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Analysis of Causes of the Bullwhip Effect: A Cork-stopper Industry case study

Dissertation in the context of the Master in Industrial Engineering and Management advised by Professor Luís Miguel Domingues Fernandes Ferreira and presented to the Department of Mechanical Engineering of the Faculty of Sciences and Technology of the University of Coimbra.

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Analysis of Causes of the Bullwhip Effect: A Cork-stopper Industry case study

Dissertation submitted for the degree of Master of Industrial Engineering and Management.

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“Above all don’t fear difficult moments. The best comes from them.”

Rita Leví Montalcíni

To my parents and brother.

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The conclusion of this chapter is only possible thanks to individuals to whom I could not fail to express my gratitude and leave unmentioned.

I want to take this opportunity to wholeheartedly thank my parents and brother for all the comfort, understanding and sacrifices made over the past five years. They have been instrumental in shaping me and guiding me to where I am now. Without them, I am confident that this path would have been significantly more challenging. Furthermore, I am grateful for the unconditional support my cousin, aunt and uncle have provided me during this time. Above all, I thank all my family for their love, patience, and belief in me.

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RESUMO

O efeito chicote é um fenómeno estudado extensivamente na literatura. Este demonstrou ter impactos prejudiciais no desempenho da cadeia de abastecimento, e diversas abordagens à sua mitigação foram propostas desde que foi introduzido pela primeira vez por Jay Forrester. A presente dissertação quantifica este fenómeno e estuda as suas causas na indústria de rolhas de cortiça. O principal objetivo é promover um melhor entendimento do efeito chicote num contexto industrial e prover a empresa com informações relativamente a este problema. São conduzidas entrevistas em dois momentos diferentes. O primeiro para diagnosticar os principais desafios à gestão eficiente da cadeia de abastecimento. O segundo para analisar detalhadamente os resultados das análises quantitativas desempenhadas. Dados de vendas ao cliente final e de encomendas de 2021 e 2022 são recolhidos para quantificar o efeito chicote. Com estas análises tornou-se evidente o efeito chicote sentido pela empresa. Isso implicou que constante pressão tenha vindo a ser exercida na capacidade produtiva do fabricante. Os principais impulsionadores deste fenómeno são a política de faturação da empresa, as políticas de inventário das *sales companies*, as tendências em sobrestimar vendas, e outros fatores como o câmbio de moedas e a falta de comprometimento em enviar os *rolling forecasts*. Sendo o efeito chicote um fenómeno inevitável, algumas sugestões são propostas com o intuito de reduzir o seu impacto. Algumas incluem a revisão da política de faturação da empresa, o reforço da comunicação com as *sales companies*, e o desenvolvimento de *dashboards* para monitorizar os principais indicadores-chave de desempenho da cadeia de abastecimento.

Palavras-chave Desempenho da cadeia de abastecimento, Efeito chicote, Causas, Abordagens à mitigação, Indústria da manufatura de rolhas de cortiça.

ABSTRACT

The bullwhip effect (BWE) is an extensively studied phenomenon in the literature. Having detrimental impacts on the supply chain's performance, several mitigation approaches have been suggested since it was first introduced by Jay Forrester. The present dissertation measures this phenomenon and studies its causes in the cork-stopper manufacturing industry. Its primary intent is to provide a further understanding of the BWE in a real-life setting and contribute to the company with insights regarding this issue. Interviews are conducted in two different instances. The first is to diagnose the main challenges to effective supply chain management. The second is to further analyze the insights extracted from the quantitative analysis conducted. Data of the final client's sales and of orders for 2021 and 2022 are collected to measure the BWE. Through these analyses, it was evident the BWE felt at the manufacturer level. This meant that almost constant pressure was put on the factory's production capacity. Its main causes lie in the company's billing policy, the *sales companies'* inventory policy, tendencies to overestimate sales, and other factors such as currency exchange and lack of commitment to provide rolling forecasts. With the BWE being an unavoidable phenomenon, suggestions are proposed to reduce its impacts. Some include revising the company's billing policy, reinforcing communication with the *sales companies*, and developing dashboards to monitor the main key performance indicators (KPI) of the supply chain.

Keywords Supply chain performance, Bullwhip effect, Causes, Mitigation approaches, Cork-stopper manufacturing industry.

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SYMBOLOGY AND ABBREVIATIONS

Symbology

σ - Standard deviation

μ - Population mean

Abbreviation

ABE – Alternative bullwhip effect

AC – Amorim Cork, S.A.

BWE – Bullwhip effect

BEM – Bullwhip effect measure

EDI – Electronic data interchange

EDLP – Every day low prices

e-POS – Electronic point of sale

IU – Industrial units

MAE – Mean absolute error

MAPE – Mean absolute percentage error

MASE – Mean absolute scaled error

MdAPE – Median absolute percentage error

MSE – Mean square error

NN – Neural networks

R&D – Research & Development

RF – Rolling forecast

RMdSPE – Median percentage error of the quadratic

RMSE – Root mean square error

RMSSE – Root mean square error

RMSPE – Root mean square percentage error

RP – Rolling plan

SC – Supply chain

SCM – Supply chain management

VMI – Vendor managed inventory

1. INTRODUCTION

The present study falls within the scope of the dissertation to obtain a Master's degree in Industrial Engineering and Management from the Faculty of Sciences and Technology of the University of Coimbra. The development of this project took place at Amorim Cork, S.A., particularly at its headquarters in the supply chain department, from now on referenced as Amorim Cork (AC).

In the current industrial environment, companies feel an ever-growing pressure to meet final clients' demands and ensure their competitive advantage. Supply chain operations are crucial to support the company's proposition and guarantee the maximization of the value created for the customer. Comprising the supply of raw materials, the manufacturing process, the packaging, and the distribution of products to the final client; supply chain management is of utmost importance to ensure that material and information flows are coordinated effectively. Otherwise, there is a possibility of changes in demand being amplified upstream, yielding a phenomenon known as the bullwhip effect (BWE) (Harrison et al., 2019).

The BWE is witnessed when there is an amplification of the variability of the demand upstream of the supply chain. This effect can stem from a lack of communication, disorganization, order batching, price variation, demand information, and free return policies (Khan and Yu, 2019). This distortion of information can cause substantial inefficiencies such as excessive inventory and lost revenues (Lee, Padmanabhan, and Whang, 1997b), due to inadequate forecasts and production scheduling. Thus, to guarantee the optimization of the company's performance, it is vital to decrease the BWE. The literature offers extensive research on this topic, including methods to measure it, potential causes, and possible ways of mitigating it and weakening its effects.

Through the quantification and analysis of the BWE and the evaluation of the forecast accuracy, this dissertation addresses this phenomenon and studies it in the cork-stopper industry, focusing on the BWE at the manufacturer level. Furthermore, it aims at identifying the impacts this phenomenon has on the management of the supply chain and, subsequently, suggest ways of reducing it, as these constitute an impediment to the efficient use of the available resources and maximization of the company's profit. This problem comes to light as the need for a clear vision of the supply chain demand increases due to the necessity of allocating resources efficiently in a business environment such as the one studied.

The dissertation is structured into six chapters. The first chapter - the introduction – exposes the practical relevance of the topic, along with the objectives and structure of the thesis. The second chapter provides the theoretical framework necessary for the understanding and development of this project. The third chapter introduces both the company and the Supply Chain Department. The fourth chapter addresses the methodology followed during this research. The fifth chapter discloses the results of this research, along with a discussion of the findings. The sixth and final chapter presents the concluding remarks.

2. THEORETICAL FRAMEWORK

The main objective of this work is to discuss and analyze a recurring problem in today's industrial environment – the bullwhip effect - which is a commonly discussed topic in the literature with extensive work done ever since Jay Forrester first introduced it in 1961. However, measuring methods and metrics are various, and solutions are diverse and, in a sense, *ad hoc* (Chen et al., 2000; Fransoo and Wouters, 2000; Yao, Duan, and Huo, 2021). Thus, studying these phenomena is not a standardized process, and should be adapted for different circumstances. Solutions to this problem tend to focus on sharing information and improving visibility throughout the supply chain.

Logistics and supply chain management will be introduced first, followed by the variability and its impacts along the supply chain, alongside the BWE. Furthermore, forecasting accuracy is mentioned considering its analysis during the development of this project.

2.1. Logistics and Supply Chain Management

In today's business environment, businesses do not compete as solo entities. Instead, they strive for cooperation between the different stages of the supply chain to gain a competitive advantage and prosper in the current competitive environment (Lambert, Cooper, and Pagh, 1998). It is increasingly important to have a more holistic vision of one's business and the role one plays in it. Nowadays, companies do not solely focus on themselves and their strengths, but on their partners and their supply chain weaknesses. This shift in focus allows them to target the factors that will improve the service provided. This integration of processes from supplier to end customer to add value to the key stakeholders is designated supply chain management (SCM).

The term "supply chain management" was first introduced by Keith Olivier in 1982 and started to gain currency in the mid-1990s. The Council of Supply Chain Management Professionals (CSCMP) describes supply chain management as "the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities", requiring "coordination and collaboration with channel partners”. Essentially, SCM comprehends supply and demand management within and across all companies of a supply chain. Thus, it is an extension of the logic of logistics.

Similar to SCM, logistics involves the management of procurement, movement, and storage of materials, sub-finished, and finished inventory, intending to minimize costs and maximize value for the customer (Christopher, 2016). According to the 7 *Right* conceptions of logistics, it is the process of delivering the *right* quantity of the *right* product, at the *right* price, in the *right* conditions, to the *right* place, at the *right* time, to the *right* customer. Herewith, logistics comprises managing material and information flow. These are also crucial tasks of supply chain management.

Harrison et al. (2019) suggest that material flow management aims at sustaining a continuous flow from end to end of the supply chain (from source to the end customer), meaning a flow with no interruptions or unnecessary stocks, which delivers on time what is needed. The author defends the importance of managing the information flow since the whole supply chain moves along with the demand signals sent by the customer. Therefore, it is essential to communicate this information to all supply chain members to guarantee the efficiency of the supply chain and the creation of value for the final customer. Technology has proved extremely useful, making this process easier and faster. This communication should also occur to give all parties an accurate picture of the business and avoid phenomena such as the bullwhip effect.

To a large extent, the main objective of supply chain management is to improve SC’s performance. Davis (2020) advocates that to do so, it is imperative to understand the current situation which comes as a result of (1) benchmarking the current performance through metrics such as inventory and order fill rate, (2) controlling uncertainty and (3) planning changes that will possibly improve performance. Currently, variability is a significant factor in SCM, and managers focus their efforts on finding ways of reducing its impacts on the SC’s performance.

2.1.1. The Importance of Measuring Performance

Supply chain costs constitute a large share of business costs. Therefore, to guarantee the maximization of the firm's profit, SC managers should focus on this aspect. To do so it is essential to analyze the performance of the supply chain and identify opportunities for improvement. Tien, Anh, and Thuc (2019) argue that measuring and controlling the supply chain performance correctly allows for an improvement of cash flow and return on assets. Table 1 presents the motivations for performance measurement, identified by Gunasekaran and Kobu (2007). Regardless of its advantages and the extensive research on this subject, this prevails as one of the biggest challenges SCM faces.

Table 1 - Motivations for performance measurement according to Gunasekaran and Kobu (2007)

Motivations of performance measurement
Identifying success
Identifying if customer needs are met
A better understanding of processes
Identifying bottlenecks, waste, problems, and improvement opportunities
Providing factual decisions
Enabling progress
Tracking progress
Facilitating more open and transparent communication and co-operation

Through the analysis of objective information about product sales, market share, costs, inventory, and customer service, it is possible to have a perception of the supply chain's performance. Akyuz and Erkan (2010) found the balanced scorecard methodology and the SCOR model, created by the Supply Chain Council, as the foundations of today's performance management systems. Currently, methods such as the balanced scorecard are combined with recent developments to create updated versions of those methodologies. For instance, Frederico et al. (2020) proposed a performance measurement framework based on the balanced scorecard for supply chains in the Industry 4.0 era. This Supply Chain 4.0. Scorecard combined the perspectives of the balanced scorecard with the supply chain dimensions in Industry 4.0, to provide measurement approaches for the supply chain in the current industrial environment. Some of these measurement approaches include the processes' efficiency, the level of flexibility, and the level and extension of process integration (Frederico *et al.*, 2020).

Additionally, as Davis (2020) suggests, benchmarking analysis is also an effective tool for evaluating SC performance. Benchmarking is the process of measuring processes against those of other relevant firms. This tool provides insights into what factors contribute to the difference in performance between these organizations. Hence, it is possible to identify which areas are susceptible to improvement. Furthermore, it is a powerful tool for breaking down reluctance to change from senior managers through insights into the outside world (Khan and Yu, 2019). Moreover, as recent research supports, the bullwhip effect measure can be used to evaluate supply chain performance (Yuan, Zhang, and Zhang, 2020), given its implications in indicators such as supply chain costs and service level.

2.1.1. Barriers to Effective Supply Chain Management

Along with measuring performance, it is indispensable to identify which challenges the supply chain faces, understand them, and find ways to overcome them. Research conducted by Fawcett, Magnan, and McCarter (2008) determined the top ten benefits, barriers, and bridges to effective supply chain management, and ranked them. Table 2 shows the ranking of barriers to effective SCM identified by this research.

Table 2 - Barriers to Effective SCM (adapted from Fawcett, Magnan, and McCarter (2008))

Rank	Barriers to Effective SCM
1	Inadequate information systems
2	Lack of clear alliance guidelines
3	Inconsistent operating goals
4	Lack of shared risks and rewards
5	Processes poorly costed
6	Non-aligned measures
7	Lack of willingness to share information
8	Organizational boundaries
9	Measuring SC contribution
10	Measuring customer demands

Furthermore, to Tien, Anh, and Thuc (2019), the current biggest threats to an effective supply chain are human resistance to change, the scale of investment, lack of trust, and poor communication. Due to some firms' questionable business practices, and subsequent lower levels of trust, it is significantly harder to establish collaborative relationships with partners across the supply chain. In some instances, it requires relinquishing control, which can be difficult for supply chain managers as they will feel at the mercy of other companies and individuals. Furthermore, each partner has a particular objective, given that they face different markets and competitive situations. Thus, to achieve an integrated SC, it is crucial to understand each partner's perspective and goals and share information between each stage of the supply chain (Chen et al., 1999). Researchers, such as Jeong and Hong (2019), have focused on studying the components of information sharing along the supply chain to further understand how it impacts phenomena such as the propagation of the bullwhip effect. A more common challenge in literature is the lack of adequate information systems that inhibit the continuous flow of relevant information. Currently, it is more important than ever to invest in information systems that support the required level of integration of the supply chain.

2.2. Variability along the Supply Chain

Variability is a term used to describe the volatility or level of inconsistency in the flow of materials from one end of the supply chain to the other. Statistically, it is the amount of data points in a statistical distribution that differ from each other and their mean value.

Operations Management has long recognized the damaging effects of variability in the supply chain. Harrison et al. (2019) consider that controlling variability in logistics processes and dealing with uncertainty creates a logistic advantage, which manifests itself through competitive factors such as product availability in the marketplace. Furthermore, due to variability's detrimental impacts on a company's performance, and potential amplification across the supply chain, it is pivotal to analyze and control it (Germain, Claycomb, and Droge, 2008). It is unanimous in the literature the costs that variability engenders (Balakrishnan, Geunes, and Pangburn, 2004; Germain, Claycomb, and Droge, 2008), which further supports the premise that this phenomenon impacts a firm's performance negatively. These costs are associated with overtime hours, excess or insufficient inventory, premium freight, and others.

A common way of dealing with variability is inventory, specifically buffer or safety stocks. Safety stocks are a permanent layer of stock used as a way of protecting the company from unusual peaks in demand (Tien, Anh, and Thuc, 2019). These inventories are a function of both the [leadtime, and demand] variability, registered at the echelon where they are situated, and the service level the supply chain aims to offer. There are several ways of calculating these buffers, and the literature grants extensive research on this matter (Becker et al., 2013; King, 2011; Radasanu, 2016).

The transmission of this variability upstream of the supply chain is named upstream variability propagation, and Balakrishnan, Geunes, and Pangburn (2004) reveal how to dampen this effect by order smoothing policies. However, the amplification of variability as one moves up the supply chain has worse repercussions and is referred to in the literature as the bullwhip effect.

2.2.1. The Bullwhip Effect

This phenomenon was first introduced by Jay Forrester as the Forrester effect and later renamed as the bullwhip effect. As mentioned above, the BWE is the amplification of variability as one moves up the supply chain. It occurs as forecasts and orders move from the retailer to the manufacturer, as illustrated in Figure 1. This phenomenon constitutes one of the biggest challenges faced by supply chain managers since it makes it challenging for managers to understand real market needs. It is imperative to find the root causes of this effect and discover ways of minimizing its impacts, given that the greater the variability the more expensive it is to run the supply chain. Over the decades, many researchers have worked toward the development of these mechanisms (Ernawati et al., 2021; Fransoo and Wouters, 2000; Fu et al., 2015; Tien, Anh, and Thuc 2019; Moyaux, Chaib-Draa, and D’Amours, 2007).

Variability can originate in production problems, demand variability, and others. Subsequently, this variability culminates in quality issues, delivery issues, forecasting issues, and demand issues (Tien, Anh, and Thuc, 2019). All result in poorer delivered service and a decrease in SC performance. With the amplification of variability, entities in the supply chain tend to stockpile in anticipation of fluctuations in demand and to protect themselves from stock-out periods, leading to a rise in inventory costs.

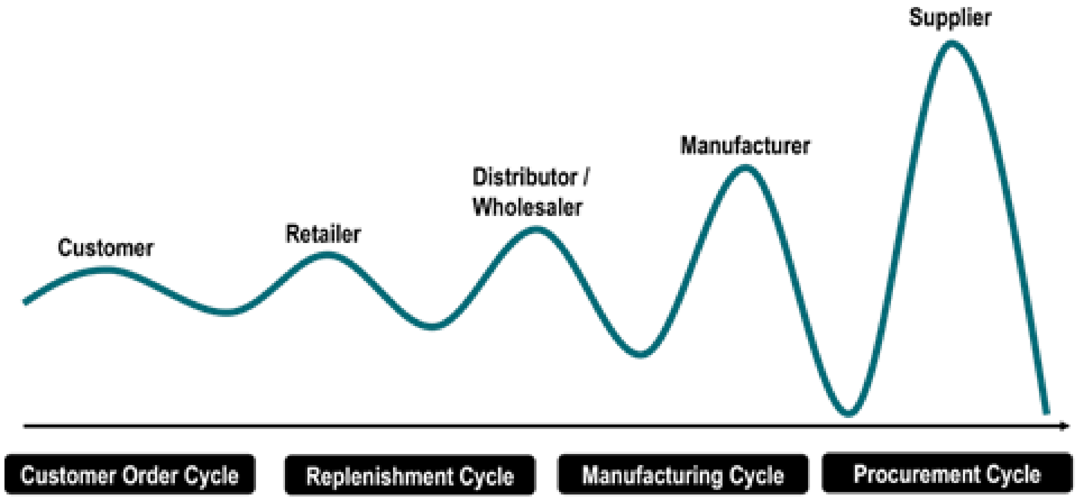

Figure 1 - The Bullwhip effect (adapted from The Bullwhip effect on Supply Chains | The Geography of Transport Systems, 2022)

2.2.1.1. Causes of the Bullwhip effect

Authors identify order batching, lead time, price fluctuation, demand information, and lack of communication as the primal causes of the bullwhip effect (Chen et al., 1999; Fransoo and Wouters, 2000; Khan and Yu, 2019; Tien, Anh, and Thuc, 2019). However, other causes such as demand forecasting techniques and inventory/replenishment policies are studied and conclusions are drawn regarding their implications on the BWE (Jakšič and Rusjan, 2008).

