Figure 25 - WaitForProducts1 and waitForProducts3 Blocks

Block *Sink* – This block is normally used at the end of processes of this type. The model has two blocks of this type: "Sink" and "Sink1". These are used to end the pull production strategy simulation model and the push production strategy simulation model.

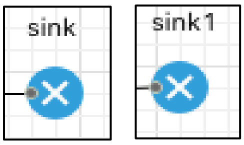


Figure 26 - Sink and Sink1 Blocks

Block *Stock* – This type of block is used two times on the model:

- The block called “products” or “products1” in the model, was used in the simulation model to represent the stock in storage during the simulation.

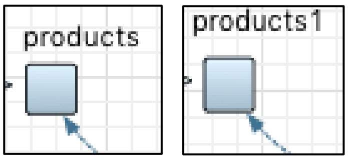


Figure 27 - Products and products1 Blocks

- The quantity of these blocks change:
  - Whenever, production is required because there is not enough stock to satisfy the customer order. When this happens, the stock is increased by the quantities that have been produced. This action was assisted by a java code that was inserted in the “waitForProducts” and “waitForProducts2” blocks in the *On exit* field (appendix J).
  - Or, whenever the agent is in the block “waitForProducts1” or “waitForProducts3”, once the quantities ordered by the customer will be dispatched. At that stage the quantity of the “products” or “products1” block will reduced according to the order quantity. This action was also supported by a java code (appendix K).

4.4.2.4 Blocks Capacity

Here, as in the previous model, will be explained how some data related to capacity of the resources was consolidated and adapt from the reality.

a) The blocks “ordersQueue” and “ordersQueue1” have no defined capacity since there is no maximum order capacity during the simulation period. In this way, all orders can be on hold until their turn to be produced;

b) The capacity of the “waitForProducts” and “waitForProducts2” blocks is one unit.

c) The capacity of the blocks "waitForProducts1" and "waitForProducts3" is also one unit at a time, in order to reflect that orders are dispatched one by one;

d) The “products” and “products1” blocks have no capacity, but it is necessary to indicate the initial value. In the “products” block this value will always be 0 units (Pull Production strategy) and in the “products1” block it will always be 561 units (Push Production strategy) as it will be explained on points 4.5.3 and 4.5.4.

4.4.2.5. Assumptions

To facilitate the computational simulation process, some information was consolidated and simplified. The model is based on the following assumptions:

a) Orders are received in a random way, but according to the forecast in each scenario under study;

b) Orders are fulfilled by order of request, that is, by FIFO logic, the first orders to be placed are the first to be satisfied.;

c) It was stipulated that whenever there is no stock and the product must be produced, the production time takes X seconds per unit.This time will be defined after. The time was defined, divided by the time of production, with the maximum quantities possible to produced on the push or pull production strategy.

$$\frac{3.600\ seconds}{units\ produced\ in\ one\ hour\ on\ the\ push\ or\ pull\ production\ strategy} \cong X\ seconds/unit \qquad (17)$$

d) It was considered that if there is stock, the waiting time for the customer is zero seconds. Once, the only existing time is the production time. Thus, it is considering that when the product is produced, it is immediately dispatched to the customer.

e) In this model, the same analysis of six days was also considered, which were also converted to one hour, in order the outputs of the two models are comparable.

f) It was defined that each customer orders only one unit (a box) each time they placed an order;

g) The main goal of this model is understanding the costs of holding stock on the two production strategies and on the different demand scenarios. As explained in the literature review, the cost of holding stock is equivalent to multiplying the stored quantity, by its respective value and by the holding stock rate. According to data provided by Portuguese COMPANY X, the stock rate corresponds to 30%. This percentage was used in the simulation model in order to conclude about these costs. The formula used in the simulation system was the follow:

$$S \times PCun \ \times R \tag{18}$$

S represent the stock produced as a result of the simulation, Pcun represent the unit cost of production and R, represent the stock rate. The unit cost of production (Pcun) was updated in every scenario and was calculated divided the cost of production and units produced on each scenario of the production model. This cost will be accounted by every day which in the model is represented by every 600 seconds.

$$\frac{3600 \ seconds \ x \ 24 \ hours}{144 \ hours} = 600 \ seconds \tag{19}$$

4.5 Step V – Applying the Two Simulation Models in the Two Different Strategies: Push and Pull Production Strategies

At this point, it will be explained how the simulation models that were created and described above were adapted to each type of production strategy. In both models will be analyzed different forecast scenarios and the impact on the two KPI’s.

It is important to remember that in all simulation models all times and quantities were reduced to one hour, that is, an equivalent reduction was made from six days to one hour.

4.5.1. Coffee Production Model – Push Production Strategy

The simulation model explained above was adapted in order to represent the push production strategy. According to John Maher and Rich Denison (2013) , the production schedule is developed according to the forecasts made and assumes that everything is constant over time. In this way, the quantities to produced in this model were stipulated based on the histories of Portuguese COMPANY X's production plans of 2019 year. These production quantities were planned according to the forecasts made.

This simulation was modeled in order to produce the quantities planned in "mass". In this way, the entire quantity of Product A will be produced, and only afterwards the quantities of Product B are going to be produced, as the graphic below shows:

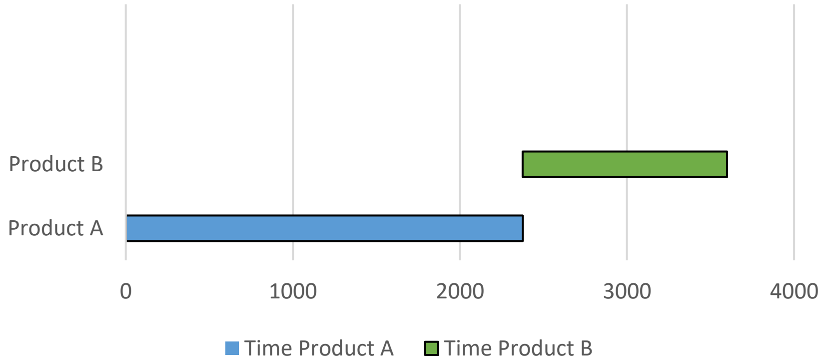


Figure 28 - Production Plan - Push Production Strategy

4.5.1.1. Model Data

Below, in addition to the general inputs of the model previously presented, the inputs of the production model will be presented when a push production strategy is applied:

1. Based on the previous year production plans, it was analyzed that on average, 116 000 Kg of retail products formats are produced per week in the Portuguese COMPANY X factory. And 80,000 Kg are produced in the "G14" resource and the remaining 36,000 Kg are produced in the "ROVEMA" resource. This, in the simulation model is equivalent to a total of 806 Kg in one hour, of which 556 Kg corresponds to the quantities of Product A produced in Block "G14" and 250 Kg corresponds to the

quantities of Product B, produced in block “ROVEMA”. So, it was defined that 556 KG of Product A and 250 KG of Product B will be produced.

2. The quantities to be produced are always the same on the different scenarios which will be studied, once the production plan is based on the forecast and if demand decrease or increase suddenly it’s not possible to predict it.
3. Based on what was previously presented, it is possible to see that normally all the production capacity is used, once the maximum capacity of Portuguese COMPANY X factory on this type of product is 116 000 Kg.
4. The model will start with the production of Product A, where the 556 KG will enter all at once for the blocks called "Silos ...".
5. The quantities to be produced in Product B will only enter the model once all quantities of Product A have been produced. Thus, an event was created to inject this quantity into the model, at the exact moment when the production of Product A is finished.

4.5.1.2 Results Analysis

In order to conclude on the results of the push production strategy, several demand scenarios were simulated, based on the current scenario of Portuguese COMPANY X, i.e, based on information shown in the table 7:

	Current Scenario	
	Kg to produce (According Forecast)	**Units to produce (According Forecast)**
Product A	556	463
Product B	250	104
Total	806	568

Table 7- Current Scenario

As a first analysis, the current model was simulated in order to conclude about the units produced and the respective costs. After running the simulation model, it was possible to draw the following conclusions demonstrated in the table below.

	Current Scenario			
	Kg to produce (According Forecast)	**Units to produce (According Forecast)**	**Units produced (Simulation Model)**	**Production cost (Simulation Model)**
Product A	556	463	459	27.540 €
Product B	250	104	102	5.760 €
Total	806	568	561	33.300 €

Table 8 - Current Scenario Outputs

Through table 8 it is possible to conclude that at the end of 1 hour (equivalent to 6 days) 561 units are produced with a cost of 33.300 €, with 459 units of product A and 102 units of product B. As it is possible to verify, the units produced resulting from the simulation model, correspond to 99% of the units to be produced (568 units).

$$\frac{561\ units}{568\ units} \cong 99\% \tag{20}$$

This small discrepancy happens, since the simulation model is parameterized to produce 14,5 kg at a time and since 806 kg is not divisible by 14,5 kg, it is expected that there will always be an associated waste. Although this conclusion is drawn from the simulation model, the same happens in the production process of Portuguese COMPANY X, since the expected totality is never produced, as there is always wasted raw material throughout this process.

