Development of a Sustainable Replenishment Model for Fast-Perishable Products through reduction of Total Waste

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Abstract:

This work develops a replenishment model in which through the focus on total waste reduction it provides both a sustainable solution as well as a viable and efficient model for real life use.

This work is research based, going through many of the already developed replenishment models and finding a way for improvement.

Through the addition of a variable that works closely with Minimum Order Quantity to the formula and a compliance with the 3 Sustainability Pillars, a solution is presented.

Currently most Replenishment Models developed are geared towards optimizing profits and costs, often on misalignment with Sustainability dimensions. This one aims differently and more consciously.

Preface

This Master´s Thesis was written by João Garcia Pinto on the 4th semester of the MSc in Engineering - Operations and Supply Chain Management at Aalborg University - Denmark. The thesis is a direct result of an investigative work on Replenishment Models and Sustainability.

Acknowledgements

To those that matter. Because you only truly regret that which you haven´t lived.

Para ti, Mãe. Avó. Valter. Krisz. Obrigado por tudo!

Reading Guide

The style of reference is done through the Harvard method, presented as: (Last Names of the first author, year of publishing). Figures and tables have their referral number under their chapter. Additionally, any abbreviations that might be present have their full counterpart appearing before.

João Garcia Pinto

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Chapter 1

Introduction

Supply Chain management (SCM) has a crucial role in improving efficiency in the operations of any business. A good set for a definition would be the following:

"A set of approaches utilized to efficiently integrate suppliers, manufacturers, warehouses, and stores, so that merchandise is produced and distributed at the right quantities, to the right locations, and at the right time, in order to minimize system-wide costs while satisfying service level requirements." (Levi et al. 2003)

In case of indefinitely storable products this task is rather simple and there is a comprehensive amount of literature about it (Nahmias 1982). However, there are fast-perishable products, those that have a short lifetime after which these become unfit for further use or consumption (Nahmias 1982). Examples can be found in the food, chemical, pharmaceutical and healthcare industries (Duan & Liao 2013). There are critical issues in planning inventories of these products, such as the unpredictability in supply and demand, supply lead times, the short shelf lives and the different consumer behaviour towards them (Omar Ahumada & Villalobos 2011),(Lowe & Preckel 2004).

Interestingly, most theoretical perishable inventory models were developed in teh past to solve the blood banking problem (Nahmias 1982), however recently researchers attention has become more oriented to the fast-perishable products in the food retail industry as well (Paam et al. 2016). The food supply chain (FSC) is particularly relevant on one hand because food is one of the most important physiological needs for human's survival (Maslow 1943), and also because it has a substantial share and impact in the global trade. For instance, according to Kinsey's estimation the food and agricultural sector accounted to over 9% of the US GDP. (Kinsey 2001)

Since the time of hunter-gatherers, FSC have went through substantial changes. The food systems emerged by the beginning of the civilization, when agriculture and animal domestication made it possible to settle permanently (Choffnes 2012). Since then, until today the food systems are constantly evolving which does not only bring advantages but great challenges by the insanely complex and diverse nature of today's FSC. Each of the ingredients of our meals come from multiple sources in multiple countries. (Choffnes 2012)

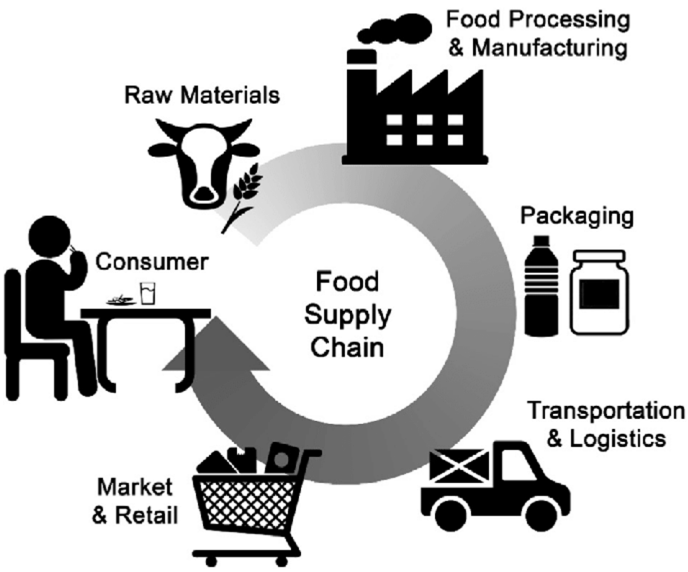

Figure 1.1: Food Supply Chain

(Tzounis 2019)

Today's FSC are complex global networks that create pathways from farms to consumers, involving production, processing, distribution, and even the disposal of food

(Omar Ahumada & Villalobos 2011). The most important aspect that makes the FSC different from supply chains of any other products today, is the continuous and substantial change in food quality throughout the entire supply chain until the final consumption (Vorst 2000), (Omar Ahumada & Villalobos 2011), (Lemma et al. 2014). This, in addition to the perishable nature of the products, the high fluctuations in demand and prices, the high dependence on climate conditions and concerns of food safety (Aramyan 2006), make the FSC an extremely complex chain compared to other supply chains (Lemma et al. 2014). There are many variables to be considered when looking at the FSC.

Consumers in developed countries more and more expect fresh food products to be available all year, which enhances further the need for globalized chains due to the natural constraints at play. This goes hand in hand with the growing global competition amongst businesses, and the ever growing distance between the production and consumption locations (Nagurney 2012).

Meanwhile, it is also worth considering that the food industry typically has a substantially lower profit margins, which gives an even greater importance on differentiation and competitive advantages. Product freshness is considered as one of the major differentiating factors and often a competitive advantage for retailers (Nagurney 2012) (Aiello 2012). However, this does not go without cost. Due to the the fast-perishable nature of food products the result is usually a high quantity of total food waste, which is further straining the food chains, ny having implications on their profitability and product quality (Yu 2013) (Nagurney 2012).