Order batching occurs due to factors such as economic order quantity, the need to reduce transportation costs, and periodic inventory reviews. As proven through the work of Hussain and Drake (2011) and Ponte, Dominguez, and Cannella (2021), it often contributes to the BWE, imperiling the performance of the supply chain. Hussain and Drake (2011) further found a non-linear relationship between the batch size and demand amplification if the batch size is lower than the average demand. Otherwise, the BWE increases rapidly and linearly.

Research conducted by Kelepouris, Miliotis, and Pramatari (2008) proved that short lead times are crucial for efficient supply chain operations. Wang et al. (2008) investigated the impact of lead times on the BWE under an order-up-to replenishment policy and found a correlation to the order rate. The longer the lead time the more oscillations are to the order rate. Furthermore, the same practitioners proved that reducing the lead time can reduce the risk of stockouts and smooth inventory levels. To refute the premise that a reduction in lead time will always lead to a lower BWE value, a recent study by Gaalman, Disney, and Wang (2019) proved that this assumption may be accurate depending on the demand process.

Price fluctuation is one of the primary causes of the BWE. There are several motives behind price fluctuations. For instance, when there are special discount offers and promotion activities (Khan and Yu, 2019). When these take place, consumers buy more than necessary and accumulate stock. Hence, it causes distortions in buying patterns, with periods of increased sales followed by intervals of minimal sales.

The lack of communication and information distortion is heavily addressed in the literature when discussing the BWE. Rahman, Rahman, and Talapatra (2020) found that as the size of the supply chain, and the number of echelons, increases, the reliability of the information flow tends to decline. Improper communication and lack of demand visibility among supply chain partners lead managers to perceive demand differently as it moves from retailers to manufacturers. This is detrimental to the supply chain performance and can be minimized through mechanisms of shared information. Moreover, Kelepouris, Miliotis, and Pramatari (2008) support the premise that information sharing can significantly reduce order oscillations and inventory levels in the upper nodes of the supply chain.

Inventory policies define what factors are considered and at what point in time an inventory replenishment decision should be made, as well as what quantity to order. Jakšič and Rusjan (2008) studied how different replenishment models affected the BWE and their correlation to the demand pattern. These researchers support that some replenishment policies can in themselves induce the BWE, identifying the order-up-to policy as one. This had been previously found in a different study carried out by Dejonckheere et al. (2003). Others were proven to have the opposite behavior, not generating a BWE regardless of the demand pattern (Jakšič and Rusjan, 2008). One of these policies is a simple exponential smoothing equation where order quantity follows demand forecasts of the following period. Furthermore, several practitioners have focused on the impacts of demand forecasting techniques on this phenomenon with Chen et al. (1999) having proved the negative impact of demand forecasting on the BWE and having presented techniques to reduce it. This will be addressed later in section 2.2.1.2.

Maaz and Ahmad (2016) ranked the operational causes of the BWE introduced by the literature using the analytical hierarchy process (AHP). This ranking was determined by the perceptions of the enquired SC managers. The results are in Table 3.

Table 3 Ranking of operational causes of the bullwhip effect (adapted from Maaz and Ahmad (2016))

Rank	Factors	Priority (%)
1	Order batching	29.98
2	Demand signal processing	25.38
3	Lead time	16.58
4	Inventory policy	14.93
5	Price fluctuation	5.58
6	Lack of trust	4.27
7	Number of echelons	4

Although classic studies have focused on the operational perspective, others have shown that human factors, both psychological and behavioral, may lead to the BWE. A review conducted by Yang et al. (2021) has shown that over the last decades, there is an increasing number of researchers who are devoting their attention to studying the impacts of human factors on the BWE. Research conducted by Nienhaus, Ziegenbein, and Schoensleben (2006b) proved that human behavior contributes to the amplification of variability along the supply chain with two types of extreme behavior; (1) 'safe harbor' where humans order more than necessary accumulating more safety stock, and (2) 'panic' which subsists of the use of the whole stock until an increase in customer demand, resulting in stock-outs. Furthermore, this investigation recognized humans as obstacles to information flow in supply chains. These behaviors were further supported by an experiment by Maaz, Ahmed, and Hussain (2019). In addition, the same practitioners found that an individual's personality affects his performance in the supply chain concerning inventory management.

2.2.1.2. Methods to Measure the Bullwhip Effect

As previously mentioned, performance measurement is indispensable to identify areas for improvement. One of the ways in which this performance can be affected negatively is through the bullwhip effect. Therefore, it is relevant to measure the BWE felt at each echelon, identify its main causes, and determine ways to minimize it.

According to Fransoo and Wouters (2000), there can be four levels of aggregation when quantifying the BWE. Assuming P products and M outlets, these levels are shown in Table 4.

Table 4 - Levels of data aggregation for the calculation of the bullwhip effect (adapted from Fransoo and Wouters (2000)

Level of aggregation		**Number of bullwhip effect measurements (BEM)**
Product/outlet	No aggregation of data - provides a more detailed analysis	P x M
Product	Aggregation of product demand over all outlets – indicates the variability of a certain product at an entire echelon	P
Outlet	Aggregation of the demand at a certain outlet over all products – indicates the variability of a certain outlet	M
Echelon	Aggregation of all products' demand at all outlets – indicates the variability at a single echelon	One

Chen and Lee (2017), Fransoo and Wouters (2000), and Parra Peña, Mula, and Campuzano-Bolarín (2012), calculate the BWE at a particular echelon as the quotient of the coefficient of variation of orders by that echelon and the coefficient of variation of actual demand (equation (1)).

$$BWE = \frac{\frac{\sigma_{orders}}{\mu_{orders}}}{\frac{\sigma_{demand}}{\mu_{demand}}} = \frac{cv_{orders}}{cv_{demand}} \quad (1)$$

Where the *BWE* is the value of the bullwhip effect generated at a given echelon, σ is the standard deviation of the orders/demand, and μ is the average of the orders/demand.

Additionally, if the terms of the inequation (2) are met, it is possible to conclude that the company has a BWE.

$$\frac{cv_{orders}}{cv_{demand}} \geq 1 + \frac{2L}{p} + \frac{2\,L^2}{p^2} \tag{2}$$

Where L is the lead time, and p is the number of periods considered.

Parra Peña, Mula and Campuzano-Bolarín (2012) adapted the calculation of the BWE to spreadsheet use to facilitate the quantification of this phenomenon. The researchers proposed a transformation of the general variance formula (Equation (3)).

$$Var(x) = \frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1} \tag{3}$$

Where x_i is a vector of *n* elements that represents the orders, with the first n-1 elements equal to zero and the *n*-th term is the value of orders to the t period, and $\bar{x}$ is the average of the orders.

Given that the vector of orders is composed of n-1 terms equal to zero, the variance calculus implies a sum of the n-1 identical terms and the *n*-th term. Thus, the equation of the general variance is transformed into equations (4) and (5).

$$Var(x) = \frac{(\sum_{i=1}^{n}(x_i - \bar{x})^2) + (x_n - \bar{x})^2}{n-1} \tag{4}$$

$$Var(x) = \frac{(n-1)(-\bar{x})^2 + (x_n - \bar{x})^2}{n-1} \tag{5}$$

According to the previous assumption, the order average $\bar{x}$ can be calculated as the orders received in the *n* periods x_n, divided by *n,* resulting in equation (6).

$$Var(x) = \frac{(n-1)(-\frac{x_n}{n})^2 + (x_n - \frac{x_n}{n})^2}{n-1} \tag{6}$$

Subsequently, the bullwhip effect measure ($\mathrm{BEM_t}$) is calculated as a cumulative expression of the effect of individual distortions, as seen in the following equation.

$$BEM_t = \begin{cases} BEM_{t-1} \; if \; orders_t - sales_t = 0 \\ BEM_{t-1} + \frac{Var\,(Orders)}{Var(Sales)} \; other\ wise \end{cases} \tag{7}$$

An alternative metric was introduced by Disney et al. (2006) as NSAmp (Net stock amplification), and later labelled Alternative Bullwhip effect (ABE) by Ponte et al. (2015); which considers the coefficient of variation of the net stock. Hereby, oscillations in stock are considered, which is particularly important in firms that have stockouts followed by periods of excess inventory. It is represented through equation (8).

$$ABE = \frac{cv_{NS}}{cv_D} \tag{8}$$

Where cv_{NS} is the coefficient of variation of the net stock and cv_D the coefficient of variation of demand.

2.2.1.3. Strategies to Manage the Bullwhip Effect

As previously mentioned, the literature offers several strategies to minimize the effects of the bullwhip effect in the supply chain. Some include reducing uncertainty, variability, and lead time, strategic partnerships, everyday low pricing (EDLP), and demand signaling.

Chen et al. (1999) found that demand forecasting has a detrimental effect on the BWE and that smoother demand forecasts can reduce it. Any forecasting method that updates the mean and standard deviation of demand at each period will result in the BWE. It is relevant to mention the impact of the forecasting technique used to predict demand, as Chen et al. (1999) revealed that simple exponential smoothing augments variability more than the simple moving average. Furthermore, Wright and Yuan (2008) found that the BWE can be reduced by up to 55% by choosing an appropriate forecasting method and ordering policy. Researchers also suggest that when in the presence of long lead times more demand data must be used to generate forecasts.

However, solely employing more suitable forecasting techniques is not sufficient. Implementing shared communication systems is imperative to enable the manufacturer's awareness of the actual market demand, in real-time. Moyaux, Chaib-Draa, and D'Amours (2007) demonstrated how information sharing grants the supplier a perception of market changes and adjustments to orders triggered by these changes. This visibility helps reduce the BWE. A few systems of shared information include Electronic Data Interchange (EDI), Electronic Point of Sale (e-POS), or Vendor Managed Inventory (VMI). Disney and Towill (2003), later supported by Ernawati et al. (2021), proved that using the VMI system reduces the BWE at each echelon of the supply chain, revealing the impact a system of this nature can have.

Tien, Anh, and Thuc (2019) mention two other strategies crucial in managing the BWE; (1) defining a fixed quantity per year and specifying ordering quantities, and (2) negotiating prices upfront to stabilize the supply chain. Together with the first suggestion, Hussain and Drake (2011) advise managers to monitor trends in average demand to foresee periods of greater output variance and adjust the batch size accordingly to avoid such phenomena. Additionally, Ponte, Dominguez, and Cannella (2021) suggest that to mitigate the BWE generated by order batching, managers can stipulate batch sizes that are a divisor of the mean production rate. Going hand in hand with the latter, an EDLP strategy can reduce variability and stabilize customer demand, given that a consistent price leads to periodic ordering.

A recent review conducted by Rafati (2022), compiled all initiatives suggested in the literature to manage the BWE, shown in Table 5.

Table 5 Initiatives to manage the bullwhip effect (adapted from Rafati (2022))

Causes of the BWE	Information Sharing	Channel Alignment	Operational Efficiency
Demand forecast method and procedures	Use metaverse Use point of Sale (POS) data Electronic data exchange Internet and Intranet Computer-aided ordering Enterprise resource planning (ERP)	Vendor managed inventory (VMI) Information sharing Directed communication with consumers	Lead time reduction Echelon-based inventory control
Order batching	Electronic data exchange Internet ordering	More collaboration on logistics systems Demand consolidation	Fix cost reduction in the ordering system Computer-assisted ordering
Price variations		Continuous forecast	Every day low pricing

2.3. The Impact of Forecasting Methods on the Bullwhip Effect

As mentioned in section 2.2.1.2, the forecasting technique used to predict demand has repercussions on the bullwhip effect generated (Chen et al., 2000; Chen et al., 1999). However, contrary to certain convictions, the BWE exists even when different supply chain stages use the same forecasting method and inventory policy and share demand information.

Every method that updates the mean and variance of demand, periodically, will amplify the variability upstream (Chen et al., 2000). A model developed by Kim and Ryan (2003) led to the conclusion that forecasting updating by the retailer results in increased variability for the manufacturer. Furthermore, it will yield higher inventory costs for the manufacturer. Such an outcome can be avoided through customer demand data sharing. A study carried out by Wright and Yuan (2008) demonstrated that Holt's and Brown's forecasting techniques can significantly reduce the BWE. However, to achieve considerable results these should be combined with an appropriate ordering policy.

To make it possible to further reduce the impacts of forecasting on the BWE, forecasts should be more accurate. As a result, there has been a transition to research in the

Artificial Intelligence field and work toward applying machine learning (ML) to forecasting methods, specifically Neural Networks (NN) (Benboubker, Kissani, and Mourhir, 2019). Practitioners have also developed hybrid models, where features from statistical methods and ML methods appear combined, with the intent to benefit from the advantages of both (Benhamida et al., 2021). However, more sophisticated techniques do not always mean more accurate forecasts. Benboubker, Kissani, and Mourhir (2019) conducted a study comparing the accuracy of traditional models against Neural Networks, given that the latter claims to provide more rigorous results. After applying these models to data on weekly sales, this research concluded that the NN method offered more accurate results. However, Benhamida et al. (2021) suggest that ML methods perform poorly and do not provide more precise results than statistical methods, as shown in large-scale comparative studies. According to Cerqueira, Torgo, and Soares (2019), the volume of the data is a crucial factor when comparing these two types of models, and companies should consider this when choosing a method to forecast their sales.

2.3.1. Methods to Measure the Forecast Error

Due to the impact that forecasting has on the bullwhip effect, it is clear the influence it has on a firm's performance. Taking this into consideration, it is important to measure the forecast error and find ways of reducing this error. Additionally, the analysis of this data enables the detection of patterns and relations of causality.

There are numerous methods to calculate forecast accuracy. However, not every method is suitable for every situation. In a review carried out by Shcherbakov et al. (2013), all formulas were presented with their respective drawbacks. These were categorized into 7 groups: absolute forecasting errors, percentage-based measures, symmetric errors, relative errors, scaled errors, relative measures, and other error measures. The most widely used measures are absolute forecasting errors and percentage-based measures. However, scaled errors can be extremely useful when comparing the forecast accuracy of products with different scales of sales and actual demand values equal to zero.

Absolute Forecasting Errors

As exhibited in the study, the only group of forecast error measures free of errors when in the presence of null values of actual demand is the absolute forecasting errors. However, they are not applicable if there are different scales or magnitudes. This category comprises the Mean Absolute Error (MAE), Mean Square Error (MSE), and Root Mean Square Error (RMSE). It is worth noting MSE and RMSE's low reliability.

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|actual\ demand_i - forecasted\ demand_i| \tag{9}$$

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(actual\ demand_i - forecasted\ demand_i)^2 \tag{10}$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(actual\ demand_i - forecasted\ demand_i)^2} \tag{11}$$

Where *n* is the number of periods in consideration.

Measures Based on Percentage Errors

This class of measures is the most common in this field. It includes the Mean Absolute Percentage Error (MAPE), the Median Absolute Percentage Error (MdAPE), the Root Mean Square Percentage Error (RMSPE), and the Median Percentage Error of the Quadratic (RMdSPE). As stated by Shcherbakov et al. (2013), these error measures are biased with outliers having a considerable impact on the result. Furthermore, when the value of the actual demand is equal to zero there is a division by zero.

$$MAPE = \frac{1}{n}\sum_{i=1}^{n} 100 * \left|\frac{actual\ demand_i - forecasted\ demand_i}{actual\ demand_i}\right| \tag{12}$$

$$MdAPE = median_{i=1,n}\left(100 * \left|\frac{actual\ demand_i - forecasted\ demand_i}{actual\ demand_i}\right|\right) \tag{13}$$

$$RMSPE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(100 * \left|\frac{actual\ demand_i - forecasted\ demand_i}{actual\ demand_i}\right|\right)^2} \quad (14)$$

$$RMdSPE = \sqrt{median_{i=1,n}\left(100 * \left|\frac{actual\ demand_i - forecasted\ demand_i}{actual\ demand_i}\right|\right)^2} \quad (15)$$

Where *n* is the number of periods in consideration.

Scaled Errors

This group provides symmetrical measures, resistant to outliers. However, if the forecast horizon values are all equal, division by zero occurs. This category comprises the Mean Absolute Scaled Error (MASE) and the Root Mean Square Scaled Error (RMSSE).

$$MASE = \frac{\sum\left(\frac{\left|actual\ demand_j - forecasted\ demand_j\right|}{\frac{1}{n-1}\sum_{i=2}^{n}\left|actual\ demand_i - actual\ demand_{i-1}\right|}\right)}{n} \quad (16)$$

$$RMSSE = \sqrt{\frac{\sum\left(\frac{\left|actual\ demand_j - forecasted\ demand_j\right|}{\frac{1}{n-1}\sum_{i=2}^{n}\left|actual\ demand_i - actual\ demand_{i-1}\right|}\right)^2}{n}} \quad (17)$$

Where *n* is the number of periods in consideration.

2.4. Concluding Remarks

Supply chain management is crucial in today’s competitive business environment, with cooperation between supply chain partners being essential to achieving a competitive advantage. It comprises the management of procurement, movement, and storage of materials, aiming at improving the supply chain’s performance and creating value for the customers. Furthermore, it emphasizes the importance of an efficient flow of materials and information to minimize supply chain costs and maximize the value generated.

Measurement and control of supply chain performance is essential to improve operational efficiency. The literature offers several performance measurement frameworks, with the balanced scorecard and the SCOR model being the most recognized. Since their creation, these tools have proved to be useful in delivering valuable insights into critical performance indicators and helpful in identifying improvement opportunities. Over the years, more modern frameworks have been developed, combining these classical tools with recent developments, and adapting them to the current industrial environment. Additionally, the determination of the bullwhip effect can help comprehend the supply chain's performance, as this phenomenon can have detrimental impacts on its performance.

At the moment, variability is one of the biggest challenges supply chain managers face, engendering additional costs and affecting supply chain performance. The amplification of this variability upstream in the supply chain is known as the bullwhip effect. Commonly, variability is managed through inventory, specifically buffer, and safety stocks. However, these constitute unnecessary costs. There are other forms of managing variability and allaying its effects. Some include appropriate demand forecasting techniques and information-sharing systems. Human factors also play a crucial role in the propagation of variability upstream and should be considered. Research has exposed how human behavior affects the BWE negatively. Further, there is a need to overcome challenges such as human resistance to change, lack of trust, and poor communication. Moreover, it is imperative to understand each partner's perspective and goals and invest in systems that allow for the desired level of integration of the supply chain.

In conclusion, it is essential to embrace collaboration, measure performance, measure, and control variability, and address the challenges supply chains face, to compete in today's industrial environment. By these means, organizations can improve their supply chain performance, reduce costs, and deliver value to their customers.

3. CASE STUDY COMPANY

Before the quantification and analysis of the bullwhip effect, it is important to provide a contextual description of the project's setting. This chapter gives context on Amorim Cork and its products. Furthermore, it will introduce its Supply Chain department, the tactical planning model it follows, and the tools used for the planning of production and stock management.

3.1. Amorim Cork, S.A.

The development of the current project took place in the Supply Chain department of Amorim Cork, SGPS, S.A. (AC). The company integrates the group Corticeira Amorim SGPS, S.A., which has five business units: Raw-Materials, by Amorim Florestal, S.A.; Cork Stoppers by Amorim Cork, S.A.; Floor & Wall Coverings by Amorim Cork Flooring, S.A.; Composite Cork by Amorim Cork Composites, S.A.; Insulation Cork by Amorim Cork Insulation, S.A. Figure 2 shows Corticeira Amorim's organigram.