In a second analysis, conclusions were drawn based on the different demand variation scenarios, as shown in appendix L.

In the push production strategy, applied by Portuguese COMPANY X, production planning is carried out based on forecasts of market needs. In situations of sudden changes in demand, this strategy is not prepared to immediately follow the market, which is why, for any scenario, the quantities to be produced and the respective costs will not vary, as shown in the graph 30. The graph was constructed in such a way that it is possible to compare production costs with the quantities produced in their entirety. In this way, the production costs are illustrated by the gray line, while the quantities produced are represented by the columns. As a form of reference, the leftmost column of the graph, highlighted in gray, represents the quantities produced from the current scenario developed and explained above.

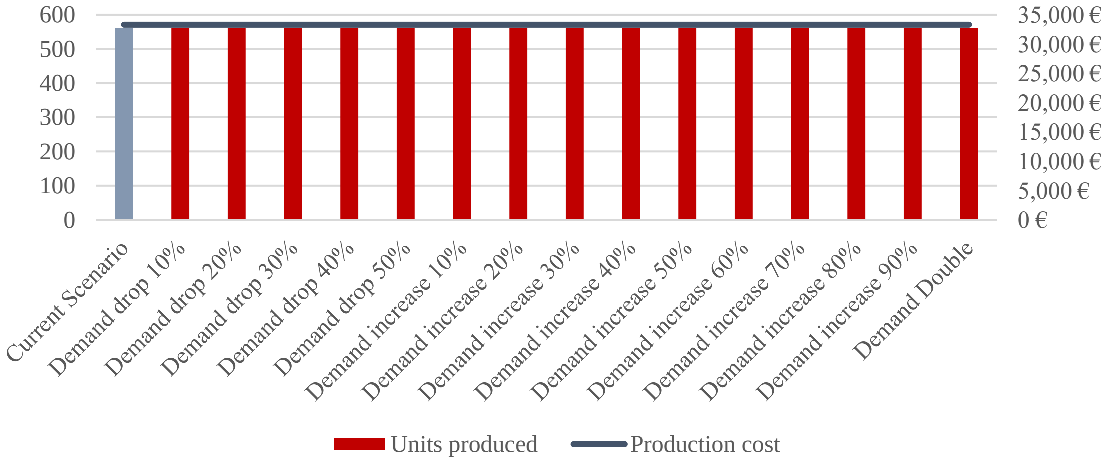


Figure 29 - Units produced vs Production Costs on push production model

As mentioned before in all scenarios the quantities produced were 561 units and the production costs were 33.300€. This behavior is in line with what was mentioned, in previous points of this document, by John Maher and Rich Denison (2013), where the planning becomes obsolete even before being executed. This conclusion is also reflected through the graph 31, because in scenarios where demand decreases, the quantities produced are well above from the quantities required by the market.

As shown in the graph 31, the quantities produced do not follow the variation in demand. However, it is important to emphasize that, from a certain point, in the scenarios where the demand increases, it would not be possible to meet the needs, since the maximum capacity is already reached in the current scenario, as already explained in point 4.4.1.5 of this document.

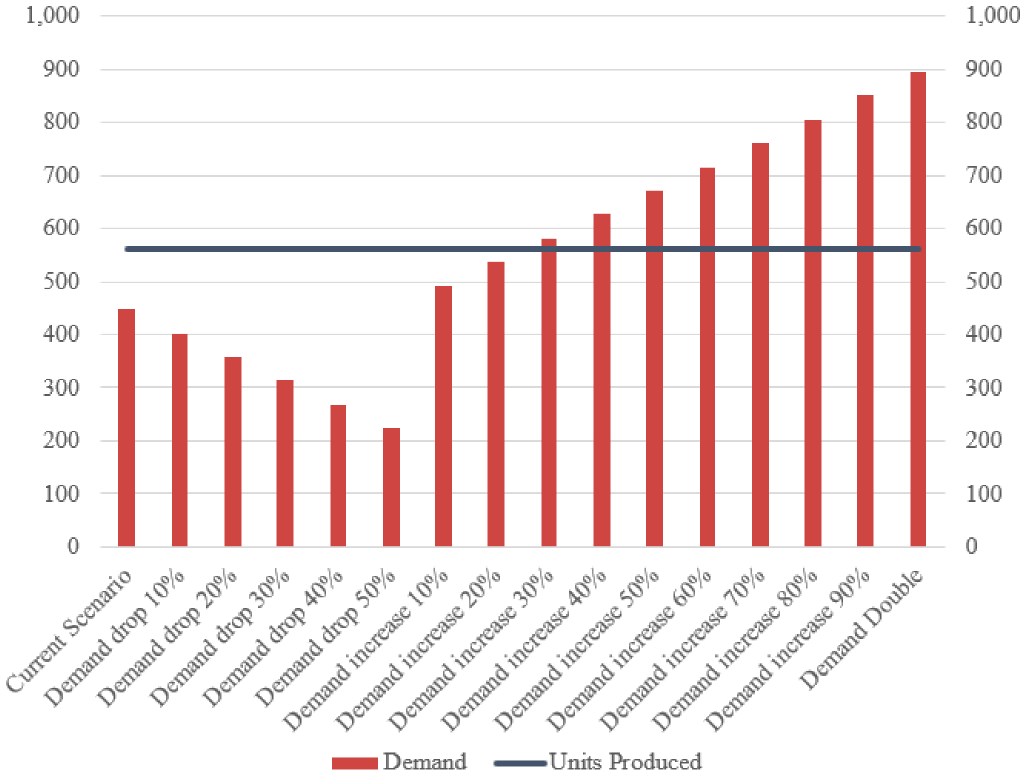


Figure 30 - Demad vs Units produced on push production strategy

4.5.2. Coffee Production Model – Pull Production Strategy

According to Zhou & Benton (2007) pull production strategy works in such a way that production orders are guided by the actual demand so the factory only starts to be processed after a consumer demand signal be triggered (Vlachos, 2015). Therefore, in this model there are no previously defined quantities to be produced. Production orders are originated when orders are placed by customers, so a production order is not stipulated.

The production is done according to the order of arrival of the orders and only what is ordered is produced, never having, therefore, available stock. A hypothetical production plan is present in figure 32.

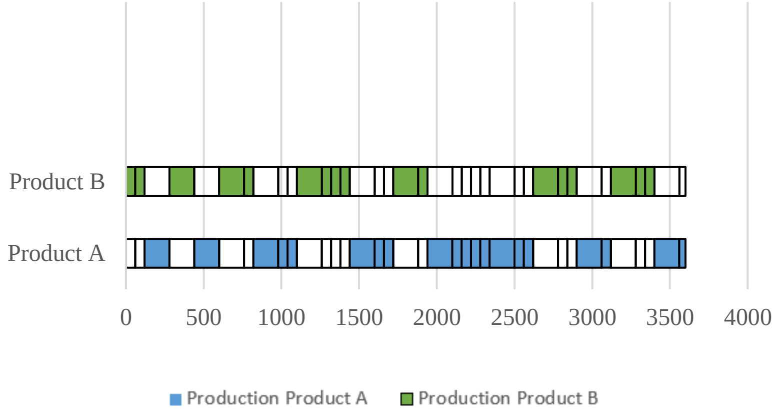


Figure 31 - Production Plan - Pull Production Strategy

4.5.2.1 MODEL DATA

- In this model when pull production strategy is applied, differents Kilograms will be produced according to the different scenarios. These quantities will be defined considering the quantities normally produced per week and the level of accurate forecast. It is possible, after running the production model in the push strategy, that normally the quantities produced are 561 units, although the set was 568 units but there is always some waste. Taking into account these quantities and the forecast accuracy that Portuguese COMPANY X presents (79%) it is possible to reach the real demand for this type of products:

$$568\ units\ \times 79\ \%\ \cong\ 448\ units \tag{21}$$

- Considering these quantities as the quantities of the current scenario, the remaining scenarios will be analyzed based on these quantities. In addition to the current scenario, anothers scenarios will be analyzed until the demand decreases by half and until the demand increases by double compared to the current demand;
- It was considered that orders requested by the customers are always entering during the simulation period, as in the push production strategy model, in order to compare the quantities that is possible to produce in one hour;

- The beginning of the model works in the same way as in the push production strategy. At the beginning there is the quantities (in KG) of Product A and the quantities (in KG) of Product B, which are equally distributed among the following five Silos. The quantities present in the 10 Silos only go to the next block to be produced when an order is placed by a customer;
- The quantities of each product depend on the demand scenario that will be analyzed;
- Orders are created randomly and are generated through an event that was placed in the model - "event1". This event causes the alternation of the input channel that connects the blocks where each type of product is mixed with the "Roaster".