Waste means the decrease of food mass, in whatever part of the supply chain is being considered, which in turn leads to edible food for humans (Gustavsson et al. 2011) (Paam et al. 2016). While some food waste is unavoidable throughout the FSC network, mainly in transportation and handling, according to estimations, as much as one third of the global food production becomes waste annually (Gustavsson et al. 2011) (Thompson n.d.). In addition, fresh food products need special handling compared to other products, including special transportation and storage technologies. Even despite the special handling the quality of these products decreases with time exponentially (Gustavsson et al. 2011).

A recent United Nations (UN) report estimates that food waste reaches as much as 931 million tonnes globally, each year (UNEP 2021). Therefore, it does contribute to the three main planetary crisis we face today - namely climate change, nature and biodiversity loss, pollution and waste. Decreasing this tremendous amount of waste does not only impact food security and profitability, but also provides sustainability in the industry (Lemma et al. 2014), (Paam et al. 2016). The importance of this issue is shown by Sustainable Development Goal 12.3 (SDG 12.3) as well, which aims to reduce food loss and halve food waste by 2030 (UNEP 2021). As a consequence there is an increasing number of environmental, legislative and social impact forcing the companies to reconsider the overall operations of their supply chains from the sustainability point of view (K. Govindan et al. 2013). The next figure shows some examples of food loss and waste during the various stages of the supply chain.

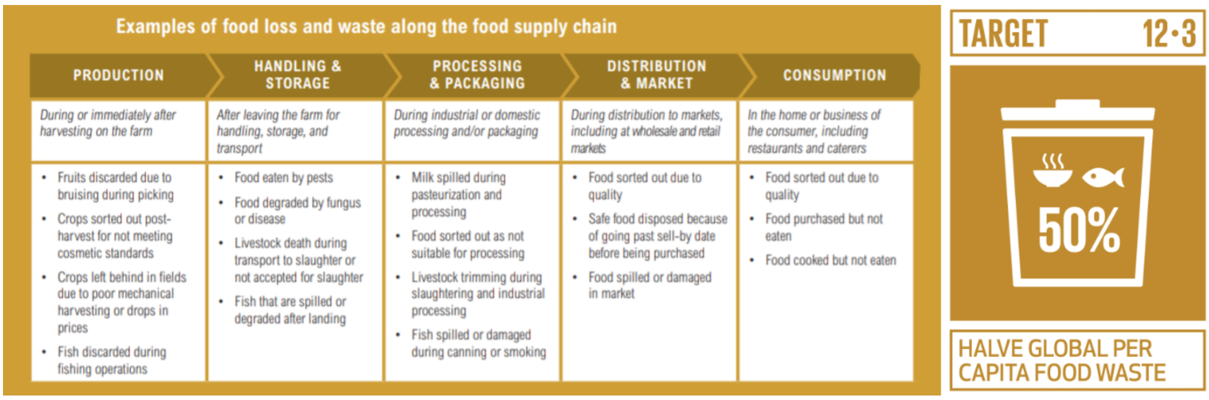

Figure 1.2: Food waste along the food supply chain and SDG 12.3

(Lipinski 2019)

“If we want to get serious about tackling climate change, nature and biodiversity loss, and pollution and waste, businesses, governments and citizens around the world have to do their part to reduce food waste.” (Inger Andersen, UNEP)

Food waste is commonly considered for its environmental impacts, not only because it represents large part of the overall waste stream, but also because the production of food requires land, water and other resources in extensive quantities (Mourad 2016) (FAO 2013). Additionally, both the production and disposal of waste contributes to Green House Gas (GHG) emissions, directly impacting climate change. According to calculations of WRAP in 2010 the avoidable food waste led to 17 million tons of CO2 equivalent (WRAP 2011) (Papargyropoulou et al. 2014). Almost one quarter of this is connected to the agriculture, forestry and land-use sectors, another quarter is the electricity and heat production, thirdly 21% is connected to the industry in general, 14% is the transportation and buildings and energy use account for the leftover 16% (WWF 2020). It is estimated that if the food production and consumption continues in the current direction, planetary boundaries will be reached by 2050 (WWF 2020) (Springmann et al. 2018). While other planetary boundaries have already been crossed (WWF 2020) (Steffen et al. 2015).

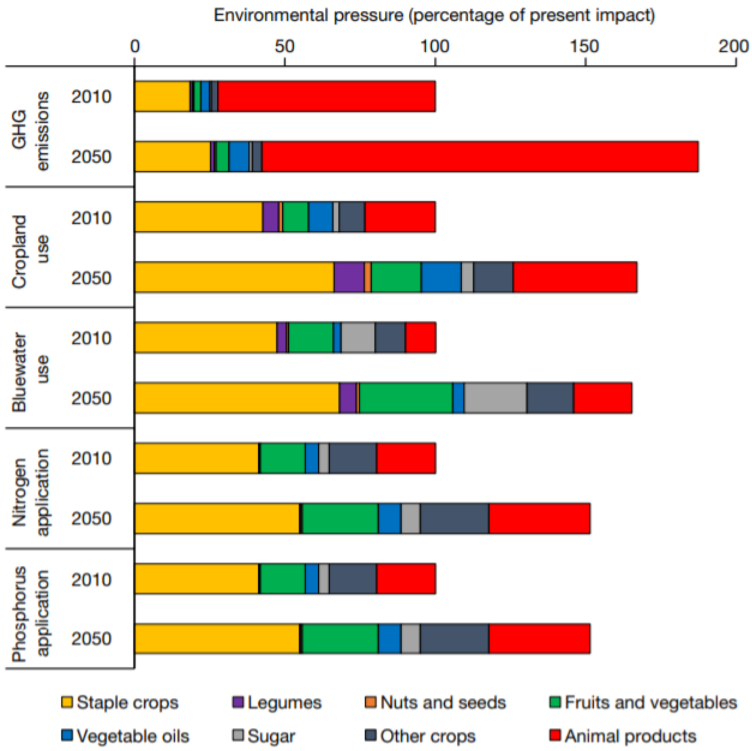

Figure 1.3: Present (2010) and projected (2050) environmental pressures divided by food group.