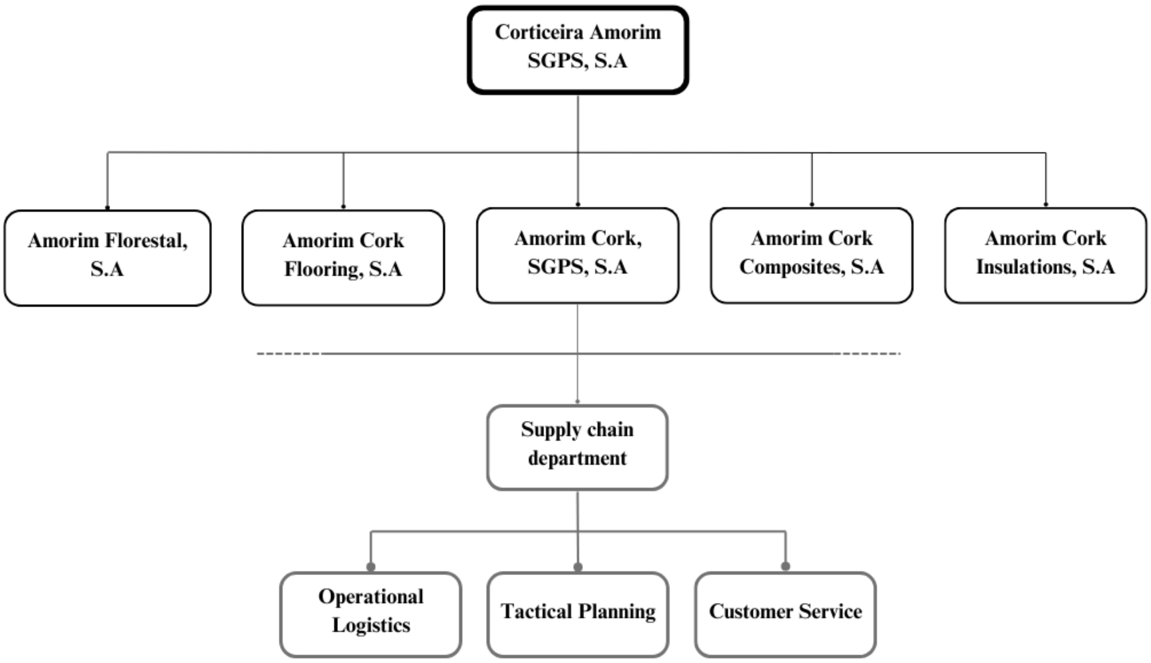

Figure 2 - Corticeira Amorim's organigram

The group is currently present in twenty-six countries and caters to a vast clientele of twenty-seven thousand clients. Corticeira Amorim is the world's largest cork processing group, with a significant impact on the world's economy and the cork industry's innovation and sustainability. Established in 1870 as a cork-stopper manufacturing facility, the company gradually recognized the potential of this raw material, prompting them to expand its portfolio of products. Complementary, the group placed great importance on research & development (R&D), making them pioneers in the industry with products and processes unique to them and of better quality and interest to their customers.

The group's history is shown in chronological order in attachment A and can provide a better understanding of the journey of Corticeira Amorim.

The group's mission is "To add value to cork, in a competitive, distinctive and innovative way that is in perfect harmony with Nature". Its vision is "To be a sustainable company, providing suitable value for the capital invested while promoting social equity and environmental safeguards, with differentiating factors at product and service level." (Amorim, 2023).

Amorim Cork focuses on selling cork stoppers and comprehends every industrial unit responsible for producing cork stoppers and its distributors – *Sales Companies* – which are present worldwide. AC produces more than 5.5 billion cork stoppers per year and is accountable for most of the group's sales. Herewith, this business unit is crucial for the business health of the group, and it is essential to manage its operations appropriately.

3.2. Cork

As stated previously, the primary raw material AC uses is cork, provided by Amorim Florestal, S.A., extracted from the cork oak (Quercus Suber L.) that originated in the Mediterranean basin. The cork oak can live up to two hundred years and can only be harvested for the first time after approximately twenty-five years. Afterward, the cork can be extracted from the tree every nine years without damaging it. During its lifespan, a cork oak can be of use to the industry sixteen times, on average. In Portugal, the *montados* are protected by legislation, and the unauthorized felling of these trees is prohibited. It's important to mention that the first two harvests can´t be used to produce cork stoppers. By this means, guaranteeing the continuous availability of this raw material is difficult, considering the business' high growth rate. Herewith, the management of raw materials in this industry is of great importance, considering only one primary material is used to fuel the whole supply chain.

3.3. Products

Since the 1990s, the main issue Amorim Cork has targeted is the TCA in corkwood to reduce its incidence in wine. TCA is an acronym for the chemical compound 2,4,6-trichloroanisole that gives the "corkiness" and musty aroma to the wine when present in the cork stoppers. AC has developed several anti-TCA technologies and currently guarantees that every cork stopper is exempt from noticeable TCA.

There are three main segments of wines for which cork stoppers are produced by Amorim Cork: still, spirits, and sparkling wine.

For the still wines segment, AC produces twelve types of cork stoppers that include Natural cork stoppers, Acquamark, Helix, Twin Top®, Twin Top Evo, Qork, Xpur®, Neutrocork®, Advantec®, Advantec Colours, Agglomerate cork stopper, and NDTech.

The spirit wines segment includes only capsulated cork stoppers. These are produced by one of Amorim Cork's companies – Amorim Top Series (ATS). ATS produces any variation of capsulated cork stoppers, from standard products to fully customizable ones. These can range considerably in price according to specifications and level of customization.

The sparkling wine segment contains One Disk and Two Disk cork stoppers for sparkling wines, NeutroCork and NDTech Sparkling.

More information regarding the product portfolio of AC is in attachment B.

The different products manufactured and commercialized by Amorim Cork are classified into different family of products. For instance:

- NATURAIS: including Natural cork-stoppers;

- TT: including all Twin Top cork-stoppers;
- 1D: including all One Disk cork-stoppers;
- MICRO SUPER CRÍTICO: including Qork and Xpur cork-stoppers;
- MICRO: including Neutrocork cork-stoppers;
- 2D: including all Two Disk cork-stoppers.

3.4. The Supply Chain Department

Given that this project integrates the Supply Chain department of Amorim Cork, it is appropriate to introduce its activities and scope. Given the company's highly verticalized production chain, this department holds significant importance.

The Supply Chain department acts as the connecting point between the company and the markets, guaranteeing the availability of its products to its customers. The department is responsible for the planning and control of production, the management of stocks, the outbound logistics, and customer service, as shown in Figure 3.

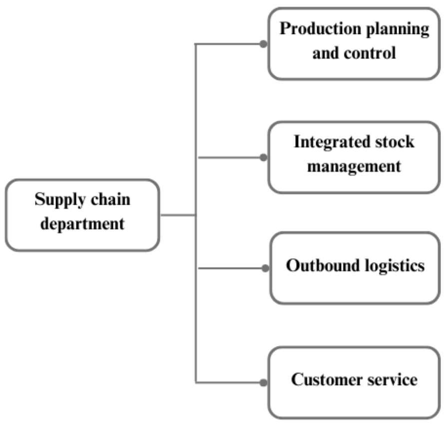

Figure 3 - Supply Chain department's operations

The supply chain of Amorim Cork begins with the acquisition of the primary raw material – cork - from Amorim Florestal, which both produces and buys them from external companies. It is later sent to the various industrial units to be processed. Both finished and semi-finished (without the marking and the final surface treatment) products exit these units. The first go directly to the end customer and the latter to the sales companies (distributors).

The sales companies are a point of interaction with the client and are responsible for product customization. The supply chain of Amorim Cork is modeled in attachment C.

Amorim Cork has branches in 14 countries, scattered across 5 continents. Some include Australia, Chile, France, Germany, and the United States of America. Amorim Cork uses 2nd-party (2PL) and 3rd-party (3PL) logistic providers. It delegates the transportation, from A to B, to logistics partners and outsources the distribution to partners while coordinating the operation (the partner is responsible for storing and transportation).

3.4.1. Supply Chain Operations

To efficiently manage the supply chain of Amorim Cork, the SC department has defined a model of information and material flow that supports it.

Material flows unidirectionally from the production units to both Portugal's finishing units and the *sales companies* and subsequently to the final client.

Information flows are both unidirectional and bidirectional, with the latter being unanimous agreements between both parties. The Supply Chain department stipulates production plans monthly and weekly, at the tactical level, to identify which final clients' orders will be fulfilled and schedule their distribution. A monthly distribution plan is agreed upon with the Portuguese finishing units based on the annual sales and operational plan. The communication with the *sales companies* is more extensive, with access to consumption records and forecast plans which lead to a stock-level agreement. With these units, it is implemented a VMI stock replenishment model. Additionally, the logistics department has access to the final clients' sales.

Figure 4 illustrates the information and material flows of Amorim Cork.

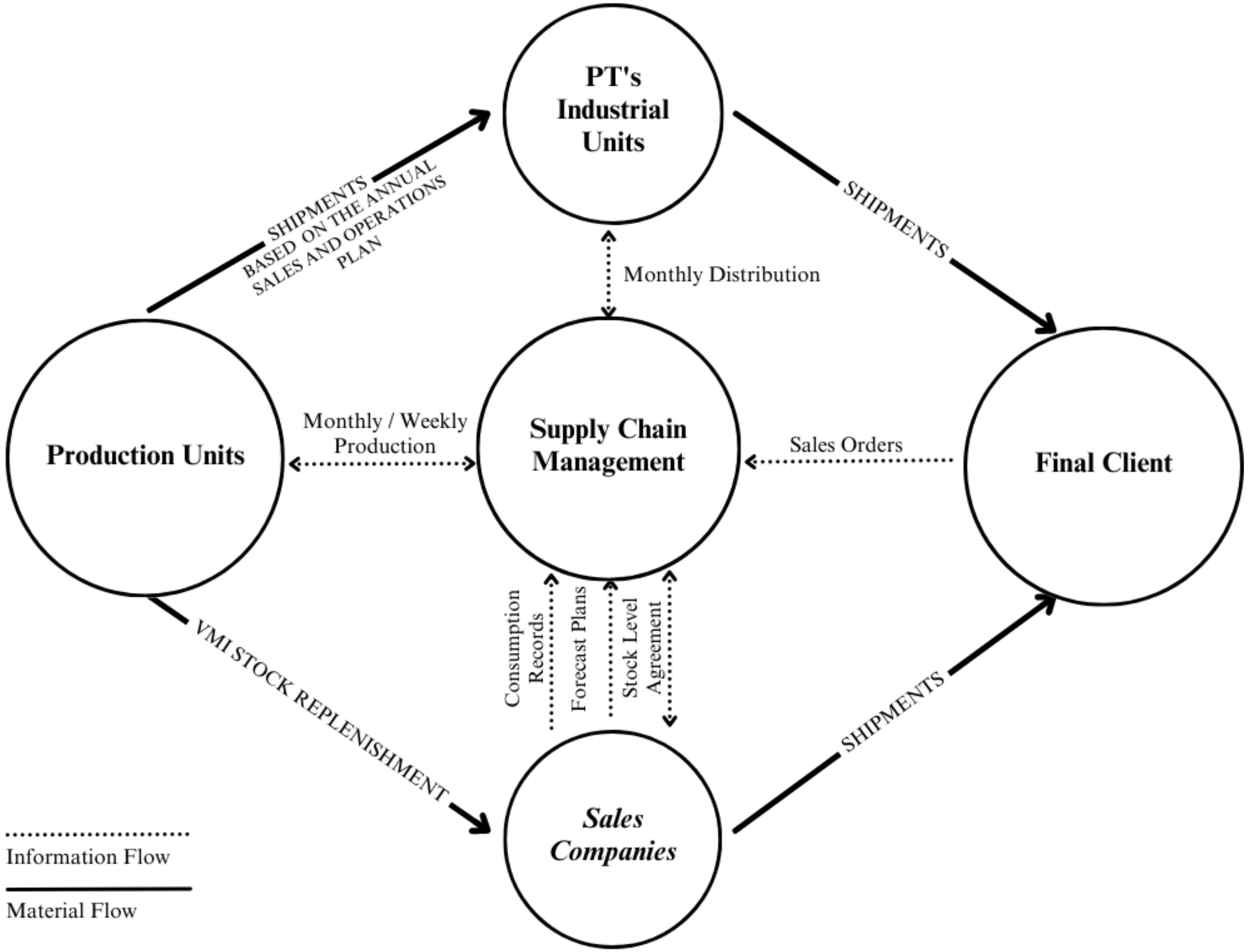

Figure 4-Information and material flow of Amorim Cork's supply chain

3.4.1. Tactical Model

Currently, the Supply Chain department of Amorim Cork follows all markets for non-capsulated cork-stoppers, which balances the production capacity installed with the markets' needs. This is a highly delicate job, with the main difficulties arising when production problems occur.

The planning and control of production are executed using rolling plans and forecasts, which can derive from two software applications (1) Service Optimizer 99 (SO99) and (2) E-Supply. The first is for *sales companies* with SAP, a system that grants access to daily information on stock levels, final clients' sales, and stock replenishment models. The second is a software with several manual inputs, such as sales forecasts and stock levels, given that it is for *sales companies* that have not implemented SAP. As mentioned previously, *sales companies* provide this information. However, both methods result in the same type of analysis – comparing stock levels with the desired safety stock and deciding where to allocate resources/products based on forecasted sales. The rolling plan is further analyzed in a monthly meeting with the sales company's team, where sales expectations and shipment plans are aligned.

3.4.1.1. Rolling Plans and Forecasts

Rolling forecasts (RF) and rolling plans (RP) are non-static planning tools for continuous planning (medium-term) subject to periodic reviews and regular updates. Every month, based on the recently updated rolling forecasts, the planning done prior is revised and redone if necessary. These periodic revisions ensure that more-current information is integrated into the planning as time passes. The main objective of this tool is to plan procurement, levels of stock, and production, and it intends to release production orders. Another important goal is to ensure that the *sales companies'* stock is as close as possible to the safety stock previously calculated. A rolling plan enables tactical planners to make better-supported decisions. If there are problems with production capacity, this tool facilitates making more informed decisions on what client's orders to fulfill.

Arguably, a rolling plan follows the logic of the demand-driven material requirement planning (DDMRP), since it is a demand-driven production planning aiming at guaranteeing the client's stock replenishment and avoiding stockouts. Figure 5 shows the appearance of a rolling plan in Excel.

									mai/23						jun/23
Familia	Descrição Externa	ABC	Stock Final A	Arriva	PO#	Needs	Safety Stock	Estimated Stock	Deviati	Arriva	PO#	Needs	Safety Stock	Estimated Stoc	Deviati
Natural			**1 660,000**	**1 090,000**		**1 088,000**	**1 163,819**	**1 662,000**	**498,181**	**920,000**		**972,000**	**981,819**	**1 610,000**	**628,181**
Natural	**38x24mm SUPER CLC**	**B**	**66,000**	**0,000**		**20,000**	**45,909**	**46,000**	**0,091**	**40,000**		**40,000**	**15,909**	**46,000**	**30,091**
Natural	38x24mm SUPER CLC	B								40,000	NEW PO02				
Natural	**38X24mm 1st CLC**	**A**	**502,000**	**0,000**		**260,000**	**106,136**	**242,000**	**135,864**	**0,000**		**100,000**	**51,136**	**142,000**	**90,864**
Natural	38X24mm 1st CLC	A													
Natural	**38x24mm EXTRA CLC**	**A**	**49,000**	**0,000**		**10,000**	**21,364**	**39,000**	**17,636**	**0,000**		**20,000**	**11,364**	**19,000**	**7,636**
Natural	38x24mm EXTRA CLC	A													
Natural	**45x24mm SUPER CL0**	**B**	**10,000**	**10,000**		**10,000**	**10,727**	**10,000**	**-0,727**	**10,000**		**6,000**	**12,727**	**14,000**	**1,273**
Natural	45x24mm SUPER CL0	B		10,000	NEW PO3					10,000	NEW PO57				
Natural	45x24mm SUPER CL0	B													
Natural	**45x24mm SUPER NATURE**	**A**	**34,000**	**400,000**		**200,000**	**174,545**	**234,000**	**59,455**	**240,000**		**150,000**	**204,545**	**324,000**	**119,455**
Natural	45x24mm SUPER NATURE	A		80,000	PODE2300064 Natur M					80,000	PODE2300105 45 Supe				
Natural	45x24mm SUPER NATURE	A		160,000	NEW PO5					160,000	NEW PO6				
Natural	45x24mm SUPER NATURE	A		160,000	NEW PO38										
Natural	**45x24mm SUPER CLC**	**B**	**14,000**	**20,000**		**10,000**	**18,864**	**24,000**	**5,136**	**10,000**		**10,000**	**23,864**	**24,000**	**0,136**
Natural	45x24mm SUPER CLC	B		**20,000**	**PODE2300064 Natur M**										
Natural	45x24mm SUPER CLC	B								10,000	NEW PO54				
Natural	45x24mm SUPER CLC	B													
Advantec			**307,000**	**345,000**		**400,000**	**0,000**	**252,000**	**252,000**	**970,000**		**0,000**	**0,000**	**1 222,000**	**1 222,000**
Advantec	**38x23mm ADVANTEC - COLRUYT**	**B**	**255,000**	**345,000**		**400,000**	**0,000**	**200,000**	**200,000**	**460,000**		**0,000**	**0,000**	**660,000**	**660,000**
Advantec	38x23mm ADVANTEC - COLRUYT	B		**100,000**	**PODE2300069 38 Advan**					460,000	PODE2300099 Advantec				
Advantec	38x23mm ADVANTEC - COLRUYT	B		245,000	PODE2300069 38 Advan										
Advantec	**44X23mm ADVANTEC - Colruyt**	**A**	**52,000**	**0,000**		**0,000**	**0,000**	**52,000**	**52,000**	**510,000**		**0,000**	**0,000**	**562,000**	**562,000**
Advantec	44X23mm ADVANTEC - Colruyt	A								510,000	PODE2300099 Advantec				
Neutrocork			**1 308,000**	**2 240,000**		**2 750,000**	**2 256,818**	**798,000**	**-1 458,818**	**2 070,000**		**1 400,000**	**2 306,818**	**1 468,000**	**-838,818**
Neutrocork	**38x24mm NEUTROCORK BEERW.**	**B**	**248,000**	**200,000**		**350,000**	**188,636**	**98,000**	**-90,636**	**200,000**		**100,000**	**238,636**	**198,000**	**-40,636**
Neutrocork	38x24mm NEUTROCORK BEERWASHIN	B		200,000	PODE2300018 Neutro					200,000	PODE2300018 Neutro				
Neutrocork	38x24mm NEUTROCORK BEERWASHIN	B													
Neutrocork	**44x24mm NEUTROCORK BEERW.**	**B**	**1 060,000**	**2 040,000**		**2 400,000**	**2 068,182**	**700,000**	**-1 368,182**	**1 870,000**		**1 300,000**	**2 068,182**	**1 270,000**	**-798,182**
Neutrocork	44x24mm NEUTROCORK BEERWASHIN	B		**340,000**	**PODE2300018 Neutro**					340,000	PODE2300018 Neutro				
Neutrocork	44x24mm NEUTROCORK BEERWASHIN	B		**340,000**	**PODE2300018 Neutro**					340,000	PODE2300065 Neutro M				
Neutrocork	44x24mm NEUTROCORK BEERWASHIN	B		**340,000**	**PODE2200063 Neutro**					340,000	PODE2300065 Neutro M				

Figure 5- Rolling plan in Excel

3.4.1.2. Service Optimizer 99 (SO99)

This software, as seen below in Figure 6, gives more extensive information than the one provided by E-Supply, and it is updated daily, based on daily inputs of stock levels and final clients' sales. Additionally, it is possible to extract reports and do detailed analyses as desired.