Figure 32 - Event1 Block

To make this possible, is was used a java code (appendix M). During the simulation process, a limitation was identified regarding the number of times that alternation may occur. That is, if the number of times is greater than the optimal number of times (total production time to be divided by the maximum roasting time) it will cause a bottleneck in the roaster, since the product that would be produced will not be able to enter, because the roasting process of the previous product would still be taking place. In this sense and in order to avoid these constraints in the roaster, it was defined that the maximum number of times that the alternation in question would occur would be 58 times. This quantity was defined based on the following calculation:

$$\frac{3.600\ seconds}{61{,}8\ seconds} \cong 58\ times\ per\ hour \tag{22}$$

Where, 3,600 seconds correspond to the total production time and 61.8 seconds correspond to the maximum time that the roasting process can take (process time + roaster cleaning time). This amount of alternation that occurs during the simulation process was used in all scenarios and ensuring that the order of the requests entry will also be the same, so that the stops are identical in all scenarios.

4.5.2.2. Results Analysis

In order to conclude about the results of the pull production strategy, several demand scenarios were simulated, based on a hypothetical scenario explained previously in point 4.5.2.1 of this document. It is important to reinforce, as explained in this same point, that the order of the customers requests is the same for all scenarios. This happens, so that the results obtained are comparable and that the number of stops, combined with the product change, are not influenced, that is, that they are the same for all scenarios.

The data of the current hypothetical scenario, which will be the basis of comparison for the creation of the remaining scenarios, are represented in the table 9.

	Hypothetical Current Scenario	
	Kg to produce (According Demand)	**Units to produce (According Demand)**
Product A	438	365
Product B	198	83
Total	636	448

Table 9 - Hypothetical Current Scenario on pull production strategy

As a first analysis, the simulation results were obtained based on the inputs represented above, being possible to build table 10:

	Hypothetical Current Scenario			
	Kg to produce (According Demand)	**Units to produce (According Demand)**	**Units produced (Simulation Model)**	**Production cost (Simulation Model)**
Product A	438	365	253	39.997 €
Product B	198	83	82	12.963 €
Total	636	448	335	52.960 €

Table 10 - Hypothetical Current Scenario Outputs on pull production strategy

Through the results presented above, it is possible to conclude that it was only possible to produce 75% (335 units of 448 units) compared to the quantities ordered with a production cost of 52.960 €. This low level of performance when compared to the push production strategy, is explained by the fact that this production strategy requires a greater number of stops, coupled with the satisfaction of orders on the order of arrival, thus limiting the fulfillment of total production in the period under analysis (6 days, which is equivalent to 1 hour in the system). In addition, part of the percentage in question is explained by the waste existing throughout the production process, as explained in the push production strategy.

In a second analysis, conclusions were drawn based on the different demand variation scenarios. As such, this analysis begins by examining scenarios where demand decreases and later scenarios where demand increases.

Demand Decrease Scenarios

In order to obtain a more comprehensive perspective of the impact of reduced demand on the pull production strategy, 5 scenarios of reduced demand were simulated, with a variation of 10 in 10%.

As such, after simulating the various scenarios, it was possible to build the graph 34, with the support documented in the appendix N.

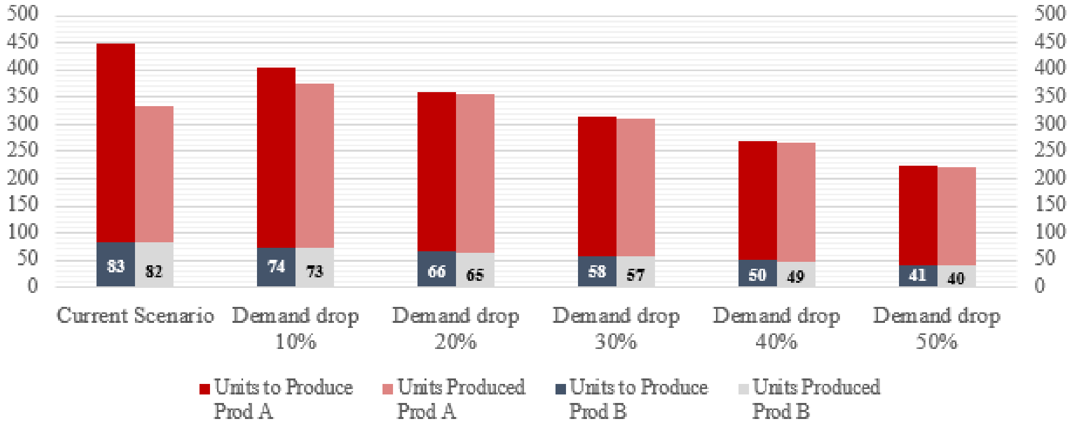


Figure 33 - Demand decrease scenarios: Units to produce vs units produced on the pull production strategy

The graph 34, shown above, was constructed in order to compare the quantities, by product, to be produced according to customers orders (bars on the left) and the quantities produced (bars on the right), resulting from the simulation results. The bars of reddish tones represent the quantities to produce/produced of product A, while the bars of gray tones represent the quantities to produce/produced of product B.

Through the analysis of the graph 34, it is possible to highlight the following conclusions:

In all scenarios, it was possible to produce all the quantities of product B, and the small quantities missing in all scenarios are associated with the waste that exists throughout the production process.

The quantities of product A are only produced entirely from the scenario where demand drops by 20%, and it can be concluded that it is from this behavior of demand that the number of stops, although constant, allows to produce almost 100% of the quantities ordered. In short, it is only from this scenario that the factory is able to respond to all order requests in the desired period (6 days). It is possible to verify this behavior through table 11:

Scenarios	**Units to produce (According Deamand)**	**Units produced (Simulation Model)**	**% of production**
Current Scenario	448	335	75%
Demand drop 10%	403	375	93%
Demand drop 20%	358	355	99%
Demand drop 30%	314	311	99%
Demand drop 40%	269	266	99%
Demand drop 50%	224	222	99%

Table 11- Demand decrease scenarios: percentage of production on pull production strategy

At the same time, it is possible to verify that, in the scenarios where the demand falls 10% and 20%, the total quantities produced are greater when compared to the quantities produced in the current hypothetical scenario. This is explained by the fact that, as previously mentioned, the quantities of product B are always produced in full. Thus, as the production of product B ends earlier in the scenarios in question, the remaining quantities of product A are produced without any major stops associated with the product exchange. These scenarios thus allow to achieve greater productivity in the production process. Even so, in view of these conditions, in the scenario where demand falls 10%, it is still not possible to produce all the desired quantities.

Additionally, it is relevant to monitor the performance of costs associated with the different scenarios presented. As explained in point 4.4.1.5 of this document, the costs calculated by the simulation model, were only obtained by multiplying the units produced by the process time in the Roaster resource, as well as by the cleaning time of that same machine. This rationale was due to the fact that this process is the only one to cause different impacts in view of the two types of production strategy analyzed.

That said, after simulating the different scenarios previously presented, it becomes possible to build graph 35:

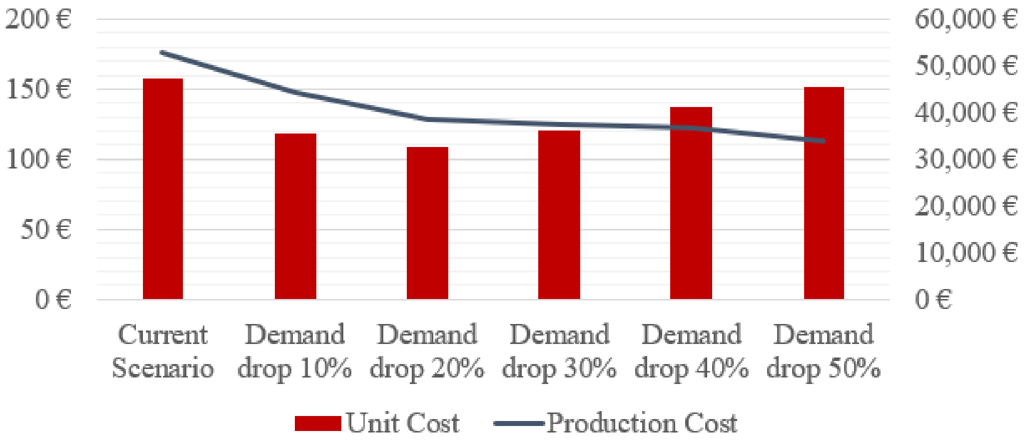


Figure 34 - Demand decrease scenarios: Unit Cost vs Production Cost on pull production strategy

In view of the analysis of total production costs, it is relevant to analyze unit costs, since the quantities produced after one hour (6 days) are different in the simulated scenarios.

Through graph 35 it is possible to draw the following conclusions:

1. As expected, the total cost of production follows the decrease in demand, since the total quantities produced are also decreasing, as demonstrated in the previous point.
2. Contrary to the previous point, the unit cost of production accompanies the decrease in demand, up to only 20%, and in the remaining scenarios it presents an increase of around 40 €. In this way, it is possible to conclude that, based on the scenario where demand falls by more than 20%, the quantities to be produced are not compensatory, in view of the costs of stoppages required in the process.

Demand Increase Scenarios

As was done for the demand decrease scenarios, 10 demand increase scenarios were simulated, with a 10% variation, in order to have a greater perspective of the respective impacts.

As such, after simulating the various scenarios, it was possible to build the following graph, with the support documented in the appendix N.