(Springmann et al. 2018)

However, apart from the environmental concerns, the social and economic implications also need to be taken to account to attain Sustainability (Mourad 2016), according to the 3 Pillars of Sustainability. From the economical point of view, food waste has a substantial impact due to the economic value of food produced throughout the supply chain. The avoidable food losses have a direct negative economical impact in all agents in the supply chain (Gustavsson et al. 2011), (Papargyropoulou et al. 2014) (Lundqvist 2008). The operational costs that food waste implies, also include waste treatment costs and disposal costs (EPA 2012). The third aspect of sustainability, the social implications regarding food waste, mainly refer to the ethical and moral dimensions of food waste as it shows inequality between the wasteful practices and food poverty (Papargyropoulou et al. 2014) (Evans 2011) (Stuart 2009) (Wrigley 2002).

Although avoidable and unavoidable food waste is present all along the supply chain, more value both in terms of capital and resources are added with every link of the chain, therefore if food is being wasted at the end of the chain, the bigger the economic implications are, acting as a bullwhip effect that reverberates throughout the whole chain. This implies that reducing food waste closer to the end of the supply chain, will bring more potential economic benefits per unit mass of waste (SEPA 2012) (Eriksson et al. 2015). Therefore, even though more waste occurs during the production, (FAO 2013) (Eriksson et al. 2015) while less in the wholesale and retail, still it is worth to consider the waste streams of retailers when it comes to waste reduction.

Papargyropoulou et al. introduce a framework by applying the waste hierarchy in the food waste perspective. Not only does it take into consideration all three dimensions of sustainability, it gives a holistic approach in addressing and tackling it (Papargyropoulou et al. 2014). According to this hierarchy the most favourable option is waste prevention, which implies the decrease to a minimum of food surplus and of avoidable food waste (Papargyropoulou et al. 2014). The second favourable option is re-use, which means the usage of surplus food for people affected by food poverty, for instance with redistribution networks or food banks (Papargyropoulou et al. 2014). Third option is recycling the food that has quality issues and is not any more proper for human consumption. This includes animal feeding and composting (Papargyropoulou et al. 2014). Fourthly the food waste can be recovered for energy, for instance by anaerobic digestion, or as the least favourable option, food waste also can be disposed into landfill (Papargyropoulou et al. 2014).

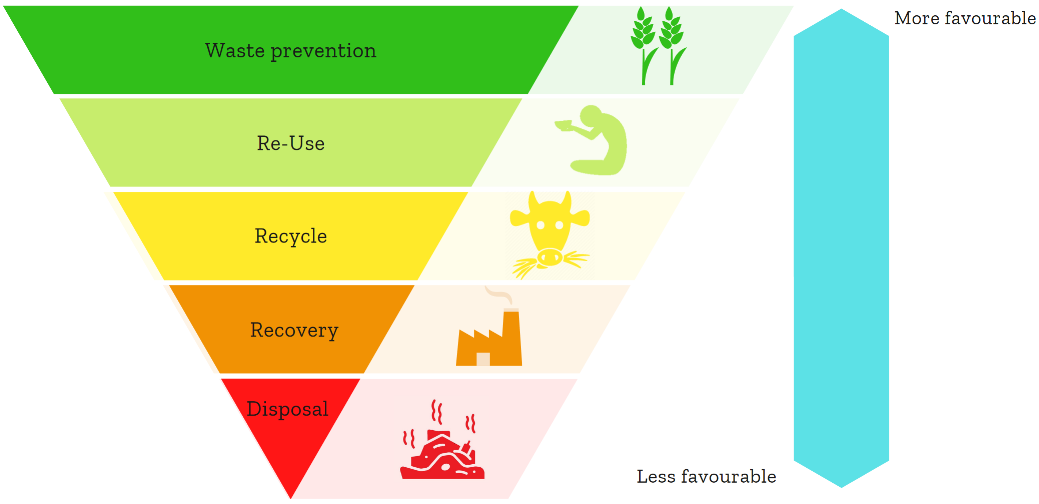

Figure 1.4: The Waste Solution Hierarchy - Own figure inspired by (Papargyropoulou et al. 2014)

Previous studies have addressed food waste solutions from the lower to higher levels of the waste solution hierarchy, however, moving towards upper levels makes it less certain and difficult to measure the environmental impacts (Eriksson et al. 2015). Amongst all, prevention shows to be the least tangible, therefore studies of systemic outcomes in food waste prevention are rather scarce(Mourad 2016).

This work aims to contribute to those sustainable supply chain management practices. It will do so by utilizing inventory management theories in the shape of replenishment models to prevent and reduce waste at the retail stage for fast perishable products.

Chapter 2

Methodology

This chapter will provide information regarding the investigative procedures taken throughout the work.

Approach

- **Inductive Approach**

  This study is purely based on a Inductive approach, as described on (Brooks et al. 2013). An approach which starts from specific to a general case, where a rule is introduced based on the premises observations. The work builds a theory based on academic literature (Brooks et al. 2013).

Methods

- **Literature Review**

  Since this is an investigative work, this method has been the most used amply used, on several levels. On each of these levels different types of publications have been reviewed. Most importantly, for the investigation on Sustainability concepts and Inventory Management, Scientific Literature review has been utilized.

  However, for the remainder of topics, governmental and non-governmental publications have been researched, including statistics, policy briefing, Sustainable Development Targets, etc.

- **Observational**

  Personal observations from previous and current work experiences from directly dealing with replenishment models served as a tool to help tie concepts and reach some of the conclusions of the study.

Data Validity & Reliability

- **Data Validity**

  All numerical data utilized in this work has been retrieved from several sources, please refer to the references at the end of the work. Governmental and non-Governmental sources have been used, as well as Scientific papers.