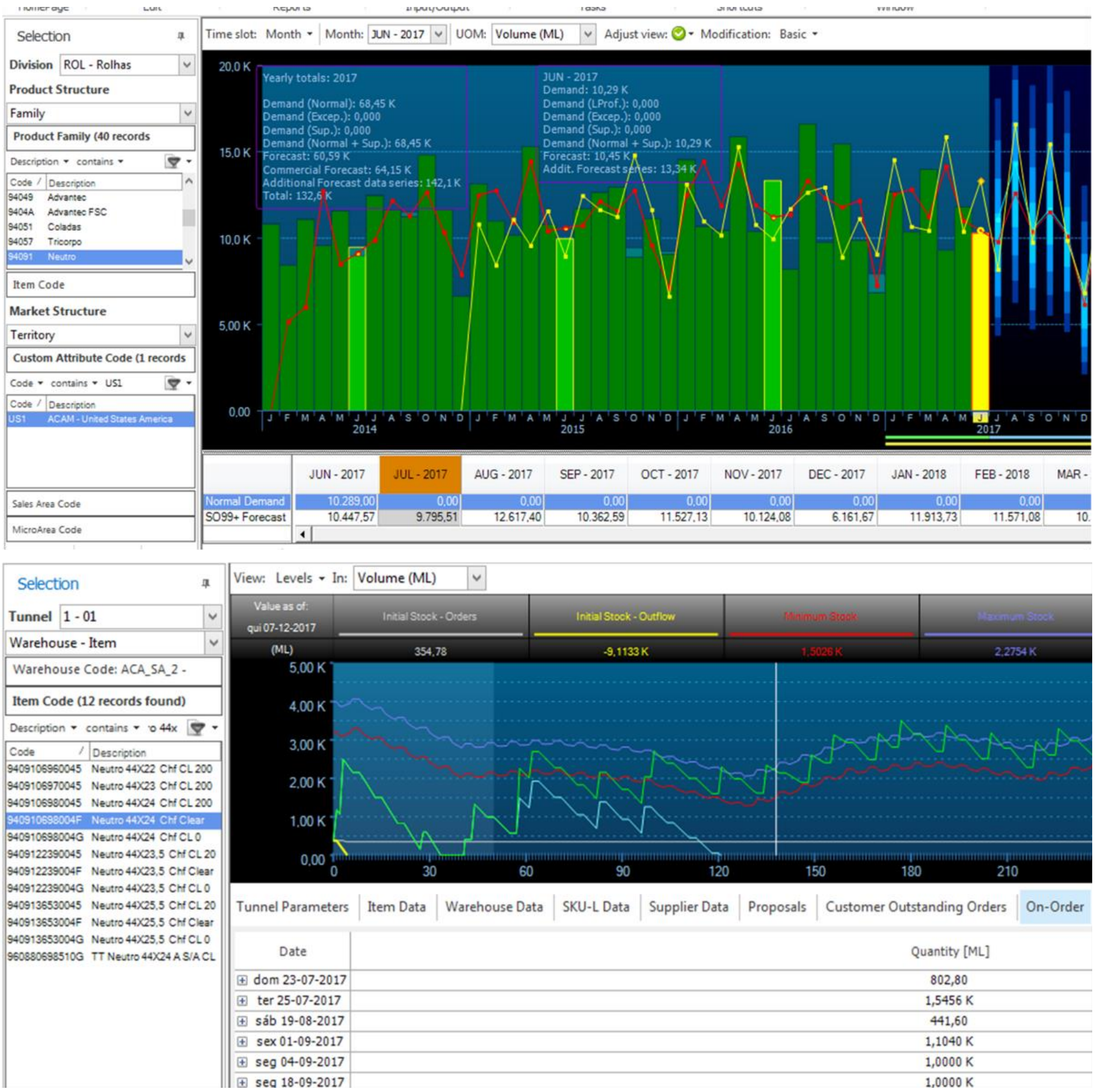

Figure 6 - Service Optimizer 99 screens

3.4.1.3. E-Supply

E-Supply is a tool with several capacities, including generating rolling plans, by uploading the rolling forecasts provided by the *sales companies*. Essentially, this tool aims to present to the user what is observable in a rolling plan in Excel. This consists of monthly forecasted sales, stock levels, and orders in transit. In comparison to SO99, E-Supply does not allow for detailed analyses. Figures 7 and 8 show this tool's rolling forecast and rolling plan screens, respectively.

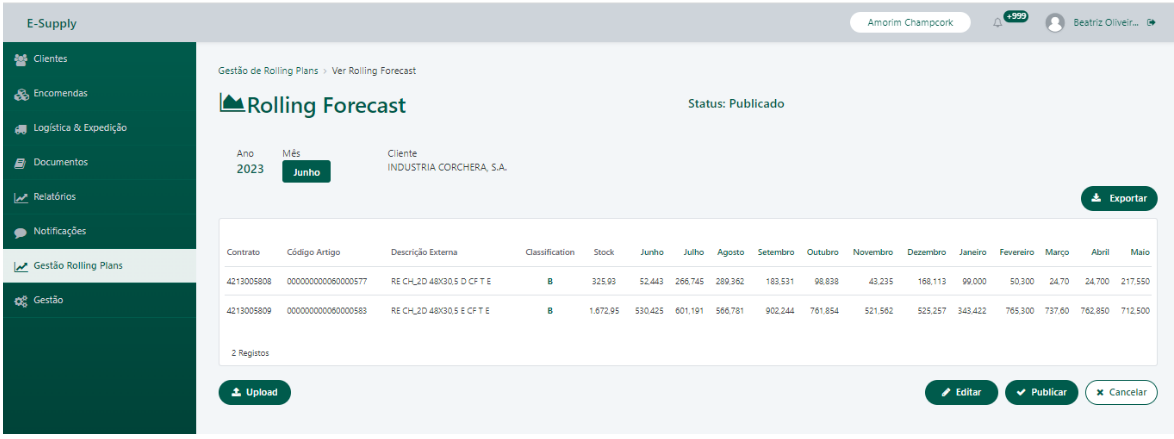

Figure 7 - E-Supply screen: rolling forecast

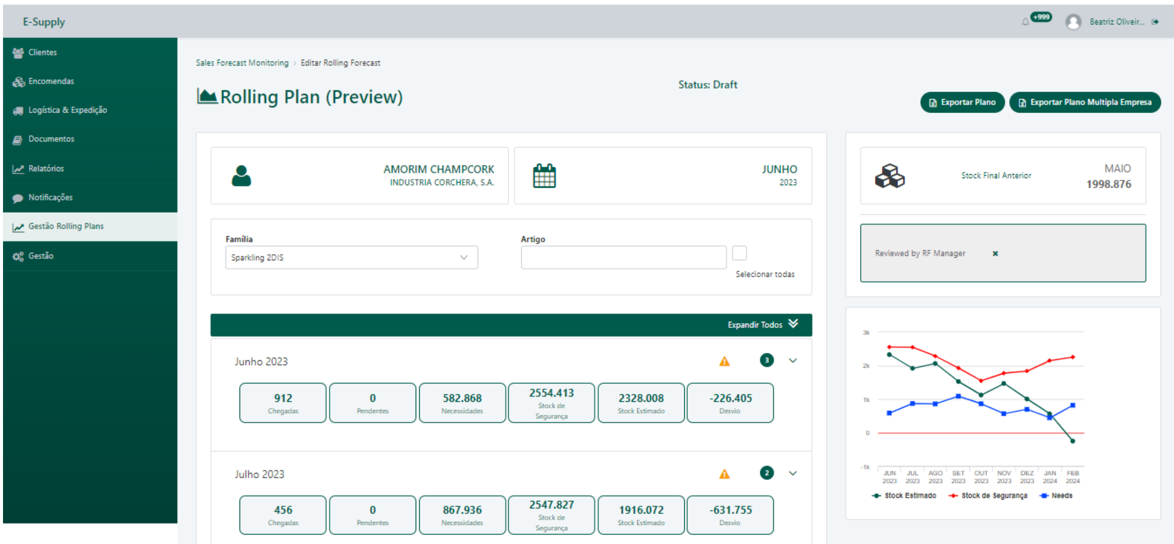

Figure 8 - E-Supply screen: rolling plan

3.5. Diagnosis

All products manufactured by Amorim Cork rely mainly on a single raw material – cork. Therefore, the efficient allocation of resources is of the utmost importance. To put it simply, with limited offer and high demand, products need to be adequately allocated to each client. This process is the responsibility of the tactical planning team. One of the biggest challenges the department faces when managing the supply chain is the long lead time between the supply of cork and the final products' availability in the market. According to the director of the supply chain department, "the strategic decision regarding the volume and acquisition mix of raw material is made in the first semester of every year for year n+2". Further explaining, "the evolution of the markets and the rising/decreasing presence of our competitors in those markets might lead to gaps in demand and offer affecting the stock management globally".

Over the years there has been a great effort to improve the communication channels between Amorim Cork's companies. In addition to constant communication through e-mails, several meetings are scheduled throughout the year to keep the department up to date regarding issues such as market needs and stock levels. However, "there are branches with greater proximity, frequency of communication, and importance in comparison to others. I would say the issue lies not so much in the way of communicating, but rather in the commitment that teams have toward the communicated forecasts".

Through the gathering of information regarding the tactical model followed by the company, it was made clear that the *sales companies* which are more prone to generating a bullwhip effect are the ones that do not have SAP implemented. The forecasts provided by these branches are an estimation of sales made by the local team based on previous years and orders already placed by clients. When asked about the challenging factors of managing the supply chain, the director of the supply chain department mentions the "difficulty in having concrete market forecasts". Adding "We have key account clients with significant demand fluctuations, influenced by their strategies regarding the placement of their wines in the market. In aggregate terms, we can achieve good forecast accuracy, but when we delve into a market or item-level analysis we start to observe inferior forecast accuracy". Furthermore, to emphasize the importance of the forecasts provided, it was reinforced that "the non-fulfillment of the forecast is what later causes imbalances in terms of stock, material availability, etc", supporting that "the commitment to the forecast should be more emphasized". Therefore, this project will focus on *sales companies* without SAP.

As for future improvement measures it is emphasized the need for stabilizing processes implemented during the last 5 years, "In terms of timeframe, in the last 5 years, we have implemented tactical planning, demand forecasting, SAP, and recovered the rolling plan model through E-supply. These processes require monitoring, stabilizations, and reinforcement of commitment".

4. METHODOLOGY

4.1. Research Methodology

To study the bullwhip effect of a cork-stopper manufacturer, a methodology based on the work of Saunders, Lewis, and Thornhill (2012) was developed. The Saunders research onion is illustrated in Figure 9.

Firstly, focusing on the third layer of the research onion – the methodological choices - in this project, a mixed method (combination of quantitative and qualitative methods) is employed. First, a semi-structured interview is conducted to help diagnose the main problems the supply chain faces and frame the present project. Excel is used to quantify the BWE, and relevant equations are applied to calculate the variance in order quantities and sales to final clients. This quantitative analysis provides numerical data to measure and analyze the BWE. Furthermore, interviews are conducted to gain a deeper understanding of the results obtained through quantitative analysis. The interviews serve as a qualitative research technique to explore the underlying causes and implications of the BWE. Key stakeholders within the company, such as the director of the supply chain department, were interviewed to gain their perspectives and insights.

Moving inward, the research strategy adopted is case study research. The BWE is studied in a specific industrial environment, namely a cork-stopper manufacturer. Data regarding the orders and sales of the company are collected and further analyzed. All conclusions and interpretations are adapted to the environment the phenomenon is observed in. The main objective is to gain an in-depth understanding of this issue in a practical scenario.

The next layer of the onion focuses on the time horizon considered in the research. The data collected in this study is from 2021 and 2022. These data serve as the foundation for the quantitative analysis and help identify patterns related to the BWE. Given the research of a phenomenon at a specific moment, the study utilizes a cross-sectional time horizon.

The methodology for this research study on the BWE of a cork-stopper manufacturer comprises quantitative analysis of data from 2021 and 2022 using Excel and relevant equations, and qualitative insights gathered through non-structured and semi-structured interviews. This approach allows for a comprehensive examination of the BWE and facilitates a deeper understanding of its causes and consequences, within the context of the cork-stopper manufacturing industry.

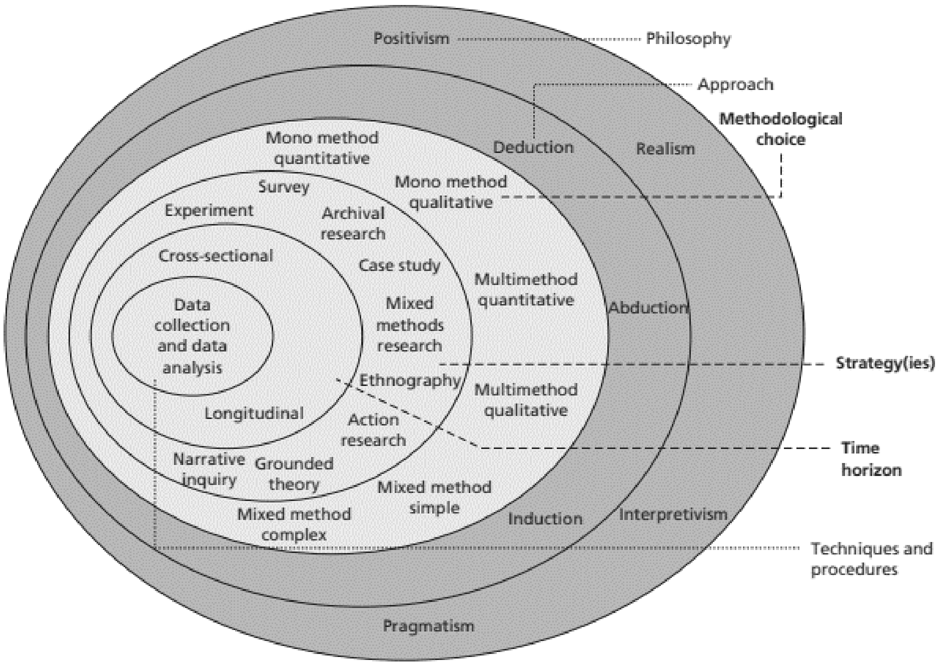

Figure 9 - Research Onion (adapted from Saunders, Lewis, and Thornhill (2012))

4.2. Data Selection

Intending to quantify and analyze the bullwhip effect observed at Amorim Cork (manufacturer), and considering what the literature supports, data of final client's sales and orders placed by *sales companies* are collected. Further, these data are aggregated by the family of products by *sales company*. Moreover, to analyze the forecast accuracy, the sales forecasts provided by the *sales companies* are collected. The forecast provided two months before is used for the quantification of the BWE at a given month and to calculate forecast accuracy All the data are collected monthly, from years 2021 and 2022.

Through the collection of these data, it was possible to carry out all calculations necessary for the quantification and analysis of the BWE in this supply chain.

4.3. Data Analysis Approach

There are four *sales companies* in this analysis which are *sales companies* without SAP. As previously clarified in section 3.4.1, these send their own sales forecasts to AC. The tactical planning for these companies is made using the tool E-supply (mentioned in section 3.4.1.3). Therefore, these are the *sales companies* that exhibit a higher susceptibility to creating a bullwhip effect. The other *sales companies* use software that generates forecasts based on daily inputs of sales and stocks.

Following the choice of which *sales companies* to consider, a Pareto analysis of the aggregated values of the *sales companies* selected is executed to identify which families of products weigh more on the volume of sales. Afterward, this analysis is conducted for each *sales company* to understand how each of these families impacts their volume of sales. This study focuses on the families identified in the first Pareto analysis, which have a significant weight on each *sales company* individually.

The bullwhip effect measure is determined using equations (1) and (7). This measure is obtained per *sales company* per family of products. Considering that there are four *sales companies* in the analysis along with four families of products, there are sixteen possible BEMs. Some of these BEMs are studied in depth if a particular family of products has little weight in a *sales company's* volume of sales. The calculus of the forecast accuracy is conducted using the MASE measure, seen in equation (16). In an analogous way to the BEM, the forecast accuracy is calculated by the family of products by the *sales company*.

After a quantitative analysis of the data collected, it is essential to analyze the results qualitatively. This is achieved through conducting non-structured and semi-structured interviews with the individuals responsible for the tactical planning of the company. The main objective of these interviews is to understand the motives behind the phenomena observed in the data.

4.4. Methodology Framework

For future requirements or investigation purposes, the framework used for this study is presented in Figure 10.

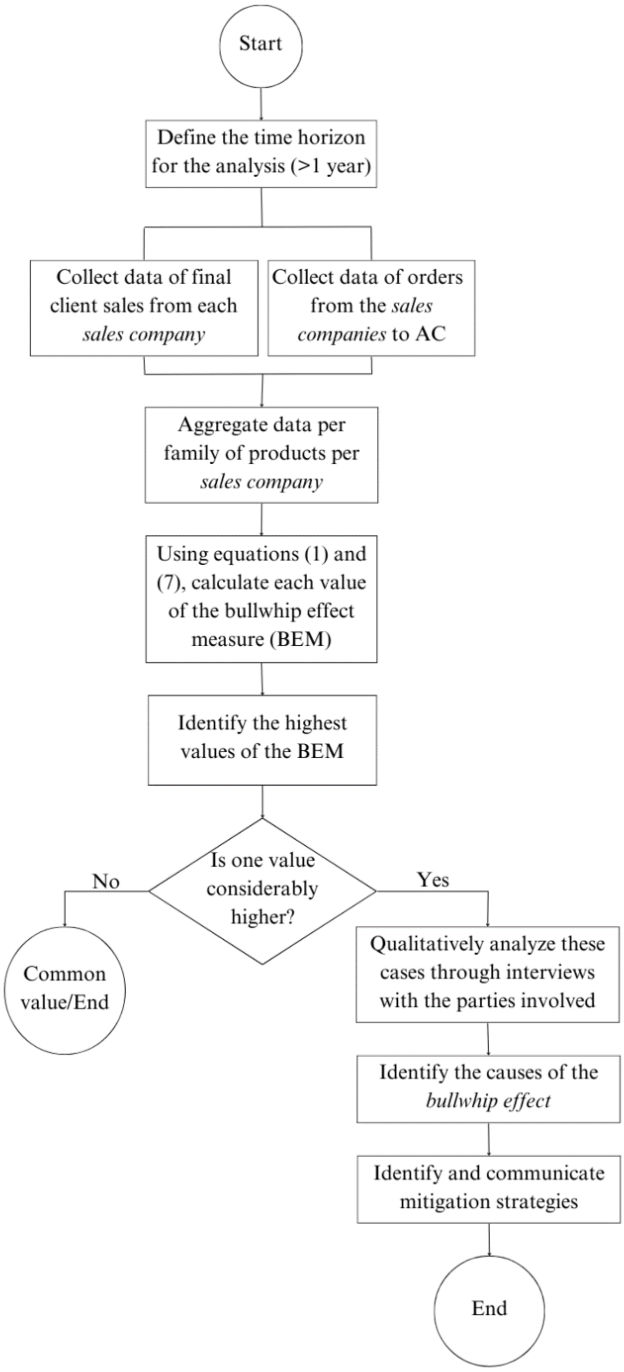

Figure 10 - Methodology Framework

5. RESULTS AND DISCUSSION

As mentioned in Chapter 1, this project aims to quantify and analyze the bullwhip effect felt at the manufacturer level of a cork-stopper company's supply chain. Along with the identification of possible causes and mitigation approaches.

As previously stated, the BWE is measured through Parra Peña, Mula, and Campuzano-Bolarín (2012)'s adaptation of the BEM to spreadsheet use. Afterward, a qualitative analysis is conducted through non-structured and semi-structured interviews with one of the people responsible for the tactical planning of the company. Furthermore, the forecast accuracy measures are determined using the MASE measure (equation (16)) to analyze the forecasts provided by the *sales companies*.

This chapter presents the findings of these analyses, both quantitative and qualitative. This section also presents a discussion of these results and suggests improvement measures.

5.1. Quantitative Analysis

As mentioned in section 4.3, this analysis focuses on the *sales companies* that do not have SAP. This includes AAUS (Amorim Australasia), ACDE (Amorim Cork Deutschland), ACSA (Amorim Cork South Africa), and ICSA (Industria Corchera). Among this set of *sales companies*, ICSA has the most considerable impact on the sales made to final clients, as seen in Figure 11.