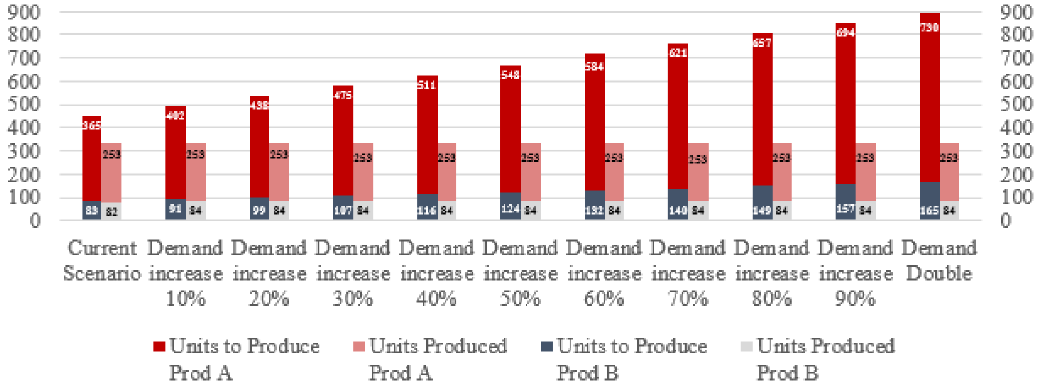


Figure 35- Demand increase scenarios: Units to produce vs units produced on the pull production strategy

The graph 36 shown above was constructed in order to compare the quantities, by product, to be produced according to demand (bars on the left) and the quantities produced (bars on the right), resulting from the simulation results. As in the graph above, the reddish tones bars represent the quantities to be produced/produced of product A, while the gray tones bars represent the quantities to be produced/produced of product B.

Through the analysis of the graph 36, it is possible to highlight the following conclusions:

1. In all scenarios it was possible to produce, exactly, the same quantities in total and both product A and product B. However, when compared to the current hypothetical scenario it is possible to conclude that in this scenario fewer quantities of product B were produced. It is explained by the fact that, in this scenario, the quantities produced of product B were fully satisfied, and the missing quantity of product B is explained by the waste that occurs during the production

process. With this we were able to conclude that, when the demand is higher than 448 units, we only managed to produce 337 units in total, considering the restrictions of the pull production scenario.

2. Additionally, it is possible to conclude, through the table 12, that the percentage level of quantities produced decreases along the scenarios of increased demand.

Scenarios	Units to produce (According Deamand)	Units produced (Simulation Model)	% of production
Current Scenario	448	335	75%
Demand increase 10%	493	337	68%
Demand increase 20%	537	337	63%
Demand increase 30%	582	337	58%
Demand increase 40%	627	337	54%
Demand increase 50%	672	337	50%
Demand increase 60%	716	337	47%
Demand increase 70%	761	337	44%
Demand increase 80%	806	337	42%
Demand increase 90%	851	337	40%
Demand Double	895	337	38%

Table 12 - Demand decrease: percentage of production on pull production strategy

It is possible to verify that when the demand increases 10%, it is only possible to satisfy 68% of the orders in the period under analysis. This percentage decreases over the scenarios, and in the scenario where demand increases twice the quantities produced represent only 38% of the orders placed during those 6 days.

After analyzing the quantities produced, it is also relevant to analyze the associated production costs, as shown in the graph below.

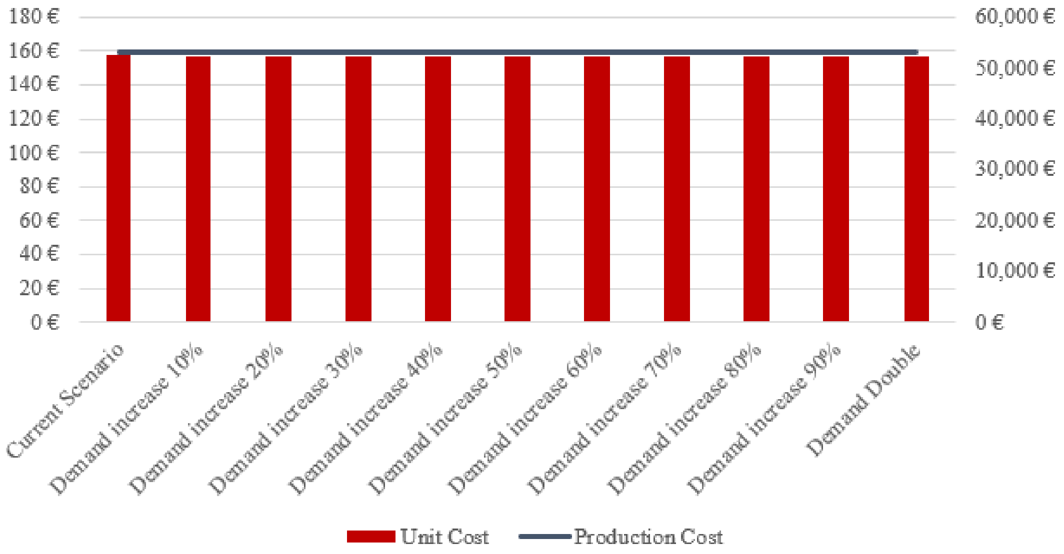


Figure 36 - Increase demand scenarios: Unit costs and production costs on pull production strategy

As it is possible to verify on graph 37, the total and unit production costs are the same in all scenarios. This conclusion is in line with the results of the analysis of the quantities produced, given the scenarios of increased demand. That is, as the maximum production capacity is reached in the current scenario, all scenarios where demand increases, it will not be possible to obtain quantities greater than those obtained in that same scenario.

4.5.3 Coffee Stock Model – Push Strategy

Here, it will be explained how the "Coffee Stock Model" that was analyzed in detail previously, was adapted to be studied the push production strategy in terms of holding stock costs and how the different scenarios of the forecast will impact the results.

4.5.3.1 Model Data

1. This model starts with an initial amount of stock. This initial quantity of stock considered the total units produced in the "Coffee Production Model". The initial quantities on the stock are equal on the different scenarios, that will be studied, once as it was explained, the quantities produced are defined based on the forecast so if the demand change the quantities produced are the same:

$459\ units + 102\ units = 561\ units \rightarrow> initial\ stock$ (quantities produced on push production strategy)

2. The number of orders that should be generated during an hour will be inserted on the block “Order1”.

3. It was stipulated that whenever there is no stock and the product must be produced, the production time takes 6,4 seconds per unit. This time was defined based on the following calculation:

$$\frac{3.600\ seconds}{561\ units\ produced\ in\ one\ hour} \cong 6{,}4\ seconds/unit \qquad (23)$$

The time was defined, divided the time of production with the maximum quantities possible to produced on the push production strategy as was possible to see on the results of the production model.

4. The holding stock costs on the push production strategy is calculated with the following formula:

$$S \times PCun\ \times R \qquad (24)$$

S depends on the quantities in stock at the end of each day, Pcun is equal in all scenarios once on the production model is always produced the same quantities and the production cost is always the same. R is 30%, information confirmed by Portuguese COMPANY X.

4.5.3.2 Results Analysis

After analyzing the different quantities and production costs in each of the simulated scenarios, it is also relevant to analyze their impact with respect to storage time and respective costs.

As previously verified, in the push production system, the quantities produced are not influenced by the variation in demand, since forecasts are made in advance and based on past events, making it impossible to react to real market needs.

As such, the objective is to understand the costs of storing the quantities produced in the face of different scenarios of changing demand.

As it was possible to verify, in graph present on figure 31, the quantities produced do not follow the variation in demand, and in scenarios where demand decreases, it is expected that the holding stock costs will be higher than the costs associated with the current scenario and the scenarios of increase demand. As support and validation of the analysis performed on storage costs, the graph 38 was constructed:

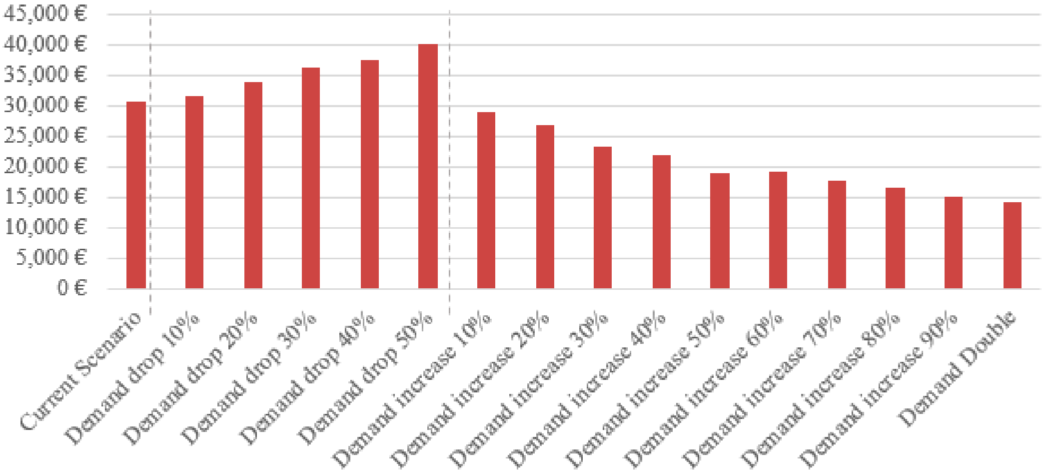


Figure 37 - Holding stock costs on Push Production strategy

Holding stock costs have been calculated, as described in 4.5.3.1. Only the quantities that are in stock at the end of the day were considered for the calculation, as it is considered that with each passing day the product loses value, since it reduces its “useful life”. Thus, at the end of each day, costs that have already been incurred in the previous days are added. It is important to note that, since there is no shipping lead time, that is, there is no waiting time for stored quantities to be shipped, at the end of the day, the quantities that remain in stock correspond only to the quantities that were not ordered yet.