- **Data Reliability**

  The data utilized from the different sources might not be precise, but it´s a close representation of reality.

Chapter 3

Literature Review

This chapter will go through selected concepts from both Inventory Management and Sustainability to serve as a basis of knowledge for the work.

3.1 Conceptualization of Sustainability

The term Sustainability can be traced back until the Brundtland Report from 1987 (WCED 1987). As an answer to our limited resources and the danger of environmental degradation, the commission's answer was sustainable development:

"...development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (WCED 1987)

Since then, there have been several major literature reviews on topic, introducing different understandings of the concept of sustainability (Kuhlman & Farrington 2010). According to Kuhlman and Farrington, sustainability can be interpreted in terms of three dimensions which needs to be in harmony: the Social, Economic and Environmental dimensions (Kuhlman & Farrington 2010). This in turn leads to another definition, the one of sustainable development adopted by the UN within its Agenda for Development:

"Development is a multidimensional undertaking to achieve a higher quality of life for all people. Economic development, social development and environmental protection are interdependent and mutually reinforcing components of sustainable development." (UN 1997)

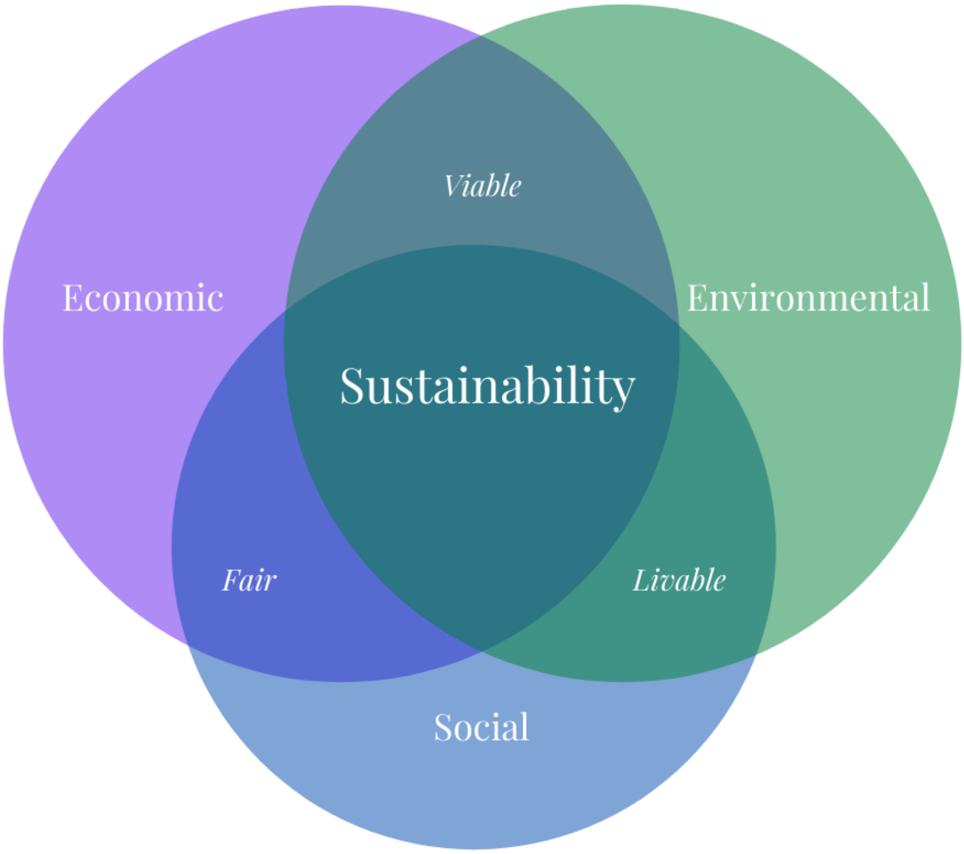

Figure 3.1: 3 Pillars of Sustainability

The idea of these three dimensions being denominated the three pillars of sustainability arose from the Triple Bottom Line concept. This suggests that apart from the conventional bottom line (profit), care for the environment (the planet), and be good for the people (the social dimension) shall be considered as well (Elkington 1994). Hence, the three main goals of sustainability: Ecologically to stay within the planet's carrying capacity; economically to provide adequate material standard of living of all, and socially to provide systems of governance that can propagate the values people aim to live by

(Robinson & Tinker 1997). However, Kuhlman and Farrington argue that social and economical dimensions can be merged together into one pillar called well-being (Kuhlman & Farrington 2010).

Another concern that needs to be clarified is the differentiation between sustainability and sustainable development. Although these many times are used interchangeably, it is suggested by Robinson that different stakeholders would use one above other according their agenda (Robinson 2004). While the private sector and government tend to use sustainable development, academic and NGO sources prefer to use the term sustainability (Robinson 2004). They argue, that hence development and growth are synonymous, the concept of sustainable development does not challenge the idea of continuous economic growth (Robinson 2004). Therefore, in the course of current project, abiding to the distinction, the work will make use of the concept of Sustainability.

3.2 Food waste and the three pillars of Sustainability

"Food production and consumption is the primary requisite for a decent life and the sustainable well-being of humankind" (Ohlsson 2014)

Food systems currently are intensely inefficient(Garcia-Garcia et al. 2016). Consequently, more than one-third of the produced food is lost before it could ever be consumed by a human being (Garcia-Garcia et al. 2016) (FAO 2013), while almost 2 Billion people live in hunger and other 2 Billion are overly obese (UNDP 2015). Additionally, the food sector is responsible for around 22% of the global Green-house Gas (GHG) emissions (UNDP 2015). Therefore, one from the seventeen Sustainable Development Goals (SDGs) that were established in 2012 Rio de Janeiro, elaborates on this specific issue (UNDP 2015). Namely, SDG12 that is to ensure responsible consumption and production patterns, has a specific target to halve per capita the global food waste at retail and consumer levels by 2030 (UNDP 2015).