First, it is necessary to determine which families of products are the focus of this analysis. As mentioned previously, a Pareto analysis of the volume of sales per family of products for the *sales companies* considered is performed. Its results are in Figure 12. The families MICRO, 2D, NATURAIS, and TT constitute approximately 80% of the volume of sales. Thus, these are the critical families of products and the focus of this analysis. Within these families' sales, the family of products with the most weight is MICRO, followed by 2D and NATURAIS, shown in Figure 13.

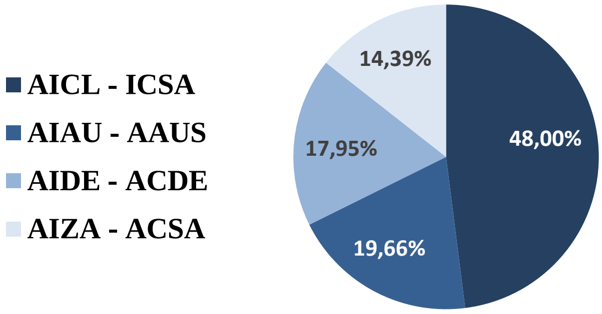

Figure 11 - Percentage of final client's sales per Sales company

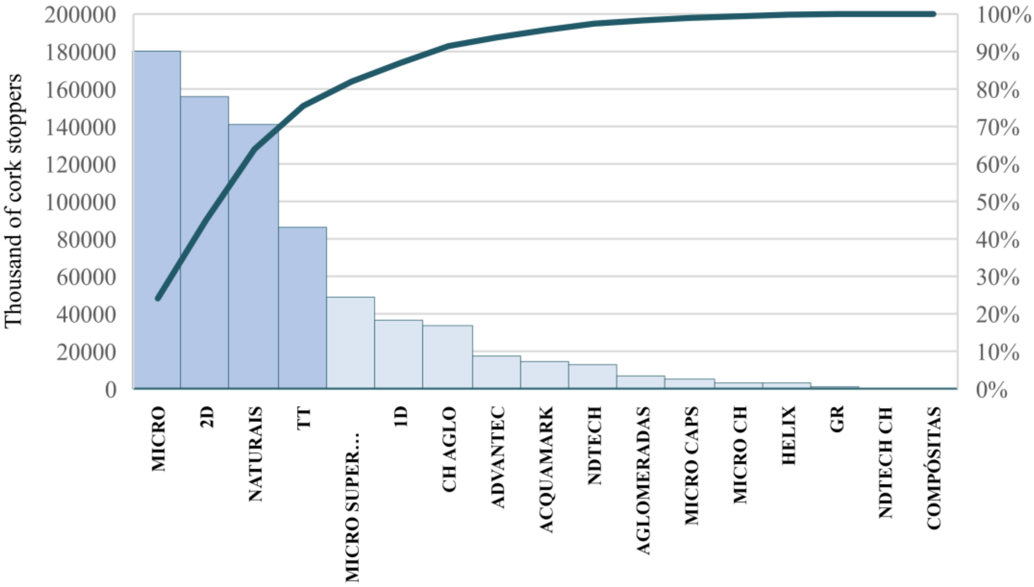

Figure 12 - Pareto analysis of the volume of sales per family of products for the *sales companies* in consideration

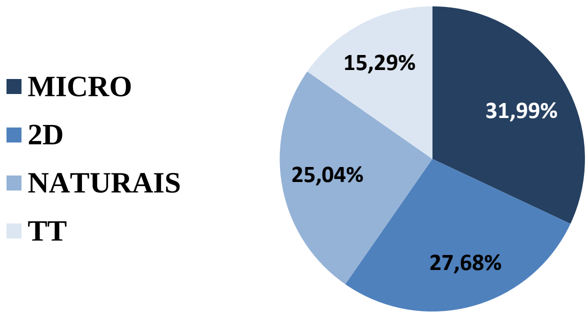

Figure 13 - Percentage of sales per family of products on the total sales of the most relevant families

Having identified the most relevant families, the weight of these families on each *sales company* is calculated. This leads to the recognition of which pairs (family of products – *sales company*) to analyze. The results of this analysis are shown in Table 6.

Table 6 - Weight of the most relevant families of products for each Sales company

Sales company	**Family of products**	**Weight on volume of sales (%)**
AAUS	2D	69.99
	NATURAIS	12.77
ACDE	2D	28.00
	MICRO	16.00
	NATURAIS	13.70
ACSA	NATURAIS	14.57
	2D	12.02
	TT	8.53
ICSA	MICRO	40.17
	NATURAIS	24.30
	TT	18.39

Succeeding the choice of which pairs of the family of products and *sales companies* to study, the bullwhip effect measure is calculated, employing the adaptation to spreadsheet use developed by Parra Peña, Mula, and Campuzano-Bolarín (2012). The results of these calculations are available in Appendix A.

Table 7 - Bullwhip effect measures by family of products by Sales company per year

		2D	**MICRO**	**NATURAIS**	**TT**
AAUS	2021	98,02	-	1,37	-
	2022	112,69	-	1,66	-
ACDE	2021	255,64	11,85	22,82	-
	2022	270,99	31,31	29,46	-
ICSA	2021	-	58,64	248,96	327,98
	2022	-	65,55	253,5	358,53
ACSA	2021	891,41	-	79,76	4,77
	2022	903,12	-	82,5	6,17

As observed in Table 7, the most concerning values for the bullwhip effect are related to the 2D product family for *sales companies* AAUS, ACDE, and ICSA. For ICSA, the TT and the NATURAIS families represent the most alarming families of products regarding the BWE. These measures are significantly higher than those of other families for the same *sales company*.

According to the company's tactical planners, the conclusions drawn from the quantitative analysis are surprising. As attested by these professionals, the 2D family has a variable but predictable demand with the orders placed being fully fulfilled. Therefore, to their understanding, having no capacity problems there is no reason for this phenomenon to be prominent for this family of products. The same applies to the TT product family. Figure 14 proves this premise by demonstrating 2D's and TT's final clients' sales over 2021 and 2022, respectively. Supplementary, the calculation of the coefficient of variation of these sales further supports this proposition. As expected, the coefficient of variation of these families of products is 20,47% and 18,65%, respectively.

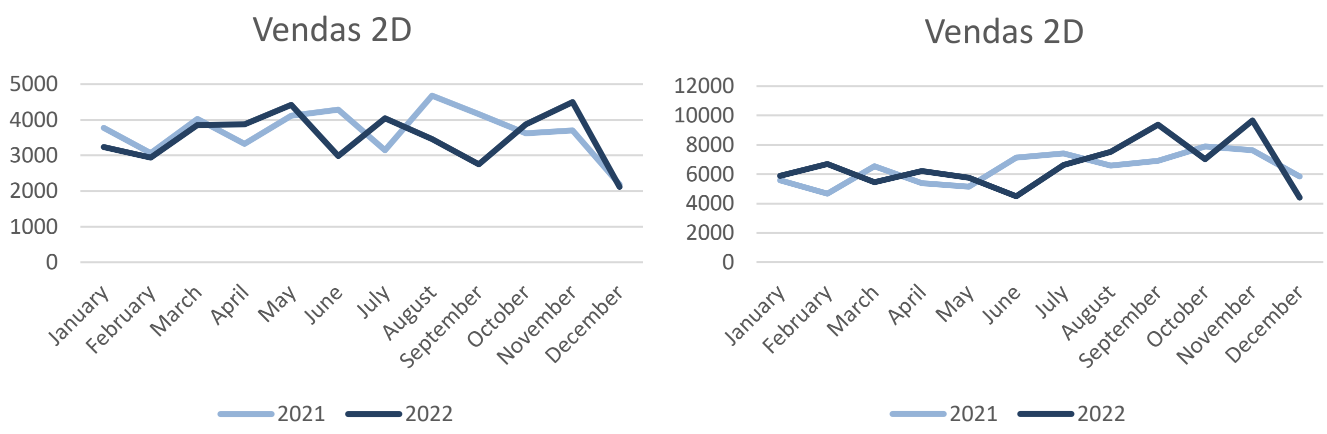

Figure 14 - 2D and TT's final client's sales in 2021 and 2022

These observations by the tactical planners create a need to re-analyze, in detail, the results of the previous calculations. The intent is to understand how the data collected might lead to incorrect conclusions. This analysis is conducted, partially, with the help of these professionals who provide insights from the data used in the quantitative analysis.

5.2. Qualitative Analysis

The results of all pairs mentioned previously are analyzed qualitatively. However, in this chapter, only one scenario is examined in detail. The choice relies on what case is the most complete and has a bigger impact on the final client's sales. Therefore, the scenario of ICSA–NATURAIS is the one in analysis. Complementary, the case of ACSA–2D will be touched upon to complete the analysis of causes and mitigation approaches. The analysis of the other pairs is in Appendix B.

The previous quantitative analysis conducted on ICSA-NATURAIS resulted in the values presented in Table 8.

Table 8 - Results from the quantitative analysis for ICSA - NATURAIS

			Final client sales	Orders	Dif	Order Variance	Sale Variance	BEM	BEM Acum
2021	JAN	0	3545,63	50,00	-3495,63	0,00	0,00	0,00	0,00
	FEB	1	3410,74	1157,50	-2253,24	669903,13	9097,66	73,63	73,63
	MAR	2	5216,70	1510,00	-3706,70	760033,33	1012026,96	0,75	74,39
	APR	3	4697,18	1700,00	-2997,18	722500,00	776921,51	0,93	75,32
	MAY	4	4155,36	8893,00	4737,64	15817089,80	583464,96	27,11	102,42
	JUN	5	3982,27	8855,00	4872,73	13068504,17	475049,14	27,51	129,93
	JUL	6	4139,51	7385,00	3245,49	7791175,00	395990,07	19,68	149,61
	AUG	7	4827,62	7312,00	2484,38	6683168,00	394483,46	16,94	166,55
	SEP	8	4040,82	886,00	-3154,82	87221,78	349890,71	0,25	166,80
	OCT	9	4150,66	3570,00	-580,66	1274490,00	311551,57	4,09	170,89
	NOV	10	3816,09	1079,00	-2737,09	105840,09	294982,55	0,36	171,25
	DEC	11	3164,66	18172,00	15007,34	27518465,33	354115,26	77,71	**248,96**
2022	JAN	12	3146,31	0,52	-3145,79	0,02	393926,07	0,00	248,96
	FEB	13	3021,11	0,00	-3021,11	0,00	435263,28	0,00	248,96
	MAR	14	3842,30	0,20	-3842,10	0,00	404961,38	0,00	248,96
	APR	15	4113,63	0,00	-4113,63	0,00	379766,72	0,00	248,96
	MAY	16	5499,61	1897,00	-3602,61	211682,88	496479,82	0,43	249,39
	JUN	17	1883,14	3314,68	1431,54	610394,64	726995,38	0,84	250,23
	JUL	18	3569,33	2153,00	-1416,33	243968,89	693271,68	0,35	250,58
	AUG	19	4303,00	3120,00	-1183,00	486720,00	664646,06	0,73	251,31
	SEP	20	3068,97	844,00	-2224,97	33920,76	666413,00	0,05	251,36
	OCT	21	2854,85	1740,00	-1114,85	137618,18	682958,99	0,20	251,56
	NOV	22	2916,56	2180,00	-736,56	206626,09	688880,21	0,30	251,86
	DEC	23	1970,46	5605,00	3634,54	1309001,04	798171,37	1,64	**253,50**

Upon a first analysis of these values, there are a few instances where values seem out of the ordinary. The first one is in December of 2021. In this month, there is a considerable rise in orders placed to the manufacturer, not supported by the same behavior on the final client's sales. According to the tactical planner inquired, this is an expected occurrence, especially for *sales companies* such as this one, where transit time is higher than one month. This is a result of the company's billing policy. If a contract with an updated price is not yet open, *sales companies* are not able to place orders for the following year. This happens because the manufacturer charges the *sales companies* for the prices that are in practice at the moment the shipments arrive. Usually, these contracts are not yet open in December, which leads *sales companies* with long transit times to place orders for the first months of the following year in December. Thus, guaranteeing product availability for the following months. The high BEM in December 2022 can also be credited to the same occurrence. Since it is an expected and mutually agreed-upon phenomenon, the manufacturer does not experience the BWE it generates and distributes these orders throughout the subsequent months. After this adjustment, there was a decrease in the accumulated BEM. The revised measures are 174,36 (previously 248,96) and 188,00 (previously 253,50) for December 2021 and December 2022, respectively, and can be consulted in Table 9.

The same adjustments were made to the remaining pairs of *sales companies* and families of products. The corresponding results are in Table 10.

Table 9 - Revised bullwhip effect measures for ICSA - NATURAIS

			Final client sales	Orders	Dif	Order Variance	Sale Variance	BEM	BEM Acum
2021	JAN	0	3545,63	50,00	-3495,63	0,00	0,00	0,00	0,00
	FEB	1	3410,74	1157,50	-2253,24	669903,13	9097,66	73,63	73,63
	MAR	2	5216,70	1510,00	-3706,70	760033,33	1012026,96	0,75	74,39
	APR	3	4697,18	1700,00	-2997,18	722500,00	776921,51	0,93	75,32
	MAY	4	4155,36	8893,00	4737,64	15817089,80	583464,96	27,11	102,42
	JUN	5	3982,27	8855,00	4872,73	13068504,17	475049,14	27,51	129,93
	JUL	6	4139,51	7385,00	3245,49	7791175,00	395990,07	19,68	149,61
	AUG	7	4827,62	7312,00	2484,38	6683168,00	394483,46	16,94	166,55
	SEP	8	4040,82	886,00	-3154,82	87221,78	349890,71	0,25	166,80
	OCT	9	4150,66	3570,00	-580,66	1274490,00	311551,57	4,09	170,89
	NOV	10	3816,09	1079,00	-2737,09	105840,09	294982,55	0,36	171,25
	DEC	11	3164,66	3634,40	469,74	1100738,61	354115,26	3,11	**174,36**
2022	JAN	12	3146,31	3634,92	488,09	1016066,41	393926,07	2,58	176,94
	FEB	13	3021,11	3634,40	613,29	943490,24	435263,28	2,17	179,11
	MAR	14	3842,30	3634,60	-207,90	880590,89	404961,38	2,17	181,28
	APR	15	4113,63	3634,40	-479,23	825553,96	379766,72	2,17	183,45
	MAY	16	5499,61	1897,00	-3602,61	211682,88	496479,82	0,43	183,88
	JUN	17	1883,14	3314,68	1431,54	610394,64	726995,38	0,84	184,72
	JUL	18	3569,33	2153,00	-1416,33	243968,89	693271,68	0,35	185,07
	AUG	19	4303,00	3120,00	-1183,00	486720,00	664646,06	0,73	185,80
	SEP	20	3068,97	844,00	-2224,97	33920,76	666413,00	0,05	185,85
	OCT	21	2854,85	1740,00	-1114,85	137618,18	682958,99	0,20	186,06
	NOV	22	2916,56	2180,00	-736,56	206626,09	688880,21	0,30	186,36
	DEC	23	1970,46	5605,00	3634,54	1309001,04	798171,37	1,64	**188,00**

Table 10 - Revised bullwhip effect measures

		2D	MICRO	NATURAIS	TT
AAUS	2021	77,6 (-20,8%)	-	1,37	-
	2022	95,52 (-15,2%)	-	1,66	-
ACDE	2021	255,64	11,85	22,82	-
	2022	270,99	31,31	29,46	-
ICSA	2021	-	40,59 (-30,8%)	174,36 (-29,8%)	295,8 (-9,8%)
	2022	-	49,47 (-24,53%)	188 (-25,8%)	332,48 (-7,3%)
ACSA	2021	891,41	-	79,76	4,77
	2022	903,12	-	82,5	6,17

After adjusting the BEMs, the most outstanding values are concerning February, May, June, July, and August of 2021. All result from abrupt rises in orders placed, in comparison to the values of the previous months, which do not translate into sales. Sales of this family of products for ICSA are relatively stable, whereas orders placed during 2021 are not. Considering the feedback obtained from the interviewed tactical planners, these oscillations can have several reasons: stock corrections or overestimation of sales to the final client, or both. Additionally, it is argued the possibility of being the result of an erroneous order placement with unrealistic predicted delivery dates. The manufacturer experiences the impact of these BEMs, regardless. During the remaining months, the BMEs are residual in comparison to previous values.

The BWE generated at the beginning of the year can be attributed to *sales companies'* desire to end the previous year with low stocks and, subsequently, reinforce them at the start of the succeeding year. Furthermore, for a *sales company* such as ICSA, situated in Chile, transit times are long and highly variable. Transit times can vary from thirty to sixty days. This affects stock adjustments, given that these corrections are made two months later, i.e., if ICSA sells more than expected at a given month, for example, this discrepancy between forecasted sales and actual sales is corrected only two months later. Moreover, this timeframe does not take into consideration product availability. If products are not immediately available to expedite to the *sales company* inventory will only be adjusted later. This dynamic explains the discrepancy between sales and order variance. Orders tend to fluctuate more and rises in orders are disparate from surges in sales. Although this phenomenon has an explanation, the BWE it generates has an actual impact on the manufacturer.

Overestimation of the final client's sales is also a potential cause of the discrepancy between orders and sales variance, i.e., it can explain the difference in behavior between the two. This is a quintessential example of the BWE. Although the tactical planners argue that there are no delays in deliveries of this family of products, there is a clear overestimation of sales. This family of products has one of the worst forecast accuracies upon analysis of this KPI for all *sales companies*, using the MASE measure (equation (16)). These values are in Table 11. For all *sales companies*, the forecasts are based on sales from the corresponding period of the previous years and the sales already in the pipeline for that month. Not one *sales company* employs an exact forecasting equation. As attested by AAUS's production planner, their forecasts are based on forecasts provided by their most important clients. In some cases, certain orders have already been placed whereas the remaining are based on expected sales. There is a tendency to rely on these forecasts which can have adverse consequences for the supply chain if these are not accurate. In the case of ICSA, professionals suggest that there is a tendency to continue to forecast high sales even when these start to decline, hoping to recover sales losses in the following months. This phenomenon is evident in Figure 15, which compares the final client's sales and forecasted sales. For instance, in October of 2021, the final client's sales start to decline while forecasts remain inflated during the subsequent months.

Table 11 - Forecast accuracy of each family of products per sales company (MASE)

	ICSA	ACDE	AAUS	ACSA
NATURAIS	1,42	0,69	0,80	0,91
MICRO	1,05	1,18	0,98	5,03
2D	0,96	0,76	0,90	0,69
TT	0,82	0,81	1,99	0,97

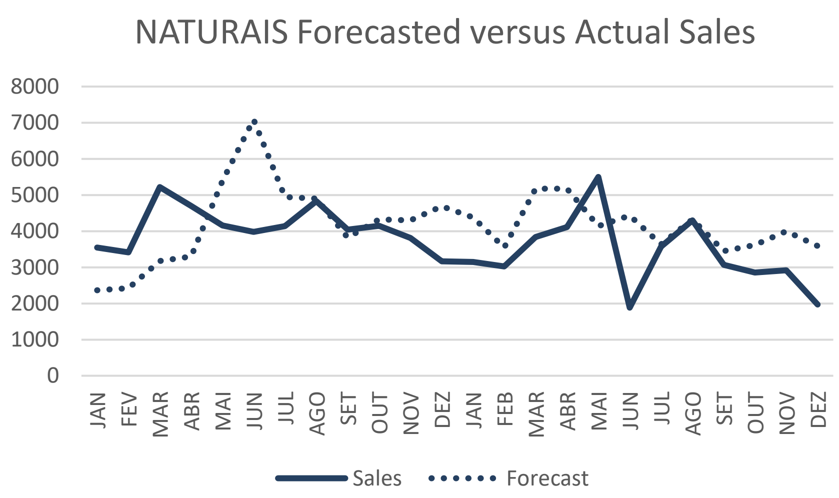

Figure 15 – ICSA's forecasted sales versus actual sales for NATURAIS family

Furthermore, erroneous order placement is a common occurrence in all *sales companies*. Orders are placed with unrealistic predicted delivery dates, assuming products are immediately available and, at times, not considering transit time and its variability. Before further analysis, the manufacturer is alerted and feels pressure to raise the production's pace. However, after engaging in further discussion with the *sales company's* management team regarding these orders, a new, more feasible, delivery date is mutually agreed upon.