4.5.4 Coffee Stock Model – Pull Strategy

Here, the “Coffee Stock Model” model was adapted in order to best reflect a pull production strategy in terms of stock in order to measure the costs of holding stock.

4.5.4.1. Model Data

1. In this model there is no initial stock. (this assumption was defined since the pure philosophy of pull is to have zero stock, however, normally companies have safety stocks, this is an aspect that will be added to future studies in order to understand what would be the ideal safety stock. Other authors, as for example, Polat (2005), used the same assumption for his study).
2. The stock is always zero, once when the products are produced according to the order made by the customer the stock is immediately dispatched;
3. Orders are generated through the "Order" block according to the scenario that will be analyzed. As explained before different scenarios of forecast will be analyzed;
4. It was stipulated that whenever there is no stock and the product must be produced, the production time takes 10,6 seconds per unit. This time was defined based on the following calculation:

$$\frac{3.600\ seconds}{337\ units\ produced\ in\ one\ hour} \cong 10{,}6\ seconds/unit \qquad (25)$$

The time was defined, divided the time of production with the maximum quantities possible to produced on the pull production strategy as was possible to conclude based on the results of the production model (graph 36).

- The holding stock costs on the pull production strategy is calculated with the following formula:

$$S \times PCun\ \times R \qquad (26)$$

S depends on the quantities in stock at the end of each day, Pcun varies according to the scenario under analysis once the quantities produced and the costs are different. R is 30%, information confirmed by COMPANY X.

4.5.4.2. Results Analysis

In the pull production strategy, the analysis of storage costs is facilitated, since there are no associated costs. This happens since only what has been ordered is produced and there is no initial stock. At the same time, it was considered that as soon as the product is produced, it is immediately dispatched, with no shipping lead time associated with the orders, as explained in point 4.4.2.5. Therefore, in this there is no time when products are stored at Portuguese COMPANY X warehouse.

This strategy was simulated in order to reflect a pure pull production strategy, where the “zero stock” principle is evaluated. Although this is a risky and difficult to achieve principle, Pheng and Hui (1999) and Pheng and Chuan (2001) state that everything is ordered, made, and delivered just when it is needed, ensuring that the materials are delivered on the same day that produced, so that there are no stored quantities.

Arditi and Polat (2007), in their simulation study, also used the principle of zero stock in order to understand the impact on the total cost of stock when implementing a pull production strategy versus a push production strategy.

4.6 Step VI – Evaluating the Strategies on the Two Models

After individually analyzing the outputs of the production and stock model, given the different production strategies, it becomes necessary to confront them, in order to conclude about the strategy that best adapts to the different scenarios of demand variation.

In this way, table 13 was built, where it is possible to identify, by scenario of demand variation, the respective production costs, holding stock costs and percentage of order satisfaction (quantities produced over quantities ordered).

Scenarios	Production Strategy	Production Cost	Holding Stock Cost	Total Cost	Demand satisfaction (%)	Yes/No
Current Scenario	Push Production Strategy	33.300 €	30.603 €	63.903 €	100%	✓
	Pull Production Strategy	52.960 €	0 €	52.960 €	75%	✗
Demand drop 10%	Push Production Strategy	33.300 €	31.683 €	64.983 €	100%	✗
	Pull Production Strategy	44.260 €	0 €	44.260 €	93%	✓
Demand drop 20%	Push Production Strategy	33.300 €	34.054 €	67.354 €	100%	✗
	Pull Production Strategy	38.560 €	0 €	38.560 €	99%	✓
Demand drop 30%	Push Production Strategy	33.300 €	36.178 €	69.478 €	100%	✗
	Pull Production Strategy	37.600 €	0 €	37.600 €	99%	✓
Demand drop 40%	Push Production Strategy	33.300 €	37.417 €	70.717 €	100%	✗
	Pull Production Strategy	36.640 €	0 €	36.640 €	99%	✓
Demand drop 50%	Push Production Strategy	33.300 €	40.019 €	73.319 €	100%	✗
	Pull Production Strategy	33.760 €	0 €	33.760 €	99%	✓
Demand Increase 10%	Push Production Strategy	33.300 €	28.815 €	62.115 €	100%	✓
	Pull Production Strategy	52.960 €	0 €	52.960 €	68%	✗
Demand Increase 20%	Push Production Strategy	33.300 €	26.780 €	60.080 €	100%	✓
	Pull Production Strategy	52.960 €	0 €	52.960 €	63%	✗
Demand Increase 30%	Push Production Strategy	33.300 €	23.233 €	56.533 €	96%	✓
	Pull Production Strategy	52.960 €	0 €	52.960 €	58%	✗
Demand Increase 40%	Push Production Strategy	33.300 €	21.912 €	55.212 €	89%	✓
	Pull Production Strategy	52.960 €	0 €	52.960 €	54%	✗
Demand Increase 50%	Push Production Strategy	33.300 €	18.868 €	52.168 €	83%	✓
	Pull Production Strategy	52.960 €	0 €	52.960 €	50%	✗
Demand Increase 60%	Push Production Strategy	33.300 €	19.186 €	52.486 €	78%	✓
	Pull Production Strategy	52.960 €	0 €	52.960 €	47%	✗
Demand Increase 70%	Push Production Strategy	33.300 €	17.830 €	51.130 €	74%	✓
	Pull Production Strategy	52.960 €	0 €	52.960 €	44%	✗
Demand Increase 80%	Push Production Strategy	33.300 €	16.655 €	49.955 €	70%	✓
	Pull Production Strategy	52.960 €	0 €	52.960 €	42%	✗
Demand Increase 90%	Push Production Strategy	33.300 €	15.133 €	48.433 €	66%	✓
	Pull Production Strategy	52.960 €	0 €	52.960 €	40%	✗
Demand Double	Push Production Strategy	33.300 €	14.142 €	47.442 €	63%	✓
	Pull Production Strategy	52.960 €	0 €	52.960 €	38%	✗

Table 13 - Conclusions by Demand Variation Scenarios

To the table shown above, a column was added where the most advantageous strategy was identified in each of the scenarios, through a " ✓ " highlighted by a green cell.

Thus, when analyzing the different outputs shown by table 13, it is possible to draw the following conclusions:

1. In the current scenario, the push production strategy is the one with the most advantageous results. As it can be observed, in the push production strategy, the total costs are higher by about 11.000 €, with the ordered quantities being fully satisfied, whereas, by the pull production strategy, only 75% of the ordered quantities are satisfied.

When the result obtained in the pull production scenario is extrapolated, for 100% of order satisfaction, a total cost of 70.824 € is obtained (about 6.000 € higher than the total costs of the push production strategy), which further reinforces plus the conclusion about which production strategy is the most advantageous in the current demand scenario. This conclusion is in line what was demonstrated in the literature review, where it is argued that when the level of forecast is high and close to reality, the push production strategy becomes always more advantageous. In the case of Portuguese COMPANY X and as already demonstrated, the demand forecast accuracy is 79%.

2. In scenarios where demand decrease compared to the current scenario, it is possible to verify that, as demand decreases, the holding stock costs, associated with the push production strategy, increase causing the difference in total costs between both strategies. At the same time, it is possible to see that, in the pull production strategy, the percentage of order satisfaction increases with decreasing demand. Thus, it is easily concluded that in view of these scenarios of decreased demand, the pull production strategy becomes the most advantageous.

3. Contrary to the previous point, the push production strategy is more advantageous in the case of increased demand scenarios. Even when, in scenarios where the total costs are higher than the costs obtained in the pull production strategy, it is possible to verify that in the push production strategy, the percentages of order satisfaction are always higher than those of the opposite strategy. In order to facilitate the analysis of the total costs of each production strategy, the table 14 was constructed. The table demonstrates the total costs stipulated for a 100% order satisfaction percentage, in view of the demand increase scenarios, meeting the conclusion that the push production strategy is the most

advantageous, since it presents lower total costs in terms of all scenarios, when compared to the results obtained in the pull production strategy.