According to the concept of Sustainability, the current aim is to develop alternatives that come with the least amount of total waste, with the objective of maximising social and economical benefits while minimizing the environmental impacts (Garcia-Garcia et al. 2016). Oppositely, the most frequent food waste management method currently is still land-filling (FAO 2013), which is while damaging the environment, and posing high risk to human health, does not have any economical benefit either (Garcia-Garcia et al. 2016), so does not have any value from the sustainability pillars perspective. While we can find literature elaborating on the Economic and the Environmental pillars of food waste management (Ahamed et al. 2016) (Martinez-Sanchez et al. 2016), research about all the three pillars is rather scarce (Garcia-Garcia et al. 2016). Even though there are major issues that can be identified in the food management systems related to all the social, economical and environmental pillars of sustainability (Ohlsson 2014).

From the Social Pillar perspective, the most obvious aspect of the food system is its contribution to the well-being and health aspects of the consumer (Ohlsson 2014). Another important issue from the social perspective is food security, which implies to both the biological and chemical safety of food (Ohlsson 2014). Other aspects are the ones that concern of human rights including child labor, rights of association, no discrimination and rights of indigenous people (Ohlsson 2014). In addition, as it was stated above, almost 2 Billion people live in hunger while at least the same amount is overweight (UNDP 2015). This paradox of the excess of daily calories towards the quota of the population which lives in poor conditions should be emphasized (Cicatiello et al. 2016), this as well shows how immoral is the food waste from human consumption (Parfitt et al. 2010). This can be seen in other situations as well: while the food waste per capita in the developed countries reaches up to more than 100 kg/year, in developing countries this number is about half, around 56 kg/year (Thi et al. 2014).

Important concept from the Social Pillar perspective is the Corporate Social Responsibility (CSR), this suggests that the company is acting as good partner or citizen in the society (Ohlsson 2014). Some literature can also be found about the 'ethics of food waste' where phenomena like 'freeganism' and 'gleaning' movements emerge as alternatives to the current consumption patterns. These groups of people are consuming food that has already became waste, in order to fight against social inequality of food access (Edwards 2007).

The yearly amount of wasted food globally accounts to around 750 Billion dollars, which is lost throughout the entire supply chain (FAO 2013). Considering the Economical Pillar, it can be seen, that food waste has a direct and negative impact on all agents of the supply chain (Ribeiro et al. 2018). Another aspect of the economic sustainability, is the fair distribution of revenues between different actors in the supply chain in order for them to be able to reach sustainable livelihood (Ohlsson 2014).

The most comprehensively studied sustainability pillar throughout the years regarding the FSC is the Environmental Pillar, starting with Rachel Carson's Silent Spring (Ohlsson 2014), (Carson 1962). This layed the groundwork for the environmental literature not only in this industry, but overall (Carson 1962). Since then, several issues arisen regarding global food systems. From the food production examples are the effluents and sewage that leak into water bodies causing degradation in water quality (Ohlsson 2014). The most commonly referred problems are nitrogen and phosphorus leakage that highly contributes to eutrophication, but other toxic compounds can be considered as major threats as well (Ohlsson 2014).

It is estimated, that food production accounts to 20% of all energy used (Sonesson 2011) and about 25% to the all global warming contribution (Ohlsson 2014). As currently food waste commonly goes to landfills, there it is converted to methane, which is a green-house gas with 25 times higher global warming potential than carbon-dioxide itself on a time-scale of 100 years (Ribeiro et al. 2018). Another major problem is the acceleration to loss of biodiversity, which is caused by methods like mono-culture agriculture and other activities (Ohlsson 2014). Water usage is another important aspect to consider; the food sector operates with using around 70% of all available freshwater in the world, which means 3 tons of water per person daily (Ohlsson 2014). There is a major concern regarding the availability of fresh water, as it is a more and more urgent issue mainly in the regions where water is a rather deficient resource already (Ohlsson 2014), (IPCC 2007).

Food waste is commonly paralleled with its environmental impacts, partly because it is a large part of the whole waste stream and also due to the food production requirements such as land, water and other resources in high quantities (Mourad 2016) (FAO 2013), these aspects from the social and the economical perspective should not be neglected.

Overall, about the food waste issue, it is not only a concern ethically, but also carries economical end environmental implications: as it comes with unnecessary use of resources in production (Ribeiro et al. 2018). In case the food waste can be reduced, there would be fewer resources required, therefore also less social, economical and environmental impacts can be attributed to food that inherently goes to waste (Thyberg & Tonjes 2016).

3.3 Sustainable Supply Chain

The majority of research in the Supply Chain Management (SCM) field has failed to incorporate all supply chain's impacts on the economic, social and environmental aspects, mostly because of favouring economically beneficial practices and profit maximisation (Touboulic 2015) (Pagell 2014). Therefore, the strategic importance on purchasing and other supply chain activities in order to achieve long-term performance, meanwhile addressing sustainability issues, emerged in the concept of Sustainable Supply Chain Management in recent years (Touboulic 2015) (Burgess et al. 2006) (Hall & Matos 2010) (Mentzer et al. 2001). SCM has a need to be broadened to the three pillars (environmental, social and economical) of sustainability and it is critical for organizational competitiveness (Ageron et al. 2012). One can easily argue that the concept of SSCM lies in the intersection of both the disciplines of Sustainability and SCM (Touboulic 2015), however it should be noted that authors have different perspectives in defining SSCM (Touboulic 2015), and that this concept is still at its infant phase (Ageron et al. 2012).