Going hand in hand with the stock corrections previously mentioned, safety stocks are extremely responsive to the final client's forecasted needs and can lead to a BWE. The manufacturer is responsible and has visibility of the *sales companies'* stocks. A dynamic safety stock equation is employed with the intent to better allocate resources. This is done because of limited production capacity and fluctuating final client sales. For instance, the safety stock determined has a coverage of 50 days. The safety stock for month N is calculated as follows.

$$SS_N = \left(\frac{Needs_{N+1}}{22\ week\ days} * 22\ week\ days\right) + \left(\frac{Needs_{N+2}}{22\ week\ days} * 22\ week\ days\right) + \left(\frac{Needs_{N+3}}{22\ week\ days} * 6\ week\ days\right) \quad (17)$$

Figure 16 exhibits three real examples of forecasted sales for products from this family of products (NATURAIS) and the safety stock calculation for each respective month. Through the observation of the trendline, it is clear how sensitive the safety stock equation is to the forecasted sales of the following three months and its oscillations over time. The tactical planning is executed according to these values of safety stock. Being a *sales company* with a transit time of 2 months, these decisions are made significantly ahead of time. If sales are considerably lower or higher than forecasted, it can lead to overstock or stockouts, respectively. Both are detrimental to the company's performance and can only be corrected in a period of 2 months. Importantly, orders are placed based on safety stock calculations, i.e., although actual sales of month one for product '49x24 mm / 2. A. Light' is estimated to be thirty-four thousand, orders will be placed based on the safety stock calculation of forty-seven thousand. The same goes for the following months, leading to a discrepancy between the number of orders placed and the final client's sales.

	Forecast													
Product	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12	Trendline	Mean
49x24 mm / 2.A Light	34	26	20	3	54	42	3	69	14	16	71	0		
SS	47	37	68	97	63	75	87	49	87					67,716
45x24 mm / 2.A Light	303	372	610	379	460	514	535	402	355	425	109	52		
SS	1 085	1 114	979	1 120	1 159	1 034	873	809	548					969,065
45x24 mm / Extra Light	12	47	0	0	0	0	0	16	25	0	15	43		
SS	47	0	0	0	5	23	41	29	27					19,233

Figure 16 - Example of safety stock levels employing the current safety stock equation

Currency exchange also plays a role in contributing to the BWE. This happens, particularly, with ACSA. Based in South Africa, ACSA trades with the South African Rand, a currency with significant fluctuations in value over time. When this currency unit devalues in comparison to the Euro, the management team chooses to order solely what is strictly necessary and avoids any other purchase from the manufacturer. Conversely, when the South African Rand rises in value more orders are placed. This results in months with minimal or no order placements, while in other months the *sales company* places enormous pressure on the manufacturer to guarantee the seamless delivery of the required products.

Additionally, there are months when ACSA fails to send rolling forecasts to the tactical planning team. Generally, during these months, orders are not placed and the rolling plan and tactical planning for this company are not conducted. This leads to orders placed in the following months needing to be shipped with urgency. This phenomenon can be observed through the bullwhip effect measure table in Appendix A.

To put it concisely, after further analysis of the BEM calculated previously, it was found that the main causes lie in the company's billing policy, the *sales companies'* inventory policies, and the nature of the planning conducted by the tactical planning team. This phenomenon can also be attributed to possible tendencies to overestimate final client's sales and delay order placement. Other factors such as currency exchange and a lack of commitment to provide monthly rolling forecasts impact the BWE felt at the manufacturer level.

5.3. Improvement Measures

Considering the bullwhip effect causes identified previously, several improvement measures are proposed in this section. To follow these proposals easily, each measure will be paired with the corresponding cause. It is important to mention that given the study of the BWE in a real-life industrial environment, these causes and respective solutions are specific to this scenario. Thus, some do not correspond to what is studied in the literature. Others relate, to an extent, to measures supported by it.

Firstly, as clarified previously, the most alarming value of the BWE tends to be in December of both years which is the result of the company's billing policy. To prevent such a phenomenon from repeatedly happening in the future, this policy needs to be revised. Currently, clients are billed for each shipment based on the date of its arrival. If the manufacturer were to bill clients based on when the shipment is expedited, there would be a possibility of placing orders for the following year before the contracts are open. As an alternative, the previous year's contracts can be extended until new contracts are open. This would help avoid the trouble of delaying orders, even if it is an expected occurrence. This scenario is specific, although not exclusive, to this company. However, this problem was not encountered in the literature review performed. Thus, the company is recommended to:

- Revise the company's billing policy. For instance, extend the previous year's contracts until new contracts are open or bill clients for orders based on their expedition date.

The company has recently introduced an improvement in SAP where contracts validation is based on requested delivery date and, currently, they are based on requested shipment date. In the case of ICSA, for instance, with this measure, two months of time to prepare for the following year's prices.

Furthermore, stock corrections are also an important contributing factor to the BWE experienced by the manufacturer. The adjustments derive from the sales companies' inventory policies. Jakšič and Rusjan (2008) studied how different replenishment models affected the BWE and found that some policies in themselves induce the BWE while others behave inversely. However, inventory levels rely solely on the desired safety stock level and are the responsibility of the manufacturer. Replenishment orders are triggered by the forecasts provided by the *sales companies* and, subsequently, by the estimated stock levels. However, these orders need to be placed by the *sales company* which might choose not to do so. Currently, the manufacturer has full visibility of the *sales companies'* stocks. Nevertheless, this information should be combined with the analysis of the behavior of the order placement. As observed in the data, if the number of orders starts to decline at the end of the year, the tactical planners should analyze if stock levels are decreasing and discuss that behavior with the *sales company's* team. The main intent is to determine if that decrease in orders placed is due to a drop in sales for the upcoming months, or if there will be a rise in orders afterward to guarantee product availability and adjust stock levels. If the motive is the latter, tactical planners should dispute that behavior and agree to a timeline for the shipments of the expected orders in the following months. This aids in preventing the placement of unnecessary pressure on the manufacturer's production capacity during the first months of the year. Therefore, it is important to:

- Jointly monitor stock levels and orders placed and dispute behaviors out of the ordinary that will later be detrimental to the manufacturer, such as delaying orders to end the year with low inventory levels.

As supported by the literature the lead time affects the BWE. Short lead times have proven to be crucial for efficient supply chain operations (Kelepouris, Miliotis, and Pramatari, 2008). Different research carried out by Wang et al. (2008) found the order rate to have more oscillations with longer lead times, under an order-up-to policy. Later, Maaz and Ahmad (2016) ranked the operational causes of the BWE introduced by the literature and found the lead time to be the third most impactful cause. In this case, the transit time is a challenging factor that contributes to the long lead time of *sales companies* such as ICSA. There is very little that can be done to reduce it. Orders are shipped in containers by sea and several routes and carriers are analyzed to guarantee the shortest transit time possible. However, transit times remain high and are a contributing factor to the BWE. Thus, the *sales company* needs to maintain a continuous communication flow with the supply chain department, more specifically the tactical planning team. The lack of communication and information distortion is heavily addressed in the literature when discussing the BWE.

Implementing shared communication systems is imperative to enable the manufacturer's awareness of the actual market demand, in real-time. Moyaux, Chaib-Draa, and D'Amours (2007) demonstrated how information sharing grants the supplier a perception of market changes and adjustments to orders triggered by these changes. This is especially important for *sales companies* such as ICSA. Divergencies from forecasted sales need to be communicated continuously, instead of only at the beginning of the following month. Thus, the manufacturer can adjust what was previously determined and prepare in advance for changes to the tactical plan. This prevents constantly placing excessive pressure on the manufacturer at the beginning of each month. Changes to the shipment plan are gradually implemented, reducing the effect of dealing with an extended timeframe. This visibility helps reduce the BWE. A prudent course of action for the company would be to:

- Enhance visibility and frequency of communication with the *sales company*, to keep the manufacturer up to date on market needs' changes if the transit time cannot be reduced.

Currently, monthly meetings are conducted with the *sales companies'* management team, although this does not occur for ACSA. The tactical planner and the sales representative responsible for that market are invited to attend, along with the director of the supply chain department and the production planner of that *sales company*. However, the attendees are often only the tactical planner and the production planner of that *sales company*. When this happens, these meetings last approximately thirty minutes, whereas with the attendance of all invitees they extend for more than one hour. During these meetings, the main intent is to analyze the rolling plan together with the *sales company*. Several issues are discussed such as the consumption of cork and non-cork products, unexpected peaks in demand, and forecasts and shipment schedules for the following months. Additionally, stock levels are evaluated to get a perception of which products have stock below the desired level and which do not. If inventory levels are at unexpected values, these are further analyzed. Actual sales are compared to forecasted sales to understand forecast accuracy. If necessary, further explanation of the forecasts is provided. If stock levels for the upcoming months are lower than desired, the tactical planner suggests orders for the upcoming months. The sales representative together with the sales company's production planner give valuable inputs regarding the market's long-term needs. This information is important for the manufacturer to begin developing a long-term production plan. If the manufacturer feels that it is necessary, a long-term shipment plan is agreed upon to gradually build inventory levels and avoid putting pressure on the production capacity. These meetings are of higher value when all invitees attend, given that when facing an issue more inputs are provided to understand its roots. However, when only the tactical planner and production planner join in, meetings are more productive. When asked about this matter, the tactical planner understood it in the same way and suggested that, if all invitees are to attend, more time needs to be scheduled for these meetings. Importantly, these only occur with one of the *sales companies* considered in this analysis – AAUS. For ICSA and ACDE, meetings do not include the production planners, and for ACSA they do not happen. Considering the importance and value of the insights provided during these meetings, an effort should be made to change this. It is evident that these meetings are instrumental in controlling and mitigating the impacts of the BWE. Furthermore, with the presence of the *sales companies'* teams, there is a better commitment to the forecasts provided and replenishment plans. Therefore, it is advisable for the company to:

- Strive for the attendance of all stakeholders in meetings scheduled with the *sales companies* to discuss and analyze the rolling plan to guarantee that these meetings are of higher value to the tactical planning.
- Seek the scheduling of these meetings with all the *sales companies* studied.

Overestimation of sales is a classic root cause of the BWE. Currently, there is no standardized method to forecast sales, and *sales companies* predict final client sales based on the previous year's actual sales for the same period in combination with the final client's orders already placed. Eventually, this method should be revised, given that the forecasting technique used to predict demand has repercussions on the BWE generated (Chen et al., 2000; Chen et al., 1999). Forecasts need to be more accurate and reliable. There has been a transition to research in the Artificial Intelligence field and work toward applying machine learning (ML) to forecasting methods, specifically Neural Networks (NN) (Benboubker, Kissani, and Mourhir, 2019). The SO99 is a software that makes use of artificial intelligence and was developed with the intent of providing more accurate forecasts. Furthermore, it would be beneficial to standardize the forecasting technique used by the *sales companies* and guarantee that these values do not rely on the individual responsible for that task, as Wright and Yuan (2008) found that the BWE can be reduced by up to 55% by choosing an appropriate forecasting method and ordering policy. However, for now, the tactical planners need to pay closer attention to the forecasts provided by the *sales companies*. For instance, using a dashboard, forecasts can be visually compared to actual sales. This enables these professionals to identify behavioral patterns and overestimation of the final client's sales. If the values provided are not per what the tactical planners feel is plausible, this should be clarified and adjusted accordingly. Thus, it would be beneficial for the company to:

- Consider employing SO99 to generate the rolling forecasts for these *sales companies*.
- Revise and standardize the forecasting method to guarantee that forecasts do not rely on one individual from each *sales company*.
- Create dashboards to monitor important key performance indicators such as forecast accuracy and the final client's sales evolution.

Figures 17 through 19 show dashboards created in PowerBI to easily analyze the main KPIs. Through Figure 17's dashboard, it is possible to monitor forecast accuracy and delve into a family of products and market level. There are two measures of forecast accuracy: (1) the average value of forecast accuracy and (2) the average of forecast accuracy weighted by volume of sales. The chart on the top right of the dashboard compares the actual sales with the forecasted sales. Whilst the chart on the bottom right shows the evolution of the forecast accuracy over time. Figures 18 and 19 exhibit dashboards created to monitor final client sales distributed by the family of products and by month for all markets and the top ten markets, respectively. In both, there is a chart in the top right that compares forecasted sales with actual final client's sales along with the forecast accuracy evolution.

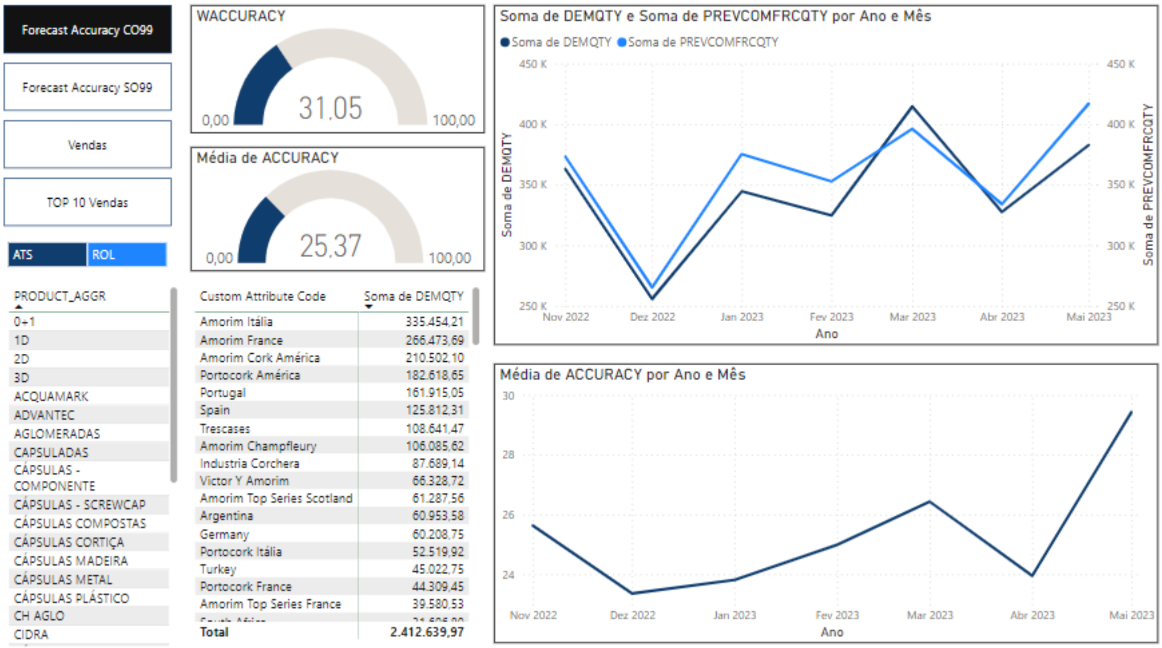

Figure 17 - Forecast accuracy dashboard in PowerBI

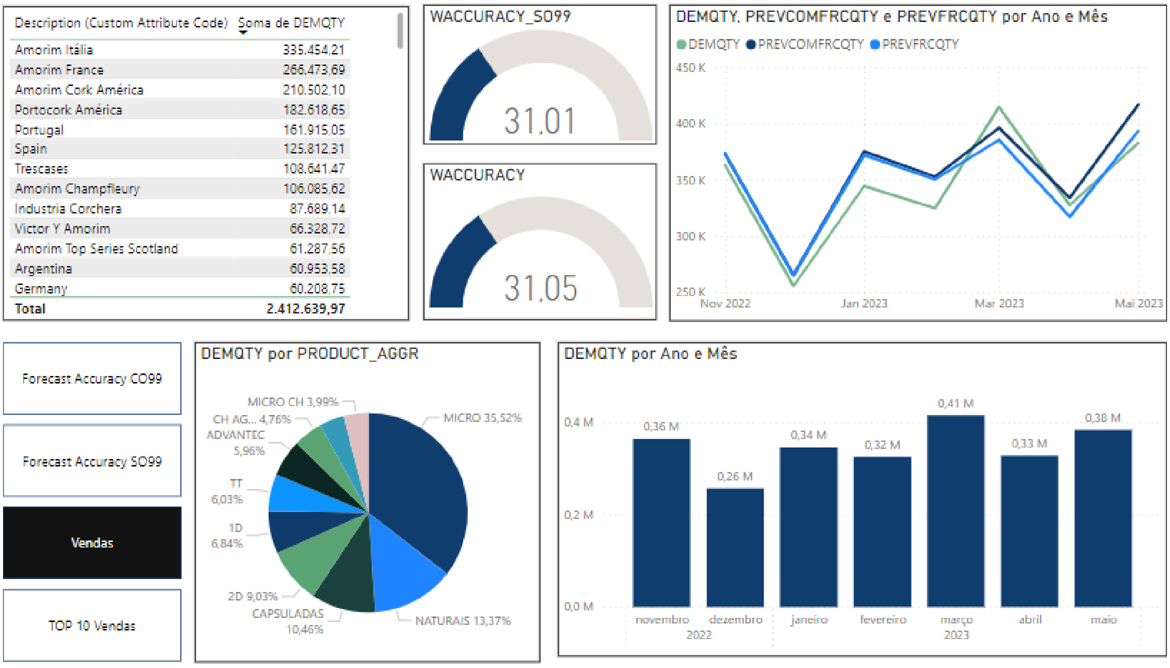

Figure 18 - Final client's sales dashboard in PowerBI

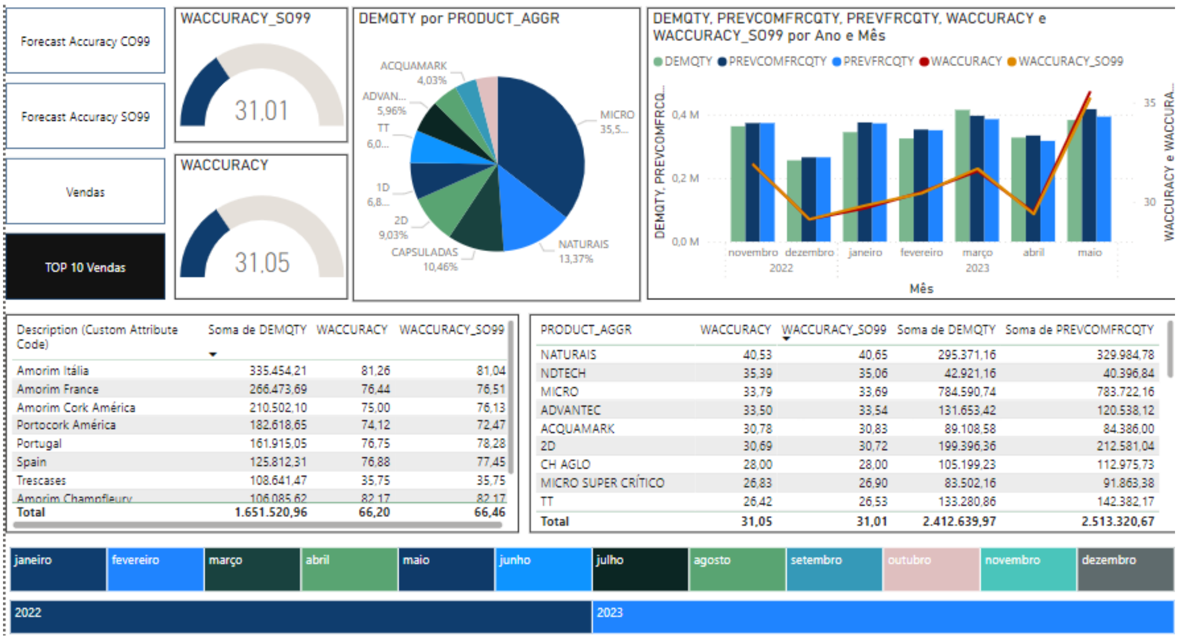

Figure 19 – Final client's sales of the top ten markets dashboard in PowerBI

Although the literature does not mention safety stock calculations as a contributing factor to the BWE, in this case, with a dynamic safety stock equation, it is. The current safety stock equation is highly sensitive to atypical values of forecasted sales. Thus, stock levels fluctuate more than desired. This factor is particularly important in situations such as the case of ICSA which has a long transit time. To an extent, these issues arise due to the long lead time for *sales companies* such as this one, which was explained previously. Due to the impossibility of reducing the lead time, other options are considered. Consequently, it is suggested to the company to:

- Revise the safety stock equation. The new equation should be less sensitive to forecasted values providing a safety stock level with fewer oscillations.