Scenarios	**Production Strategy**	**Total Cost**	**Demand satisfaction (%)**	**Yes/No**
Current Scenario	Push Production Strategy	63.903 €	100%	✓
	Pull Production Strategy	70.824 €	100%	✗
Demand Increase 10%	Push Production Strategy	62.115 €	100%	✓
	Pull Production Strategy	77.476 €	100%	✗
Demand Increase 20%	Push Production Strategy	60.080 €	100%	✓
	Pull Production Strategy	84.390 €	100%	✗
Demand Increase 30%	Push Production Strategy	58.649 €	100%	✓
	Pull Production Strategy	91.462 €	100%	✗
Demand Increase 40%	Push Production Strategy	61.708 €	100%	✓
	Pull Production Strategy	98.534 €	100%	✗
Demand Increase 50%	Push Production Strategy	62.490 €	100%	✓
	Pull Production Strategy	105.606 €	100%	✗
Demand Increase 60%	Push Production Strategy	66.987 €	100%	✓
	Pull Production Strategy	112.520 €	100%	✗
Demand Increase 70%	Push Production Strategy	69.358 €	100%	✓
	Pull Production Strategy	119.592 €	100%	✗
Demand Increase 80%	Push Production Strategy	71.771 €	100%	✓
	Pull Production Strategy	126.664 €	100%	✗
Demand Increase 90%	Push Production Strategy	73.470 €	100%	✓
	Pull Production Strategy	133.736 €	100%	✗
Demand Double	Push Production Strategy	75.687 €	100%	✓
	Pull Production Strategy	140.650 €	100%	✗

Table 14 - Conclusions with satisfying extrapolated demand

Chapter V – Conclusions

5.1 Final Results Analysis

In the context of Portuguese COMPANY X's operations, the main objective of this thesis was to explore the impacts of implementing a pull production strategy on two of performance indicators, production costs and holding stock costs.

Two discrete-event simulation models were developed in Anylogic software to represent the production and stock processes of Portuguese COMPANY X to access the costs associated in each process. A typical week was assumed and were simulated. However, as the software used was a student version it was only possible simulate during an hour. In that way, all the data of one week was converted to one hour. Results about production costs and holding stock costs were obtained and various scenarios of demand were considered to explore the feasibility of push and pull production strategies.

With the results obtained, it is possible to designate the best production strategy to adopt in various demand scenarios. It was concluded that under the conditions of the current scenario of Portuguese COMPANY X (current demand based on the demand histories of 2019 and current capacities), it is more advantageous to maintain the same production strategy - push production strategy - as it is possible to see in table 13 on the first line. It is possible to conclude it, once the costs - production and holding stock costs - are lower than if a pull production strategy was implemented at the moment at Portuguese COMPANY X. This is in line with what was presented in the literature review, since once the demand forecast, at the moment, has a high level of accuracy (79%), the company does not have high holding stock costs for overproducing and at the same time is able to reduce production costs, because it produces in “mass” to satisfy its demand.

Scenarios of increasing and decreasing demand were also explored, in order to understand the different impacts that this factor will have on each of the production strategies. It is important to clarify that the only thing that changed on these scenarios was the demand, the capacities and the other input remained the same. In this aspect, it was possible to conclude by table 13 that the push production strategy is always preferable in all scenarios presented, except in those scenarios in which demand decreases more than 20% in relation to current demand. This happens because in the push production strategy the company would have high costs associated with excess stock, in addition to production costs. In scenarios where demand increases, the preference for the push production strategy is justified by the fact that the opposite strategy causes major constraints in the factory's production capacity due to the large number of stoppages.

5.2 Recommendations

It is important to emphasize that the main purpose of this thesis was to develop a model that would allow to understand the impacts on KPI's - production cost and holding stock costs - if Portuguese COMPANY X implemented a pull production strategy instead of the currently implemented strategy - push production strategy.

However, as presented in the literature review, in addition to the KPIs analyzed in these simulation models, the level of service is another important indicator when a company's performance is assessed. In this sense, it was important that, in future studies, an analysis be made to understand how this indicator would evolve under the two production scenarios and with variations in demand.

Additionally, it is important to make a more in-depth understanding of the level of inventory in the pull production strategy. As explained previously, in the stock simulation model of the pull prodution strategy it was assumed that the level of stocks was always zero, with only what was ordered being produced. However, many companies, in view of this strategy, still maintain a small amount of inventory to protect themselves from some last-minute changes or some flaws that may exist in the production process. In this sense, it would be important to understand what would be the ideal safety stock that Portuguese COMPANY X could adopt in this production strategy.

Finally, it is also important to analyze the impact that the change of production strategy has on the planning of raw materials supply, since in the study it was considered that there would be no lack of them.

5.3 Limitations

In order to understanding what future studies could do to complement this study, it is also important to understand the limitations associated with this study.

The fact that the version used in the simulation systems only runs for an hour, as it is a version for students, it was not possible to analyze certain outputs such as the total production costs, when they require more than the simulation time to be observed. In addition, it is required that all restrictions are converted to the possible analysis time.

In order to comply with the software limitations, the quantity of orders are always equal (a coffee unity), the requests of the customers are always made in the same order, there is no stock in the pull strategy on Coffee stock model, among others. In this way it was not possible to fully simulate the operations of the company until this point. Finally, the analysis time was limited to 6 days (corresponding to one hour in the simulation model), which corresponds to a normal production cycle in Portuguese COMPANY X, so only the impacts during those days were considered.

Chapter VI – References

Aggarwal, S. C. (1985). Mrp, Jit, Opt, Fms? *Harvard Business Review*, 18(1), 22–36.

Agus, A., & Hajinoor, M. S. (2012). Lean production supply chain management as driver towards enhancing product quality and business performance: Case study of manufacturing companies in Malaysia. *International Journal of Quality and Reliability Management*, 29(1), 92–121.

Alves, A.C., Dinis-Carvalho, J. and Sousa, R.M. (2012). Lean production as promoter of thinkers to achieve companies' agility. *The Learning Organization*, 19 (3), 219-237.

Anand, G., & Kodali, R. (2008). A conceptual framework for lean supply chain and its implementation. *International Journal of Value Chain Management*, 2(3), 313–357.

Arnheiter, E. D., & Maleyeff, J. (2005). The integration of lean management and Six Sigma. *The TQM Magazine*, 17(1), 5–18.

Avci, M. G., & Selim, H. (2017). A Multi-objective, simulation-based optimization framework for supply chains with premium freights. *Expert Systems with Applications*, 67, 95–106.

Ballou, R. H. (1993). *Logística empresarial: transportes, administração de materiais e distribuição física*. Atlas.

Barbosa, D. H., Musetti, M. A., & Kurumoto, J. S. (2006). Sistema de medição de desempenho e a definição de indicadores de desempenho para a área de logística. *Xiii Simpep*, 1–11.

Bechtel, C., & Jayaram, J. (1997). Supply Chain Management: A Strategic Perspective. *The International Journal of Logistics Management*, 31(4), 67-382.

Berger, S. L. T., Tortorella, G. L., & Frazzon, E. M. (2018). Simulation-based analysis of inventory strategies in lean supply chains. *IFAC-PapersOnLine*, 51(11), 1453-1458.

Bhasin, S. & Burcher, P. (2006). Lean Viewed as a Philosophy. *Journal of Manufacturing Technology Management*, 17(1), 56-72.

Bowersox, D. J., Closs, D.J., & Helferich, O. K. (1996). *Logistical management*. New York: Macmillan.

Capital, M. (2004). Introduction to lean manufacturing for Vietnam. *Published Article by Mekong Capital Ltd*.

Carson, Y., & Maria, A. (1997). Simulation optimization: methods and applications. *Proceedings of the 29th conference on Winter simulation*, 30(2),118-126.

Carvalho, J. et al. (2012). *Logística e Gestão na Cadeia de Abastecimento* (1ª Edição, 2ª Impressão). Lisboa: Edições Sílabo.

Cavinato, J. L. (1991). Identifying Interfirm Total Cost Advantages for Supply Chain Competitivenes. *International Journal of Purchasing and Materials Management*, 27(4), 10–15.

Chandra, C., & Grabis, J. (2016). *Supply chain configuration: Concepts, solutions, and applications* (2nd ed).New York: Springer.

Charan, P., Shankar, R., & Baisya, R. K. (2008). Analysis of interactions among the variables of supply chain performance measurement system implementation. *Business Process Management Journal*, 14(4),512–529.

Chen, E. J., Lee, Y. M., & Selikson, P. L. (2002). A simulation study of logistics activities in a chemical plant. *Simulation Modelling Practice and Theory*, 10(3–4), 235–245.

Childerhouse, P., & Towill, D. R.(2002). Analysis of the factors affecting real-world value stream performance. *International Journal of Production Research*, 40(15). 3499-3518.

Christopher, M. (1997). *Logística e gerenciamento da cadeia de suprimento: estratégias para redução de custos e melhoria dos serviços*. São Paulo: Pioneira.

Čiarnienė, R., & Vienažindienė, M. (2012). Lean manufacturing: theory and practice. *Economics and management*, 17(2), 726-732.

Davis, M. and Heineke, J. (2005). *Operations Management: Integrating Manufacturing and Services*. New York: McGraw-Hill.

Dooley, F. (2005). “Logistics, Inventory Control, and Supply Chain Management”, *CHOICES: A publication of the American Agricultural Economics Association*, 20 (4) 287-291.