One of the main issues in defining SSCM is the integration of both the concept of sustainability and SCM (Seuring & Müller 2008) (Touboulic 2015). On one hand, lack of agreement can be found in sustainability and Corporate Social Responsibility (CSR) research, as there is no consensus on definition of their terms (Touboulic 2015) (Taneja et al. 2011). Phrases like 'sustainability', 'sustainable development' and 'CSR' are often used interchangeably and confusedly (Touboulic 2015) (Ashby et al. 2012). Likewise, the concept of corporate sustainability seems to be ambiguous mostly because it has been evolved in the context of the firm which is dominated by an economist view (Angus-Leppan et al. 2010) (Touboulic 2015). Ambiguities also arise in the understanding of how the human and ecological aspects relate to the economic one and the relative importance between these (Touboulic 2015). On the other hand, the interdisciplinary character of issues considered by SSCM (Amundson 1998) make it difficult to define the concept (Touboulic 2015).

Even though there is a lack of consensus on the SSCM definition, the emphasis on the supply chains' complexity and the difficulty to provide a cross-industry framework that works for the variation of issues in different sectors seems to dominate the literature (Touboulic 2015). However, incorporating sustainability with specific references to all the three pillars rather than focusing on only one or two aspects, shows that the SSCM approaches are becoming more integrated including a wider range of issues (Seuring & Müller 2008) (Touboulic 2015). This triple bottom line approach can also guide authors in the conceptualisation of SSCM (Touboulic 2015).

As from an operational perspective, SSCM literature also emphasises the importance of collaboration between partners in the supply chain (Touboulic 2015) and that SSCM practices are many times triggered by requirements of costumers or other stakeholders (Seuring & Müller 2008), the work takes on Seuring's definition of SSCM:

> "we define sustainable supply chain management as the management of material, information and capital flows as well as cooperation among companies along the supply chain while taking goals from all three dimensions of sustainable development, i.e., economic, environmental and social, into account which are derived from customer and stakeholder requirements."

(Seuring & Müller 2008)

3.4 Inventory Management

Inventory Management is responsible for the planning and control of inventory all along the supply chain (Arnold et al. 2008). Inventory management models usually utilize time and quantity as dimensions for the replenishment - The models develop usually fall within just a few categories as the following: Continuous Review, Economic Order Quantity, Economic Production Quantity or even Periodic Review.

Each of the latter offers difference advantages. For example, the continuous review model is widely used due to the low Safety Stock which can still comply with service level requirements (Duong & Wang 2015) (van Donselaar & Broekmeulen 2014).

Inventory management models utilized for fast-perishable products will inherently differ because it will all depend on the type of demand(Lian et al. 2009). In (Nahmias 2011) it is shown that with random demand the optimized values for for order placement are really difficult to attain, as multiple periods have to be considered, and no replenishment model can truly eliminate randomness from the equation neither remove the inevitable expiry of fast-perishable products (Duong & Wang 2015)(Nahmias 2011). Which then infers that possible solutions will have to be approximations of the optimized value (Duong & Wang 2015)(Pahl & Voss 2014).

3.4.1 Replenishment Models Policies

With the growing productivity and development of production means, food is ever more increasingly present both in large quantity and diversity to the costumer. For better supply management of the sites, certain replenishment models are used to calculate how much quantity of a certain product should be ordered. These models help the companies and their purchasing planners by providing information that advises the ideal optimized quantity to be ordered, given a set of pre-established constraints and preferences in the system. This quantity, like an optimization problem, will either be maximized or minimized to closer get to the goal in mind. A company has a myriad of possible approaches to this, none is inherently wrong, it will just adapt to the business model in place. For example, a replenishment model might attempt to focus on maximizing profit, maximizing service level, minimize costs or even minimize generation of waste. It is worth noting that Inventory management of perishable products has shown to be more complex and delicate compared to other types of products (Paam et al. 2016).This inherent complexity to optimize these kinds of items proves a challenge, on which different authors have been building upon concepts that have been under scrutiny and analysis over the years.

When dealing with replenishment models, immediately there is a split into two different domains, periodic review policies or continuous review policies. Mostly, the differentiating factors state that the continuous review policies might require a lesser amount of Safety Stock opposed to the periodic review policies. However, balancing the aforementioned, would be the fact that the continuous review policies undertake an on-going analysis of the available stock and the required amount to place an order (Silver et al. 1998)(Kiil et al. 2018).

Most companies selling and operating in the grocery retailing business often use a periodic review model for their replenishment, it is the most commonly seen. The most important reason is that the physical stores have preset times as to when they place orders and receive them (Kuhn & Sternbeck 2013) (Kiil et al. 2018), which will inadvertently have a better reflection of reality, as opposed to running a continuous review model, in the sense that it will closer resemble the physical constraints that are imposed for this kind of industry. However, continuous review policies have have been shown to present better results in the management and control cost department than the periodic review policies (Lowalekar & Ravichandran 2014), but are of more difficult nature to implement successfully, as it often requires a fully functional, flexible, responsive and integrated supply chain in order to properly succeed.

In order to better understand the work done in this field, some insights on previous authors are required. In most literature regarding and studying replenishment models, we can find a plethora of S. Nahmias´ work, where a series of iterations on periodic review policies are present and developed for applications in the realm of fast perishable products and inventory management. (Nahmias 1982) gives the earliest comprehensive study on periodic review policies (Duan & Liao 2013). In (Nahmias & Pierskalla 1973), the article goes through what could be described as a study to review optimum ordering policies for these kinds of products that are facing stochastic demand, while considering a zero lead time. A lot of posterior work in the field has indeed found some foundations on his work from decades ago and many of the concepts still remain relevant up to this day.

With the passage of time and more in-depth analysis on the topic , some concepts start to emerge as being key for the development of efficient replenishment models.For example, In (Nahmias 1977), (Tekin et al. 2001), (Haijema et al. 2007), it can be found that the inclusion of the age of the stock information has provided information which proves that by adding this variable the efficiency of the models improves extensively, helping further on the replenishment decisions that are bound to be made by companies (Broekmeulen & van Donselaar 2009). This is further confirmed and depicted by (Duan & Liao 2013), in which it provides insightful information that policies which take into account the shelf life of stocks actually perform better than compared to policies in which the age consideration is not included in their formulas.