In the context of the project mentioned in section 5.3.1, the safety stock equation was revised. Three options were considered. Their equations are the following. Equation SS_2 is the current safety stock formula.

$$SS_1 = \left(\frac{Needs_{N+1}}{22\ week\ days}\right) * 50\ week\ days \qquad (18)$$

$$SS_2 = \left(\frac{Needs_{N+1}}{22\ week\ days} * 22\ week\ days\right) + \left(\frac{Needs_{N+2}}{22\ week\ days} * 22\ week\ days\right) + \left(\frac{Needs_{N+3}}{22\ week\ days} * 6\ week\ days\right) \quad (19)$$

$$SS_3 = \left(\frac{\left(\frac{Needs_{N+1} + Needs_{N+2} + Needs_{N+3}}{3}\right)}{22\ week\ days}\right) * 50\ week\ days \quad (20)$$

Real values are applied to these equations to study the evolution of safety stock levels over 9 months. Each product was chosen by the tactical planning team and has a different type a behavior, to study these equations on products with different demand patterns. The values are shown in Figure 20. The highlighted rows correspond to the equation chosen – equation SS_3. This decision was made by the tactical planning team, based on the mean value and fluctuation over time. Through the trendline, it is possible to conclude that, compared to others, this formula maintains the safety stock level more stable. Through the mean value is possible to conclude that maintaining the same coverage over time but with less fluctuation of inventory levels is feasible.

	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11	Month 12	Trendline	Mean
49x24 mm / 2.A Light	34	26	20	3	54	42	3	69	14	16	71	0		
SS_1	60	45	6	123	96	6	156	31	37					61,998
SS_2	47	37	68	97	63	75	87	49	87					67,716
SS_3	37	58	75	75	86	64	75	76	66					67,859
Max(SS_1, SS_2, SS_3)	60	58	75	123	96	75	156	76	87					89,446
45x24 mm / 2.A Light	303	372	610	379	460	514	535	402	355	425	109	52		
SS_1	845	1 386	862	1 045	1 169	1 216	915	807	965					1 023,109
SS_2	1 085	1 114	979	1 120	1 159	1 034	873	809	548					969,065
SS_3	1 031	1 097	1 025	1 143	1 100	979	895	673	444					931,962
Max(SS_1, SS_2, SS_3)	1 085	1 386	1 025	1 143	1 169	1 216	915	809	965					1 079,123
45x24 mm / Extra Light	12	47	0	0	0	0	0	16	25	0	15	43		
SS_1	106	0	0	0	0	0	36	57	0					22,378
SS_2	47	0	0	0	5	23	41	29	27					19,233
SS_3	36	0	0	0	12	31	31	31	44					20,707
Max(SS_1, SS_2, SS_3)	106	0	0	0	12	31	41	57	44					32,525

Figure 20 - Safety stock calculations

Regarding the impact currency exchange has on the BWE, little can be done to avoid it. Due to it possibly not being a common occurrence, the literature fails to consider situations of this nature. Insurance against currency risk is a common method to deal with unexpected changes in exchange rates in companies that operate internationally. The company already subscribes to these types of insurance for currencies such as the United States dollar. Nonetheless, for an extremely volatile currency such as the South-African rand, the company chooses to engage in currency management and strategically time orders to maximize profit margins. However, a compromise can be reached. ACSA needs to have a sense of the difficulties this behavior causes and manage the orders placed to reduce the oscillatory nature of the order rate. Furthermore, communication with this *sales company* should be continuous to avoid placing such pressure on the manufacturer and give a sense of which products will be ordered in the upcoming weeks. A sensible suggestion is to:

- Seek to reach a compromise and maintain continuous communication with the *sales company* at issue to anticipate a higher number or lack of orders for the upcoming weeks.

Additionally, ACSA fails to send rolling forecasts every month. These are of the utmost importance since without them rolling plans cannot be made, and tactical planning cannot be conducted. The following section, regarding a project developed simultaneously with this dissertation, elucidates the importance of this tool in this context. Given all that was mentioned previously, the manufacturer must guarantee that every *sales company* sends its respective rolling forecast. Furthermore, the *sales company* should understand its importance and the role it plays in the effective management of the supply chain. It is important for the manufacturer to:

- Aim at generating the rolling plans for every *sales company*, putting pressure on their management teams to send their rolling forecasts every month.

Ultimately, the BEM is an important indicator to analyze for effective supply chain management. However, it is important to evaluate the results in detail, given that data can be biased or inaccurate. Furthermore, the analysis of the BWE should not be strictly quantitative. This phenomenon is unavoidable, and the main benefit of this analysis lies in the discussion of its causes during a qualitative analysis of the results, through tools such as interviews. As shown in this dissertation, an analysis of this nature provides valuable insights into the whole supply chain operations and triggers the discussion of issues not mentioned otherwise. It enables the identification of areas for improvement such as information-sharing mechanisms or company policies that have an indirect impact on the company's performance.

5.3.1. E-supply Improvements and Purpose

Parallel to the development of this dissertation, a project, with a duration of five months, was undertaken to improve the E-supply tool in the Rolling Plans Management component. This tool serves several benefits to the tactical planning process.

With this tool, the sales company's expectations regarding the final client's sales can be aligned with the manufacturer's expectations. Furthermore, it is possible to keep track of stock fluctuations over the following months (based on sales forecast and pending arrivals) and analyze the safety stock's coverage. Safety stock is controlled with the aid of visual tools such as graphics that enable the comparison of the safety stock levels to the estimated stock level and forecasted sales. By these means, it is possible to give inputs to keep inventory at the desired level. Additionally, problems are anticipated. For instance, if the consumption of one product will decrease to the detriment of another, these switches will cause a significant change in inventory levels for both products. Such changes are foreseen, and the manufacturer can plan and work progressively toward the desired stock level of each product. In other circumstances, these phenomena lead to stockouts and emergency shipments, such as premium air freight, resulting in additional costs.

Given the potential benefits of employing this tool, this project aimed at improving it by changing several of its functional requirements. A technology consulting service was outsourced to help the development of this tool in OutSystems. The project started with the identification of the needs and initial problems of the E-supply in the Rolling Plans Management component. Afterward, the main objectives of this project were prioritized, and a development plan was created. During the five months, daily meetings with the consultant were conducted to provide updates on recent developments and answer questions that needed further clarification. The main difficulties during the execution of this project lay in the explanation of technical terms to the consultant, and the validation of all the improvements implemented.

As mentioned previously, the safety stock equation was altered to one which maintains stock levels more stable. Additionally, an "Export Plan" button was placed at the top of the screen to enable the export of the rolling plan to an Excel file. This facilitates the analysis and the forwarding of the rolling plans to all interested parties. Several other functionalities were revised such as the automatic order suggestion based on the deviation of the estimated stock from the safety stock. Additionally, alerts were created for negative values of these deviations and stockouts to warn the tactical planner that action is required.

For instance, Figure 21 shows an example of a product whose sales will significantly rise between August and January. This leads to a considerable rise in safety stock levels from June to November. This reinforcement of inventory is more than double the usual level. Faced with such an abrupt change, the manufacturer needs to start building the stock to its desired level in advance. This tool enables this analysis more easily.

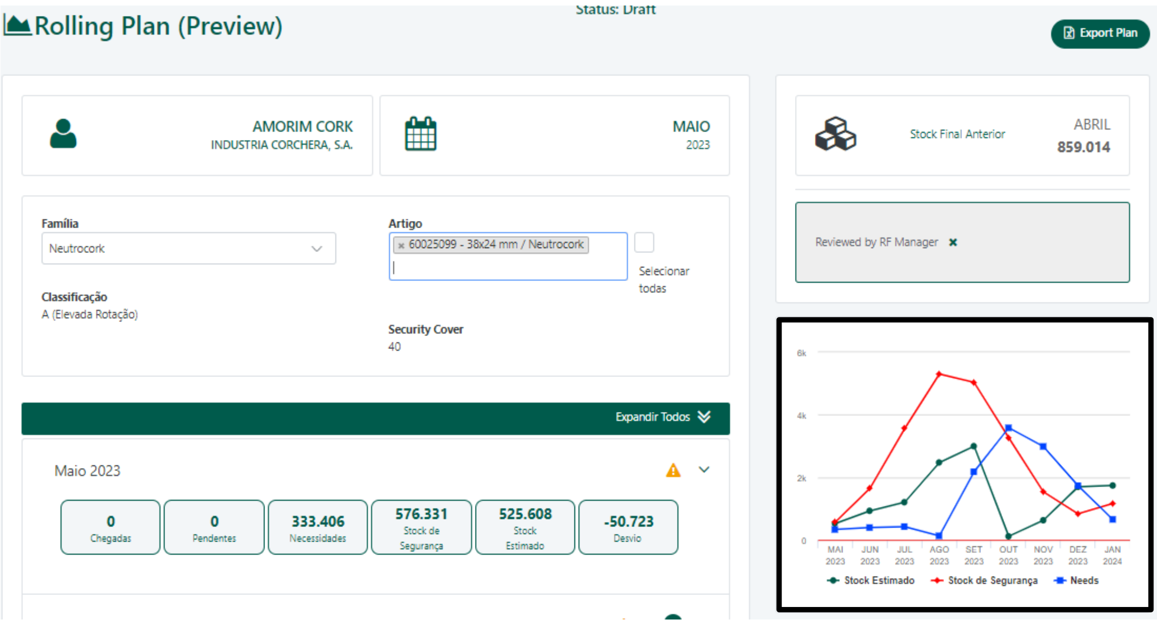

Figure 21 - E-supply screen of the rolling plan component

6. CONCLUSION

The current dissertation aimed to quantify and identify the main causes of the bullwhip effect in a company inserted in the cork-stopper manufacturing industry.

Through the collection of 2021 and 2022 data on the final client's sales and orders placed with the manufacturer, the bullwhip effect was calculated. Afterward, its results were qualitatively analyzed, and further insights were provided through interviews with the parties involved in the matter. This enabled the drawing of conclusions regarding the objective of this research.

Through the quantitative analysis, it can be inferred that there is a BWE at the manufacturer level induced by the *sales companies* studied. However, the main intention is not to simply analyze these values quantitatively. Being an unavoidable phenomenon, the focus should be on its causes. This discussion triggers important dialogue regarding supply chain operations and potential improvement areas.

It can be established that the lack of a standardized forecasting technique leading, in some cases, to overestimation of sales and long lead times inducing the BWE in this scenario. These had been previously identified in the literature by researchers such as Chen et. al (2000) and Wang et. al (2008). Other causes specific to the company were found to trigger this phenomenon. For instance, the company's current billing policy, the safety stock equation employed, the failure to send rolling forecasts, along with the currency exchange, in a particular case.

Recommendations are made to seek the reduction of its impacts on the supply chain. The revision of the company's current billing policy and monitoring of the evolution of sales, inventory levels, and indicators such as forecast accuracy through the dashboard are a few. In some cases, it is better to enhance communication and maintain a continuous information flow throughout the entire month.

Although the impacts of the BWE were not quantified in this research. Through unstructured interviews with tactical planners of the company, it was made clear the pressure the company was put under due to this phenomenon. Thus, efforts should be made to reduce its impacts and strive for its mitigation. Hence, it is advisable to adopt a proactive attitude with periodic reviews of these measures and their contributing factors. As mentioned previously, these lead to dialogues that promote a philosophy of continuous improvement.

This research makes a dual contribution to the existing literature. Firstly, the BWE is studied in a different context – the cork-stopper manufacturing industry. This enabled the discovery of causes specific to this setting, not found during the literature review. Secondly, the findings of previous research were further supported by the analysis conducted in this dissertation.

Several limitations were found during the execution of this project. Due to inconsistencies, data was aggregated by family of products. This limited the analyses conducted and led to broader conclusions. Thus, for future research, this limitation should be overcome to provide a more detailed analysis of the BWE at the product level. This would be particularly relevant for the study of this phenomenon on the most critical products. Furthermore, the quantification of the impacts of this phenomenon in the company can be interesting to validate the effects of the BWE and support the premise that it has detrimental consequences on the supply chain performance.

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ATTACHMENT A: HISTORY OF CORTICEIRA AMORIM IN CHRONOLOGICAL ORDER

- 1870 – António Alves Amorim initiates its activity with the establishment of a manual cork stopper factory, in Vila Nova de Gaia.
- 1908 – A new workshop is founded in Santa Maria da Feira to expand production.
- 1922 – The first company, Amorim & Irmãos, Lda. is born, by the children of António Alves Amorim and Ana Pinto Alves, with a social capital of ninety thousand *escudos*. This was the company that later originated the group Corticeira Amorim.
- 1930 – Amorim & Irmãos is now the largest cork stopper factory in the north of Portugal, with 150 workers. Innovative products were developed, and cork began to be used in several different products such as thermal and acoustic coverings. At this time, Amorim & Irmãos had crossed geographical borders, exporting cork products to countries such as Japan, Germany, and the United States of America.
- 1935 – A small warehouse is bought in Abrantes, close to Portugal's main cork oak forest area, with the intent of counteracting the trend of obtaining raw materials from foreign countries.
- 1944 – On the 21st of March a fire destroys the company's largest facility in Santa Maria de Lamas, originating losses of fifteen million *escudos.*
- 1950 – With its knowledge of cork and the functioning of the market, Amorim & Irmãos, Lda. regains its position as the largest cork manufacturer in the north of Portugal.
- 1962 – With the motto "not just one market, not just one client, not just one currency, not just one product", Corticeira Amorim fosters a strategy for the verticalization of the business, aiming at world leadership in the production and export of cork products.
- 1963 – Corticeira Amorim is created, an industrial unit to produce cork granules and agglomerates, with the intent of transforming 70% of the waste produced by Amorim & Irmãos, Lda. [generated by the manufacturing of cork stoppers].
- 1966 – 1969 – During this period many Portuguese and foreign companies were acquired and created, including Corticeira Amorim Algarve, Lda. - producing black cork agglomerates, used in thermal, acoustic, and vibrations insulation.
- 1969 – Corticeira Amorim invests in pioneering projects intending to incorporate cork in various products.
- 1972 – Comatral – Compagnie Marocaine de Transformation du Liège, S.A. in Skhirate, Marocoo, is founded.
- 1973 – Corticeira Amorim begins to produce cork rubber.

- 1978 – Portocork Internacional, S.A., is also established and it's responsible for producing natural cork stoppers.
- 1981 – This year is marked by an expansion overseas, with the formation of a company in Canada to market cork rubber.
- 1982 – Champcork Rolhas de Champanhe, S.A. is created to produce corks for champagne and sparkling wines.
- 1988 – Corticeira Amorim's four largest companies launch an initial public offering on the Lisbon Stock Exchange.
- 1989 – Acquisition of RARO – Rufino Alves Ribeiro e filhos, Lda., specialized in the manufacture of capsulated cork stoppers. Additionally, during this year, the Swedish Wicanders group is acquired.
- 1992 – During this year, other companies are acquired by the group. Américo Amorim is elected Chairman of the Confédération Européenne du Liège. It is also in 1992, that the Academia Amorim is founded.
- 1997 – Amorim Isolamentos, S.A. is formed to produce insulation of cork boards.
- 1999 – Corticeira Amorim acquires 50% of the share capital of the Chilean company Industria Corchera, S.A.
- 2000 – Creation of the Ponte de Sôr unit for the preparations of raw materials and the manufacture of discs.
- 2001 – During the same year, António Rios Amorim succeeds Américo Amorim, meaning the fourth generation of the family now takes the leadership of the group.
- 2002 – The process to restructure the Natural Cork Business Unit factories begins.
- 2005 – Acquisition of the Equipar Group, located in Coruche, with industrial units equipped with the most advanced technology.
- 2007 – From the integration of the Cork Rubber and Technical Agglomerates Bus, Amorim Cork Composites is created.
- 2010 – Amorim Florestal, S.A. creates the R&D department to focus on the improvement of all processes, from the cork oak forest to the final product.
- 2014 – Amorim Cork Ventures – a business incubator - was launched.
- 2017 – 2020 – Companies, including Socori – Sociedade de Cortiças de Rio Meão, S.A. (previously owned by Etablissements Christian Bourrassé), were acquired by Corticeira Amorim and its subsidiaries.
- 2020 – Amorim Australasia is established in Regency Park, South Australia, and constitutes the largest Australian importer of cork for the wine industry.

ATTACHMENT B: PRODUCT PORTFOLIO

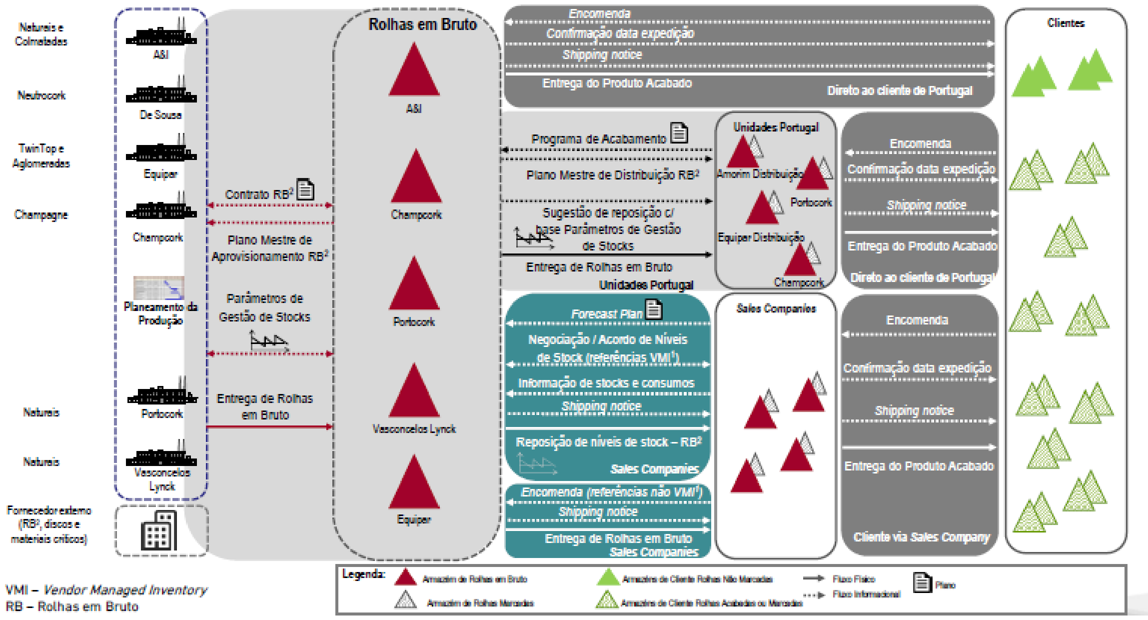
Wine Segment	Cork-Stopper	Description	Image
Still	Natural	Natural cork stoppers are carved as a single piece and are entirely natural cork stoppers. Naturity (a technology developed by Amorim Cork) is one of the processes these cork stoppers are put through to guarantee that all TCA is removed from the cork.	
	Acquamark ®	Acquamark® is a natural cork stopper with a water-based coating, making it superior in sealing effectiveness and wine preservation.	
	Helix	Helix is an ergonomically designed cork stopper and glass bottle duo, enabling the uncorking without a corkscrew.	
	Twin Top ®	The Twin Top® is an agglomerate cork body with a natural cork disc at each end of the cork stopper. The Twin Top EVO is similar, differentiating in the granulate's size – it has a micro-agglomerate cork body.	