Forza, C. (1996). Work organization in lean production and traditional plants: What are the differences? *International Journal of Operations and Production Management*, 16(2),42-62.

Frazzon, E. M., Albrecht, A., Pires, M., Israel, E., Kück, M., et al. (2018). Hybrid approach for the integrated scheduling of production and transport processes along supply chains. *International Journal of Production Research*, 56(5), 2019–2035.

Giménez Thomsen, C., & Ventura, E. (2011). Supply Chain Management as a Competitive Advantage in the Spanish Grocery Sector. *SSRN Electronic Journal*, 25(2), 25–27.

Grigoryev, I. (2012). *AnyLogic 6 in three days: a quick course in simulation modeling.* North America:Anylogic.

Han, G., Kalirajan, K., & Singh, N. (2004). Productivity, Efficiency and Economic Growth: East Asia and the Rest of the World. T*he Journal of Developing Areas*, 37(2) , 99-118.

Harrison, T. P. (2004). Principles for the strategic design of supply chains. In *The practice of Supply Chain Management: Where theory and application converge*, 3-12.

Hung, K. T., & Liker, J. K. (2007). A simulation study of pull system responsiveness considering production condition influences. *International Journal of Industrial and Systems Engineering*, 2(2), 123–136.

Inman, R.R. (1999). Are you implementing a pull system by putting the cart before the horse?. *Production & Inventory Management Journal*, 40 (2), 67-71.

Jacobs, F. Chase, R. (2013). *Operations and Supply Chain Management* (3rd edition).

Karlsson, C., & Hlström, P. (1996). Assessing changes towards lean production. *International Journal of Operations and Production Management*, 16(2), 24–41.

Kazemkhanlou, H., & Ahadi, H. (2014). Study of Performance Measurement Practices in Supply Chain Management. *International Conference on Industrial Engineering and Operations Management*, (Jan 7-9), 273–285.

Kidd, J., & Monden, Y. (1995). Toyota Production System. The Journal of the Operational Research Society, 46(5), 669.

Krafcik, J. F. (1988). Triumph of the lean production system. *Sloan Management Review*, 30, 41-52.

Lambert, D. M., Stock, J. R., & Ellram, L. M. (1998). *Fundamentals of Logistics Management*. New York: Irwin.

Lee, J., & Peccei, R. (2007). Lean production and quality commitment: A comparative study of two Korean auto firms. *Personnel Review*, 37(1), 5–25.

Lewis, M. A. (2000). Lean production and sustainable competitive advantage. *International Journal of Operations and Production Management*, 20(8), 959–978.

Li, S., Ragu-Nathan, B., Ragu-Nathan, T. S., & Subba Rao, S. (2006). The impact of supply chain management practices on competitive advantage and organizational performance. *Omega*, 34(2), 107–124.

Lin, J. T., & Chen, C. M. (2015). Simulation optimization approach for hybrid flow shop scheduling problem in semiconductor back-end manufacturing. S*imulation*

Modelling Practice and Theory, 51, 100–114.

Liu, H. C., Liu, L., & Liu, N. (2013). Risk evaluation approaches in failure mode and effects analysis: A literature review. *Expert Systems with Applications*, 40(2), 828-838.

Loyd, N. (2002). Simulation of Information System In a Lean Factory. *In Proceedings of the Huntsville Simulation Conference*. Alabama Technology Network.

Lu, L. X., & Swaminathan, J. M. (2015). *International Encyclopedia of the Social & Behavioral Sciences*. United States:lsevier.

Maher, J., & Rick, D. (2013). Gaining Control : Exploring Push & Pull Manufacturing.

Muller, M. (2003). *Essentials of Inventory Management.* New York: AMACOM.

Narasimhan, R., Swink, M. and Kim, S.W. (2006). Disentangling leanness and agility: an empirical investigation. *Journal of Operations Management*, 24 (1), 440-457.

Olhager, J. (2002). Supply chain management: A just-in-time perspective. *Production Planning and Control*, 13(8), 681–687.

Pheng, L.S. and Chuan, C.J. (2001) Just-in-time manage- ment of precast concrete components. *Journal of Construction Engineering and Management*, 127(6), 494–501.

Pheng, L.S. and Hui, M.S. (1999) The application of JIT philosophy to construction: a case study in site layout. *Construction Management and Economics*, 17 (1), 657–687.

Pinto, J. (2006). *Gestão de Operações na Indústria e nos Serviços*. Lisboa:Lidel – Edições Técnicas.

Pirard, F., Iassinovski, S., & Riane, F. (2011). A simulation based approach for supply network control. *International Journal of Production Research*, 49(24), 7205-7226.

Polat, G., & Arditi, D. (2005). The JIT materials management system in developing countries. *Construction Management and Economics*, 23(7), 697–703.

Reis, L. (2010). *Manual da Gestão de Stocks – Teoria e Prática* (3ª edição). Lisboa: Editorial Presença.

Sadraoui, T., & Mchirgui, N. (2014). Supply Chain Management Optimization within Information System Development. *International Journal of Econometrics and Financial Management*, 2(2), 59–71.

Samson, D., Sohal, A., & Ramsay, E. (1993). Human resource issues in manufacturing improvement initiatives. Case study experiences in Australia. *The International*

Journal of Human Factors in Manufacturing, 3(2), 135–152.

Sarbjit, S. (2017). Study on Push/ Pull Strategy Decision Taken by Organizations for Their Products and Services. *Universal Journal of Management*, 5(10), 492–495.

Tangen, S. (2005). Demystifying productivity and performance. *International Journal of Productivity and Performance Management*, 54(1), 34–46.

Taticchi, P., Tonelli, F., & Cagnazzo, L. (2010). Performance measurement and management: A literature review and a research agenda. *Measuring Business Excellence*, 14(1), 4–18.

Vlachos, I. (2015). Applying lean thinking in the food supply chains: a case study. *Production Planning & Control*, *26*(16), 1351-1367..

Vonderembse, M. A., Uppal, M., Huang, S. H., & Dismukes, J. P. (2006). Designing supply chains: Towards theory development. *International Journal of Production Economics*, 100(2), 223–238.

Womack, J. P., & Jones, D. T. (1997). Lean thinking—banish waste and create wealth in your corporation. *Journal of the Operational Research Society*, *48*(11), 1148-1148.

Womack,J.P.,Jones,D.T.,andRoos,D.(1990).*Themachinethatchangedtheworld:Thestory ofleanproduction*.New York:HarperPerennial.

Zheng, N., & Lu, X. (2009). Comparative study on push and pull production system based on anylogic. *Proceedings - 2009 International Conference on Electronic Commerce and Business Intelligence, ECBI 2009*, 455–458.

Zhou, H., & Benton, W. C. (2007). Supply chain practice and information sharing. *Journal of Operations Management*, 25(6), 1348–1365.

Chapter VII – Appendix

Appendix A – Demand Accuracy in Retail and Out of Home Channel in 2019

Retail Channel

Scenario	Actual	Forecast	Dmenad Accuracy %
JAN	53 512	60 295	89%
FEB	53 342	59 246	90%
MAR	48 624	68 054	71%
APR	54 617	89 845	61%
MAY	39 411	67 619	58%
JUN	44 786	60 097	75%
JUL	48 333	54 039	89%
AUG	50 786	77 858	65%
SEP	44 533	49 058	91%
OCT	57 757	57 188	101%
NOV	46 257	69 874	66%
DEC	57 535	63 227	91%
Overall Result	**599 492**	**776 399**	**79%**

Table 14 - Demand Accuracy in Retail Channel in 2019

Out of Home Channel

Scenario	Actual	Forecast	Dmenad Accuracy %
JAN	127 235	124 421	102%
FEB	122 873	135 602	91%
MAR	131 865	142 685	92%
APR	127 309	145 414	88%
MAY	138 027	160 354	86%
JUN	140 274	153 229	92%
JUL	139 059	150 220	93%
AUG	128 714	148 173	87%
SEP	140 185	140 839	100%
OCT	136 986	155 798	88%
NOV	135 533	141 609	96%
DEC	149 146	150 637	99%
Overall Result	**1 617 206**	**1 748 979**	**93%**

Table 15 - Demand Accuracy in Out of Home Channel in 2019

Appendix B- Variables on Coffee Production Model

In the model, variables were created in order to store the results of model simulation and to model some data over time:

- **Variable "c"-** This variable was created to obtain the color of the fluid that is currently in the roaster.
- **Variable "prevBatchColor"** – This variable was created to obtain the color of the fluid that was previously in the roaster. Whenever it is different from the color of the previous fluid, roasting takes more time (61.8 seconds), otherwise it takes the normal time (60 seconds).
- **Variable "TimeonFull" –** This variable was created to obtain the time that the roaster reaches its maximum capacity and starts the roasting process.
- **Variable "Time"** – This variable was created to obtain the time when the roasting process is complete.
- **Variable "Processingtime" –** This variable was created to obtain the total roasting time. It consists of the difference between the "TimeonFull" variable and the "Time" variable, since this can vary depending on whether the product to be produced is different or not from the product previously produced.
- **Variables "number" and "number1" –** These two variables count the number of units that were produced on each machine, that is, after the "fluidToAgent" block converts from kilograms to units. The "number" variable indicates the number of units produced on the "G14" machine and the "number1" variable indicates the number of units produced on the "ROVEMA" machine.
- **Variable "RelativeProcessingCost" –** This variable only indicates the fixed cost associated with the roasting process.
- **Variables "processCost" and "processCost1" –** These variables were created to define the cost of the roasting process, since it is the only cost that varies between the Push Production strategy and the Pull Production strategy. These variables multiply the "ProcessingTime" variable by the "RelativeProcessingCost" variable and by the "number" or "number1" variable, depending on the machine that is being used at that time. In that way "processCost" variable gives the roasting process cost when Product A is being produced and otherwise

“processCost1” when Product B is being produced. Whenever new quantities are produced, the new process cost of the new quantities produced is added to the current value of the variables “processCost”and “processCost1” of the previous units, once variables can store all the data over the simulation model period.