Other concepts also arise with the diffusion of the topic and the increasing need to have robust systems as to which companies can rely on. (Tekin et al. 2001) brought an altered version upon the lot-size reordering policy in the continuous review policy domain for fast perishable products. It has been shown and proved that this model was an actual improvement over the previous work done within continuous review policies regarding costs, where these policies were solely and completely managing the inventory on hand (Lowalekar & Ravichandran 2014). The model does consider an order to be placed when either the inventory drops to an established amount policy or when a certain amount of time has passed since the last time the inventory has dropped to the same established policy.

Interesting works have been developed for fast perishable products all around, not just necessarily within the food industry, there are valuable contributions to the field from blood related replenishment in health facilities, examples could be taken from (Haijema et al. 2007)(van der Wal et al. 2009)(van Dijk et al. 2009)(Lowalekar & Ravichandran 2014). These have shown great results when modifying the classical models to fit their purpose of a more efficient management of an important fast perishable stock.

It is worth noting that more modern literature work on periodic review policies has been mostly revolving around the classical approach of order-up-to-level policies, or base stock policies. These are based on the premise of ordering a certain amount of stock, within a periodic review, to meet a certain stock level that was pre-defined beforehand. The development of heuristics for periodic review policies has been rather popular, and many heuristics have been developed to help determine a better approximation to the optimum order quantity that satisfies the company´s policy currently being executed (Broekmeulen & van Donselaar 2009).

In 2013 a work came forth with what has been denominated as the OIR policy, to address challenges dealing with uncertain demand, limited shelf life and high customer service level requirements for highly perishable products (Duan & Liao 2013). This entails an order quantity that considers the amount of expiring stock with a ratio of expiring to existent stock, meaning that it is a reordering process that places emphasis and balances through the ratio not only the stock level but also the stock shelf life to reach an optimum of amount to order. This ratio signifies a threshold in which it acts as a trigger to place an order in the aforementioned process, according to the formula in (Lowalekar & Ravichandran 2014). (Duan & Liao 2013) Also proved that the OIR policy outperforms other order-up-to policies of the same kind.

Going through the existent literature, some works will eventually come up as a better fit for purpose for whatever is the objective of the work being developed. (Broekmeulen & van Donselaar 2009) have developed the EWA policy, one of the most relevant works in recent years regarding heuristics for fast perishable products, which served as basis for different iterations that improved upon it in further years. The EWA brings better results than classical approaches and is a policy which can be used in a multitude of situations (Broekmeulen & van Donselaar 2009) due to its applicability. It works with different review periods and lead-times, while really trying to emulate the reality constraints present in most company systems used throughout retail (Broekmeulen & van Donselaar 2009). The main characteristic is the considerations on expiring products in the formula, which does differ from some previous authors. The efficiency of this improvement is clearly shown and proved, as it makes the order placement decision more in line with the actual inventory requirements, thus reducing waste and costs (Broekmeulen & van Donselaar 2009).

The EWA policy introduced by (Broekmeulen & van Donselaar 2009) has been further developed by (Kiil et al. 2018) and then (Christensen et al. 2020). (Kiil et al. 2018) to improve the EWA policy has brought the EWA_{SS}. The main difference upon which the EWA and the modified formula from (Kiil et al. 2018) has to do with the ways that safety and expiring stock are being handled. (Kiil et al. 2018) shows that the latter cannot be handled independently, as both are intertwined. The reviewed version solves a gap in the original which would be blindsided specially when the expiring stock would be greater than the safety stock in place, causing often overstock situations and perpetuating the issue. (Kiil et al. 2018) Has shown that this model brings forth better results in the management of perishable stocks than its predecessor.

In the development of replenishment models an approximation and understanding of reality is a key requirement to pull forward an efficient model which can deliver results to the companies. However, adding and considering too many variables can leave more vulnerabilities for error, as well as a more difficult implementation will be ensued. Therefore, a balance must be struck, and key variables of the formula must be correctly identified. More recently (Christensen et al. 2020) presented and developed upon the latter models of the EWA policy and the EWA_{SS} policy. The model tries to focus on the customer´s choice and how it might impact the replenishment quantity needed, however it will have a multi-product approach as it considers more variables for what could affect the sales and therefore the requirements in the quantities needed for replenishment. In the formula it is contemplated areas which try to reflect reality, such as Supplier Fill-Rate, Price Reduction, and Substitution Demand. There was not a direct benchmarking against other models of the same sort, but it´s a very interesting take on the subject, as it presents itself as a theoretical extension to the already existing EWA models by really having a grasp and analysing the impacts and interdependence between different products and what this does concerning the actual amounts that need to be ordered to comply with the companies on-going policy (Christensen et al. 2020).

Chapter 4

Project Constraints and Assumptions

This chapter seeks to showcase the constraints felt when developing the work and how the results might have been implicated.

Covid-19 Pandemic

The recent Covid-19 Pandemic has impeded a more thorough research on the topic and collaborating with actual companies in the retail industry to retrieve data.

Lack of Literature with same Content

Being a research based work, it was limited to choice in available literature that contemplates and connects both Replenishment Models and Sustainability fields. Separately, there are a lot of different papers on both fields.

Tacit Knowledge

The acquirement of Tacit Knowledge through work and study experiences may have skewed some conclusions upon developing the work.

Study Scope

Due to the academic nature of the study, and the imposed time restrictions, the scope had to be adjusted. A lot of concepts, both in Replenishment Models and Sustainability had to be cut off.

Chapter 5

Problem Statement

Products with short shelf life can often originate unwanted waste, translating into additional operational costs, but also showing an increment in environmental and social impacts.

This work, at its core, will aim at improving an existent replenishment model by the lenses of sustainability. In this specific case, mainly affecting fast perishable products for retail and trying to reduce total waste quantity.