	Qork	Qork is the most sustainable micro-granulated cork stopper. It has a minimum of 80% natural cork granules and 100% vegetable polyols. It also features Xpür® - a technology that delivers non-detectable TCA performance and deviates other substances that could trigger sensory deviations.	
	NeutroCork ®	NeutroCork® is a uniform-sized micro granule cork stopper that offers excellent structural stability.	
	Advantec ®	Advantec® is an innovative coated technical cork with preventive and corrective anti-TCA measures, including the ROSA® system. This system uses steam and water under pressure to force out volatile trace compounds. Advantec Colours aims at a younger audience and combines the cork stopper's color with its technical performance.	 
	NDTech	NDTech is a quality control screening technology for natural corks that enables the delivery	

		of the first non-detectable TCA performance. NDTech is a technology developed and patented by Amorim that tests each cork stopper individually.	
Spirit		The spirit wines segment includes only capsulated cork stoppers. These are produced by one of the group's companies – Amorim Top Series (ATS). ATS produces any variation of capsulated cork stoppers, from standard products to fully customizable ones. These can range considerably in price according to specifications and level of customization.	
Sparkling	NDTech sparkling	NDTech Sparkling are sparkling wine cork stoppers that go through the TCA detecting process explained in the NDTech still wine cork stopper mentioned prior. These machines can also fit the diameters of sparkling wine cork stoppers.	
	Two Disk	The two-disk cork-stopper is made of cork granulate with two disks of natural cork on the top	

		of the cork-stopper that is in contact with the wine.	

ATTACHMENT C: SUPPLY CHAIN MODEL



(1) VMI – *Vendor Managed Inventory*
(2) RB – Rolhas em Bruto

APPENDIX A: RESULTS OF THE QUANTITATIVE ANALYSIS OF THE BULWHIPP EFFECT

AAUS - 2D

			Final client sales	Orders	Dif	Order Variance	Sale Variance	BEM	BEM Acum
2021	JAN	0	3317,80	3204,00	-113,8	0,00	0,00	0,00	0,00
	FEB	1	2587,10	4860,00	1542,20	11809800,00	266961,25	44,24	44,24
	MAR	2	3636,50	802,00	-1785,10	214401,33	289455,42	0,74	44,98
	APR	3	2168,55	212,00	-3424,50	11236,00	448964,12	0,03	45,00
	MAY	4	2611,50	2516,00	347,45	1266051,20	356692,71	3,55	48,55
	JUN	5	4290,20	5400,00	2788,50	4860000,00	624224,05	7,79	56,34
	JUL	6	4836,00	7776,00	3485,80	8638025,14	949752,18	9,10	65,43
	AUG	7	2907,50	2268,00	1212,00	642978,00	838511,96	0,77	66,20
	SEP	8	4787,00	6048,00	4184,50	4064256,00	981239,45	4,14	70,34
	OCT	9	4583,00	7092,00	-1763,00	5029646,40	998272,10	5,04	75,38
	NOV	10	4487,00	3024,00	10717,00	831325,09	974470,60	0,85	76,23
	DEC	11	3317,55	15300,00	-1169,45	19507500,00	895408,33	21,79	**98,02**
2022	JAN	12	2140,00	0,00	-3317,55	0,00	990989,58	0,00	98,02
	FEB	13	3583,50	0,00	-3583,50	0,00	915114,08	0,00	98,02
	MAR	14	2000,00	0,00	-2000,00	0,00	1003387,74	0,00	98,02
	APR	15	3397,50	72,00	-3325,50	324,00	936518,70	0,00	98,02
	MAY	16	2908,50	792,00	-2116,50	36897,88	893116,88	0,04	98,06
	JUN	17	2608,50	4572,00	1963,50	1161288,00	874150,04	1,33	99,39
	JUL	18	2970,10	4752,00	1781,90	1188500,21	832891,07	1,43	100,82
	AUG	19	4271,00	8496,00	4225,00	3609100,80	833985,91	4,33	105,14
	SEP	20	5869,50	5472,00	-397,50	1425846,86	1089681,89	1,31	106,45
	OCT	21	3348,00	8162,40	4814,40	3028398,81	1038701,65	2,92	109,37
	NOV	22	5191,10	218,40	-4972,70	2073,85	1118338,33	0,00	109,37
	DEC	23	2365,10	9487,80	7122,70	3750764,54	1128935,30	3,32	**112,69**

ACDE – 2D

			Final client sales	Orders	Dif	Order Variance	Sale Variance	BEM	BEM Acum
2021	JAN	0	1357,05	468,32	-889,73	0,00	0,00	0,00	0,00
	FEB	1	1254,20	1236,00	-18,20	763848,00	5289,06	144,42	144,42
	MAR	2	1554,78	1336,00	-218,78	594965,33	23337,27	25,49	169,91
	APR	3	1765,83	1416,00	-349,83	501264,00	51119,34	9,81	179,72
	MAY	4	1407,91	1368,00	-39,91	374284,80	39466,15	9,48	189,20
	JUN	5	1732,96	2298,00	565,04	880134,00	43277,62	20,34	209,54
	JUL	6	1449,35	3120,00	1670,65	1390628,57	36627,58	37,97	247,51
	AUG	7	2283,24	900,00	-1383,24	101250,00	107461,78	0,94	248,45
	SEP	8	760,64	1837,20	1076,56	375033,76	172433,73	2,17	250,62
	OCT	9	2036,71	2548,00	511,29	649230,40	181298,86	3,58	254,21
	NOV	10	2196,36	1716,00	-480,36	267696,00	199952,09	1,34	255,54
	DEC	11	1541,30	468,00	-1073,30	18252,00	182266,07	0,10	**255,64**
2022	JAN	12	2357,20	1743,00	-614,20	233696,08	209829,46	1,11	256,76
	FEB	13	1447,15	2180,00	732,85	339457,14	197205,55	1,72	258,48
	MAR	14	1631,97	3280,50	1648,53	717445,35	183149,46	3,92	262,40
	APR	15	1591,50	324,00	-1267,50	6561,00	171166,58	0,04	262,44
	MAY	16	1477,65	1346,00	-131,65	106571,53	162175,86	0,66	263,09
	JUN	17	1175,90	1008,50	-167,40	56504,01	164498,64	0,34	263,44
	JUL	18	1799,15	1758,50	-40,65	162753,80	157197,02	1,04	264,47
	AUG	19	1722,59	1620,00	-102,59	131220,00	149427,88	0,88	265,35
	SEP	20	1993,30	3153,00	1159,70	473400,43	148339,81	3,19	268,54
	OCT	21	2374,52	1912,80	-461,72	166309,27	165493,12	1,00	269,55
	NOV	22	2422,75	2000,00	-422,75	173913,04	182099,67	0,96	270,50
	DEC	23	1376,00	1443,00	67,00	86760,38	178835,31	0,49	**270,99**

ICSA – TT

			Final client sales	Orders	Dif	Order Variance	Sale Variance	BEM	BEM Acum
2021	JAN	0	2693,64	0,00	-2693,64	0,00	0,00	0,00	0,00
	FEB	1	2630,00	595,00	-2035,00	177012,50	2025,02	87,41	87,41
	MAR	2	2980,39	1570,00	-1410,39	821633,33	34841,46	23,58	110,99
	APR	3	2484,06	2805,00	320,94	1967006,25	43384,54	45,34	156,33
	MAY	4	3002,43	4760,00	1757,57	4531520,00	51193,15	88,52	244,85
	JUN	5	3770,85	4005,00	234,15	2673337,50	211896,93	12,62	257,47
	JUL	6	2186,17	3665,00	1478,83	1918889,29	254962,71	7,53	264,99
	AUG	7	3334,56	5735,00	2400,44	4111278,13	251497,55	16,35	281,34
	SEP	8	2822,16	3715,00	892,84	1533469,44	220502,79	6,95	288,30
	OCT	9	3241,06	2610,00	-631,06	681210,00	209165,51	3,26	291,55
	NOV	10	3415,68	2210,00	-1205,68	444009,09	211080,71	2,10	293,66
	DEC	11	1757,25	11345,00	9587,75	10725752,08	312460,41	34,33	**327,98**
2022	JAN	12	2934,84	0,00	-2934,84	0,00	286854,57	0,00	327,98
	FEB	13	2283,97	0,00	-2283,97	0,00	288954,92	0,00	327,98
	MAR	14	2979,08	0,00	-2979,08	0,00	269916,97	0,00	327,98
	APR	15	3429,67	255,00	-3174,67	4064,06	274068,43	0,01	328,00
	MAY	16	3156,77	2210,00	-946,77	287300,00	261722,27	1,10	329,10
	JUN	17	2593,99	4080,00	1486,01	924800,00	251141,83	3,68	332,78
	JUL	18	3111,10	2805,00	-306,10	414106,58	240197,67	1,72	334,50
	AUG	19	2193,77	7225,00	5031,23	2610031,25	251418,99	10,38	344,88
	SEP	20	2520,46	1275,00	-1245,46	77410,71	244021,52	0,32	345,20
	OCT	21	2878,78	2210,00	-668,78	222004,55	232491,05	0,95	346,15
	NOV	22	3204,08	765,00	-2439,08	25444,57	227801,24	0,11	346,27
	DEC	23	2005,68	8540,00	6534,32	3038816,67	247767,65	12,26	**358,53**

ACSA – 2D

			Final client sales	Orders	Dif	Order Variance	Sale Variance	BEM	BEM Acum
2021	JAN	0	496,61	539,40	42,79	0,00	0,00	0,00	0,00
	FEB	1	531,83	864,00	332,17	373248,00	620,22	601,80	601,80
	MAR	2	458,40	971,40	513,00	314539,32	1348,74	233,21	835,01
	APR	3	326,05	0,00	-326,05	0,00	8087,09	0,00	835,01
	MAY	4	467,57	43,20	-424,37	373,25	6106,49	0,06	835,07
	JUN	5	460,51	777,60	317,09	100776,96	4888,44	20,62	855,68
	JUL	6	626,19	777,60	151,41	86380,25	8171,33	10,57	866,25
	AUG	7	413,00	813,60	400,60	82743,12	7582,38	10,91	877,17
	SEP	8	661,85	777,60	115,75	67184,64	10617,46	6,33	883,49
	OCT	9	529,15	0,00	-529,15	0,00	9564,43	0,00	883,49
	NOV	10	532,60	400,00	-132,60	14545,45	8722,45	1,67	885,16
	DEC	11	585,97	800,00	214,03	53333,33	8540,52	6,24	**891,41**
2022	JAN	12	976,27	180,00	-796,27	2492,31	24733,55	0,10	891,51
	FEB	13	512,44	0,00	-512,44	0,00	22900,07	0,00	891,51
	MAR	14	738,26	1002,60	264,34	67013,78	23850,13	2,81	894,32
	APR	15	250,65	950,40	699,75	56453,76	28028,38	2,01	896,33
	MAY	16	594,31	561,60	-32,71	18552,62	26480,34	0,70	897,03
	JUN	17	364,82	432,00	67,18	10368,00	26606,62	0,39	897,42
	JUL	18	864,20	0,00	-864,20	0,00	31033,34	0,00	897,42
	AUG	19	589,70	586,40	-3,30	17193,25	29491,70	0,58	898,00
	SEP	20	656,46	587,20	-69,26	16419,23	28566,81	0,57	898,58
	OCT	21	378,20	1041,80	663,60	49333,97	28613,44	1,72	900,30
	NOV	22	1276,53	1731,20	454,67	130306,67	50507,30	2,58	902,88
	DEC	23	294,80	547,20	252,40	12476,16	51650,59	0,24	**903,12**

APPENDIX B: QUALITATIVE ANALYSIS OF THE BULLWHIP EFFECT

AAUS – 2D

Similarly, to ICSA – NATURAIS, the most noticeable moment is in December of 2021. The same explanation applies to this scenario, where orders rise in December followed by 4 months without the placement of orders. As mentioned in the dissertations, this occurs due to the company's billing policy and does not constitute an actual bullwhip effect, given that it is an expected occurrence. By dividing those orders throughout the 5 months there was a decrease in the accumulated bullwhip effect measure to 77,60 at the end of 2021 (previously 98,02) and 95,52 at the end of 2022 (previously 112,69).

			Final client sales	Orders	Dif	Order Variance	Sale Variance	BEM	BEM Acum
2021	JAN	0	3317,80	3204,00	-113,8	0,00	0,00	0,00	0,00
	FEB	1	2587,10	4860,00	1542,20	11809800,00	266961,25	44,24	44,24
	MAR	2	3636,50	802,00	-1785,10	214401,33	289455,42	0,74	44,98
	APR	3	2168,55	212,00	-3424,50	11236,00	448964,12	0,03	45,00
	MAY	4	2611,50	2516,00	347,45	1266051,20	356692,71	3,55	48,55
	JUN	5	4290,20	5400,00	2788,50	4860000,00	624224,05	7,79	56,34
	JUL	6	4836,00	7776,00	3485,80	8638025,14	949752,18	9,10	65,43
	AUG	7	2907,50	2268,00	1212,00	642978,00	838511,96	0,77	66,20
	SEP	8	4787,00	6048,00	4184,50	4064256,00	981239,45	4,14	70,34
	OCT	9	4583,00	7092,00	-1763,00	5029646,40	998272,10	5,04	75,38
	NOV	10	4487,00	3024,00	-758,00	831325,09	974470,60	0,85	76,23
	DEC	11	3317,55	3825,00	-1169,45	1219218,75	895408,33	1,36	**77,60**
2022	JAN	12	2140,00	3825,00	507,45	1125432,69	990989,58	1,14	78,73
	FEB	13	3583,50	3825,00	241,50	1045044,64	915114,08	1,14	79,87
	MAR	14	2000,00	3825,00	1825,00	975375,00	1003387,74	0,97	80,85
	APR	15	3397,50	72,00	-3325,50	324,00	936518,70	0,00	80,85
	MAY	16	2908,50	792,00	-2116,50	36897,88	893116,88	0,04	80,89
	JUN	17	2608,50	4572,00	1963,50	1161288,00	874150,04	1,33	82,22
	JUL	18	2970,10	4752,00	1781,90	1188500,21	832891,07	1,43	83,64
	AUG	19	4271,00	8496,00	4225,00	3609100,80	833985,91	4,33	87,97
	SEP	20	5869,50	5472,00	-397,50	1425846,86	1089681,89	1,31	89,28
	OCT	21	3348,00	8162,40	4814,40	3028398,81	1038701,65	2,92	92,19
	NOV	22	5191,10	218,40	-4972,70	2073,85	1118338,33	0,00	92,20
	DEC	23	2365,10	9487,80	7122,70	3750764,54	1128935,30	3,32	**95,52**

A second instance where the *bullwhip effect measure* is pronounced is in February of 2021. In this moment, there is a big discrepancy between variance of orders and variance of sales. Additionally, there is a significant difference between the orders placed for this month and the sales to final customer. This BWE is felt at the manufacturer level.

ACDE – 2D

In this case, there are not adjustments to be made to the data, and the quantitative analysis performed is accurate. From a mathematical standpoint, in February of 2021 there is a pronounced BEM given the discrepancy between order variance and sales variance, i.e., between January of 2021 and February of 2021 sales varied very little whereas orders varied greatly. The phenomenon observed in the following month (March 2021) is justified in an analogous way to the previous. The abrupt rise in orders placed in June and July of 2021, creates a BWE, given that the same does not translate to sales. The BWE generated by ACDE regarding the 2D family is indeed felt at the manufacturer and not merely observed on data. According to the tactical planners this can be a result of the erroneous placement of orders. However, from August 2021 until December of 2022, the BEMs are residual.

ICSA – TT

Similarly, to scenarios studied previously, the most unusual occurrence is the excessive placement of orders in December of 2021 followed by 3 months without orders. Having the same justification, this value was corrected which led to a decrease of the BEM. The adjusted measure is 295.80 at the end of 2021 (previously 327.98) and 332.48 at the end of 2022 (previously 358.53).

			Final client sales	Orders	Dif	Order Variance	Sale Variance	BEM	BEM Acum
2021	JAN	0	2693,64	0,00	-2693,64	0,00	0,00	0,00	0,00
	FEB	1	2630,00	595,00	-2035,00	177012,50	2025,02	87,41	87,41
	MAR	2	2980,39	1570,00	-1410,39	821633,33	34841,46	23,58	110,99
	APR	3	2484,06	2805,00	320,94	1967006,25	43384,54	45,34	156,33
	MAY	4	3002,43	4760,00	1757,57	4531520,00	51193,15	88,52	244,85
	JUN	5	3770,85	4005,00	234,15	2673337,50	211896,93	12,62	257,47
	JUL	6	2186,17	3665,00	1478,83	1918889,29	254962,71	7,53	264,99
	AUG	7	3334,56	5735,00	2400,44	4111278,13	251497,55	16,35	281,34
	SEP	8	2822,16	3715,00	892,84	1533469,44	220502,79	6,95	288,30
	OCT	9	3241,06	2610,00	-631,06	681210,00	209165,51	3,26	291,55
	NOV	10	3415,68	2210,00	-1205,68	444009,09	211080,71	2,10	293,66
	DEC	11	1757,25	2836,25	1079,00	670359,51	312460,41	2,15	**295,80**
2022	JAN	12	2934,84	2836,25	-98,59	618793,39	286854,57	2,16	297,96
	FEB	13	2283,97	2836,25	552,29	574593,86	288954,92	1,99	299,95
	MAR	14	2979,08	2836,25	-142,83	536287,60	269916,97	1,99	301,93
	APR	15	3429,67	255,00	-3174,67	4064,06	274068,43	0,01	301,95
	MAY	16	3156,77	2210,00	-946,77	287300,00	261722,27	1,10	303,05
	JUN	17	2593,99	4080,00	1486,01	924800,00	251141,83	3,68	306,73
	JUL	18	3111,10	2805,00	-306,10	414106,58	240197,67	1,72	308,45
	AUG	19	2193,77	7225,00	5031,23	2610031,25	251418,99	10,38	318,83
	SEP	20	2520,46	1275,00	-1245,46	77410,71	244021,52	0,32	319,15
	OCT	21	2878,78	2210,00	-668,78	222004,55	232491,05	0,95	320,11
	NOV	22	3204,08	765,00	-2439,08	25444,57	227801,24	0,11	320,22
	DEC	23	2005,68	8540,00	6534,32	3038816,67	247767,65	12,26	**332,48**

There are several other instances where the BEM is significantly higher. Every occasion appears to derive from the same problem. Throughout the 2 years considered, sales are relatively stable, with very small fluctuations. However, orders behave differently. There are several months with orders significantly higher or lower than those of previous months. These generate a BWE. However, behavior does not seem justifiable considering that the mean monthly value of sales is approximate to the mean monthly value of orders. The possible reasoning behind these fluctuations is analogous to the previous scenario. Additionally, in December of 2022, orders spike without reason. This might be the phenomenon seen, previously, in December of 2021.

ACSA – 2D

In this case, February of 2021 is the instance in which the BEM is significantly higher than in any other periods. This is justified by a 7% increase in sales in combination with a 60% increase in orders, in the same period (from January to February of 2021). Given the excessive increment in orders unsupported by sales growth, order variance is considerably higher than sales variance, resulting in an extremely elevated BEM. In March of 2021, sales decrease whereas orders surge. Evidently, this results in a significant BEM. Despite occasional periods without orders, the BEMs remain consistently low during the following months.