- **Variable “totalProcessCost”** – This variable adds the two process costs mentioned above, “processCost” and “processCost1”, thus this variable gives the total cost of roasting process independently if the product was produced on resource “G14” or “ROVEMA”.

Appendix C – Java code to Indicate the Resources to produce de products

The following code was used in the On Full field:

prevBatchColor = Roaster.getBatchColor(0); -> prevBatchColor indicates the color of the fluid inside the “Roaster” block;

Color1 = MixMP.getBatchColor(0); -> Color1 indicates the color of the fluid inside the “MixMP” block, which contains the mixture of green coffees necessary to produce Product A;

if(prevBatchColor == null && prevBatchColor != Color1) -> If the color present in the “Roaster” block is not null and does not match the color present in the “MixMP” block (block where is always present the mix of green coffees to produce Product A);

SelectOutputBatch.select(2); -> The fluid is directed to the second output of the “SelectOutputBatch” block in order to be forwarded to the “ROVEMA” resource, since it is Product B;

else

SelectOutputBatch.select(1); -> Otherwise, the fluid exits through the first output of the “SelectOutputBatch” block in order to be forwarded to the “G14” resource;

Appendix D – Java Code to Redirect the flow to the next Silo Block

FluidMP.select(2); -> when the “Silo1” reaches its maximum capacity, the fluid generated by the Source “ProductA” must route the fluid to the second output of the “FluidMP” block, so that it is later directed to “FluidMP1”;

FluidMP1.select(1); -> when the fluid is in “FluidMP1” it must be sent to output 1 so that it is sent to the “Silo2” block.

Appendix E – Java Code to Indicate When the Cleaning stoppage is Required

if (prevBatchColor != null && c != prevBatchColor) -> if the color is not null and is not equal to the color of the current fluid; (where "! =" means not equal and "&&" means "AND");

self.set_delayTime(x+y); -> the process takes the time needed to roast the entire quantity (x) plus the downtime to clean the roaster (y) due to the product change;

else

self.set_delayTime(x); -> otherwise, it only takes the time necessary for the roasting process (x);

Appendix F – Java Code to Measure the Roaster Time Process

On Full:

TimeonFull = Roaster.getTime(); -> the time when the roaster reaches its maximum capacity and is ready to start the roasting process;

- On Ready:

Time = Roaster.getTime(); -> The time when the roasting process is complete;

ProcessingTime = Time - TimeonFull; -> total roasting time, that is, since the process starts until it is ready;

processCost = ProcessingTime * RelativeProcessingCost * number; -> cost of roasting process for Product A.

processCost1 = ProcessingTime * RelativeProcessingCost * number1; -> cost of the roasting process for Product B.

totalProcessCost = processCost + processCost1; -> Total cost of the roasting process, that is, the roasting cost of both products is considered.

Appendix G – Variables on Coffee Stock Model

- **Variables "OC" e "OC1"** – These two variables represent the orders placed by the customers. The variable "OC" will represent the orders of the first process where we will analyze the pull production strategy and the variable "OC1" will represent the orders of the second process where we will analyze the push production strategy.
- **Variables "waitingTime1" e "waitingTime3"** – Represent the production time, if there is no stock.
- **Variables "holdingStockCost" e "holdingstockCost1"** – Represent the cost of having a unit in stock for a given period. As mentioned in the literature review, the cost of holding stock is equivalent to multiplying the stored quantity, by its respective value and also by the holding stock rate. This cost will be accounted by every day which in the model represent by every 600 seconds.

Appendix H – Java Code to Indicate the Quantaties Ordered

On at Exit:

OC=1; ou OC1 =1;-> defines that in all orders only one unit is requested as it will be explained in the assumptions chapter.

Appendix I – Java Code to Indicate the Delay Time When Production is Required

if (OC<= products) -> if the order quantity is greater than the quantity in stock (where “OC” corresponds to the order quantity and “products” corresponds to the quantity in stock);

waitingTime1 = 0; -> the waiting time is zero;

else

waitingTime1 = second()*60; -> otherwise, the waiting time is 60;

Appendix J – Java Code to add Quantaties Produced to the Stock

if (waitingTime1 > 0) -> if the waiting time is greater than zero (it menas that production was required);

products += “1”; -> therefore the quantity produced must be added to the “products” or “products1” blocks. The quantity to be produced will be always 1, once the customer order will be also always 1.

Appendix K – Java Code to Remove the Quantaties to Dispach of the Stock

products -= OC; ou products1 -= OC1

Appendix L – Diferent Demand Scenarios – Push Production Strategy

Scenarios	Kgs to produce			Units to produce			Units produced			% of Production	Production Cost
	Product A	Product B	Total	Product A	Product B	Total	Product A	Product B	Total		
Current Scenario	438	198	636	365	83	448	459	102	561	125%	33.300 €
Demand drop 10%	394	178	572	329	74	403	459	102	561	139%	33.300 €
Demand drop 20%	350	158	508	292	66	358	459	102	561	157%	33.300 €
Demand drop 30%	307	139	446	256	58	314	459	102	561	179%	33.300 €
Demand drop 40%	263	119	382	219	50	269	459	102	561	209%	33.300 €
Demand drop 50%	219	99	318	183	41	224	459	102	561	250%	33.300 €
Demand increase 10%	482	218	700	402	91	493	459	102	561	114%	33.300 €
Demand increase 20%	526	238	764	438	99	537	459	102	561	104%	33.300 €
Demand increase 30%	569	257	826	475	107	582	459	102	561	96%	33.300 €
Demand increase 40%	613	277	890	511	116	627	459	102	561	89%	33.300 €
Demand increase 50%	657	297	954	548	124	672	459	102	561	83%	33.300 €
Demand increase 60%	701	317	1018	584	132	716	459	102	561	78%	33.300 €
Demand increase 70%	745	337	1082	621	140	761	459	102	561	74%	33.300 €
Demand increase 80%	788	356	1144	657	149	806	459	102	561	70%	33.300 €
Demand increase 90%	832	376	1208	694	157	851	459	102	561	66%	33.300 €
Demand Double	876	396	1272	730	165	895	459	102	561	63%	33.300 €

Table 16 - Diferent Demand Scenarios – Push Production Strategy

Appendix M – Java Code to Change the Type of Product to be Produced on Pull Production Strategy

fluidRoaster.toggle(); -> causes the alternation of the input channel of the fluidRoaster;

Appendix N – Diferent Demand Scenarios – Pull Production Strategy

Scenarios	Kgs to produce			Units to produce			Units produced			% of Production	Production Cost
	Product A	**Product B**	**Total**	**Product A**	**Product B**	**Total**	**Product A**	**Product B**	**Total**		
Current Scenario	438	198	636	365	83	448	253	82	335	75%	52.960 €
Demand drop 10%	394	178	572	329	74	403	302	73	375	93%	44.260 €
Demand drop 20%	350	158	508	292	66	358	290	65	355	99%	38.560 €
Demand drop 30%	307	139	446	256	58	314	254	57	311	99%	37.600 €
Demand drop 40%	263	119	382	219	50	269	217	49	266	99%	36.640 €
Demand drop 50%	219	99	318	183	41	224	182	40	222	99%	33.760 €
Demand increase 10%	482	218	700	402	91	493	253	84	337	68%	52.960 €
Demand increase 20%	526	238	764	438	99	537	253	84	337	63%	52.960 €
Demand increase 30%	569	257	826	475	107	582	253	84	337	58%	52.960 €
Demand increase 40%	613	277	890	511	116	627	253	84	337	54%	52.960 €
Demand increase 50%	657	297	954	548	124	672	253	84	337	50%	52.960 €
Demand increase 60%	701	317	1018	584	132	716	253	84	337	47%	52.960 €
Demand increase 70%	745	337	1082	621	140	761	253	84	337	44%	52.960 €
Demand increase 80%	788	356	1144	657	149	806	253	84	337	42%	52.960 €
Demand increase 90%	832	376	1208	694	157	851	253	84	337	40%	52.960 €
Demand Double	876	396	1272	730	165	895	253	84	337	38%	52.960 €

Table 17 - Diferent Demand Scenarios – Pull Production Strategy