Few papers integrated inventory management and food waste issues (Paam et al. 2016). There is often a discrepancy between papers developed for replenishment models, mostly emphasizing cost reduction, and the sustainability aspect of reducing waste. Seldom are both fields merged, as one mostly seeks business improvement and the other to achieve Sustainability. One might argue that there´s an obvious correlation between the two, however, reducing waste does not necessarily mean a reduction in costs.

(Paam et al. 2016) confirmed the lack of food waste related research in inventory management by evaluating over 50 papers in a framework which included different supply chain planning models. The study shows that in the majority of the reviewed papers, food loss minimization is considered as a secondary target, with the main scope being directed at reducing costs and profit maximization. The literature shows the orientation of most studies towards the main objective function of cost minimization or profit maximization, over food loss/waste minimization. (Paam et al. 2016)

However, changes in the last couple of years are being seen. From the literature, it is evident that the number of papers published in this area have been growing. It shows the importance and attention that is being given to the field.

For the above purpose, the two main fields under scope will be the bedrock in which this work is founded on.

- **(1) Replenishment Model Policies**
- **(2) 3 Sustainability Pillars**

These two fields will complement each other in order to create a Sustainability driven model, and ultimately help work towards a paradigm shift in the retail industry, much like achieving the SDG 12.3.

The insights that are expected to be gained through the proceeding analysis, will be able to provide a higher level vision on how different aspects can affect the Supply Chain from different angles. Diverting from the traditional objective of cost reduction, it enters the realm of total waste reduction, complying with sustainability pillars and providing an analysis of its impact reverberated throughout the chain.

With the aforementioned in context, it is now feasible to formulate a **Problem Statement** in order to try and elaborate on the subjects, and ultimately, tackle the waste management issue for the given scope.

How to improve a replenishment model to account for the 3 sustainability pillars and thus help reduce total waste of fast perishable products?

- How to adequately modify the model´s formula to reduce total waste?
- Can the new model help comply with the 3 sustainability pillars?

Chapter 6

Problem Analysis

Many concepts and issues pertaining to waste management of fast perishable products have been highlighted. Following that identification, this work will now undergo a structured analysis that aims to answer the ***Problem Statement****. The next step is to pinpoint what aspects of the models should be considered for the total waste reduction, with their respective consequent improvements.*

In this problem analysis, the existent replenishment models will be under scrutiny. Through a structured step-by-step analysis, the improvement which this work aims to achieve will come through as a product of a process entailing a selection of the best model for the scope, analysing thoroughly the formula and then adding or removing elements to seize the desired outcome.

There could be different paths as to which the analysis could follow in order to obtain a similar result. The following structure was chosen to simplify the process and better blend the concepts in a perceptible manner.

Next there will be the high level view on the breakdown of the following steps, including the solution that the work intends to deliver.

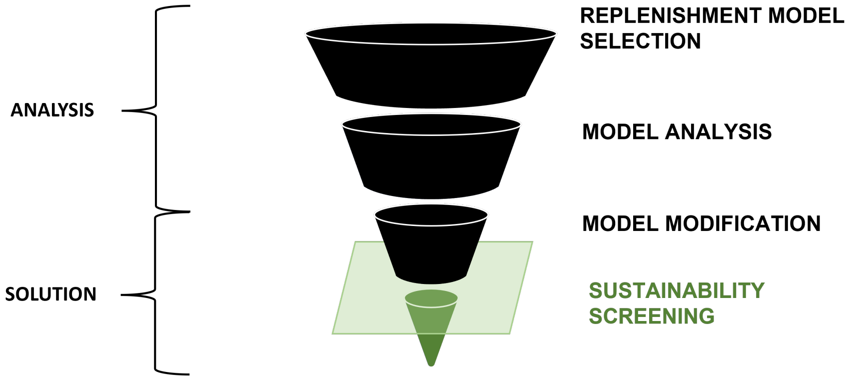

Figure 6.1: Work Structure

The Analysis will have two sections dedicated to the existing replenishment models as shown in 6.1. This will allow a better insight on what and how is being developed regarding the issue of fast perishable products by scrutinizing some of the available replenishment models. For further alignment on what to expect, comes the Solution chapter, which will include the proposed modifications in the chosen model and its application under the sustainability screen, allowing for an interconnection of both fields.

Work Structure

- **Replenishment Model Selection**

  Starting off, the Replenishment Model Selection will go trough some of the available replenishment models as shown in the Literature Review. It will go into some the formulas developed for replenishment models as well as a small overview on those works that have been done on the field so far and allow for analysis as to which one might be a better fit for improvement. This selection will serve as the basis for further development of this work.

- **Model Analysis**

  The next step will involve a thorough analysis on the selected model´s formula. By assessing the variables at play, it will be possible get a grasp on the model´s objective and how it tries to achieve it. With this, it will further enable the process as to modify and deliver a model that can ultimately aim at reducing total waste while complying with sustainability concepts.

- **Model Modification**

  With the information gathered from the formula assessment it will be possible to get insights on as to where modify the formula in order to get the improvement needed. In this section it will be presented the final model for this work in order to reduce total waste.

- **Sustainability Screening**

  While having the final model obtained, the next step will focus on the elaboration of a Sustainability screening focused on the Supply Chain variants of the field. This section works out the relationship between the three pillars of Sustainability and developed replenishment model. As shown before, this approach is seldom seen, embedding them together will further add value and insights to the developed work.

Summary

In the wake of providing a valid model improvement and it´s conjunction with the Sustainability field, a structured plan was developed.

First a step into selecting the appropriate model to fit the objective of reducing total waste of fast perishable products. Afterwards, a deeper look into the construction of the formula to understand it at its core. Next, the obvious step of building the improved version of the model, by tweaking its own elements to be fit for purpose. Finally, the added value that this work aims for, it will come in the shape of the alignment of the model with Sustainability, something often overlooked in papers of the same field which mainly aim at the total cost reduction and its variants (Paam et al. 2016).

With this approach to the objective at hand, it is expected that some new valuable insights can be obtained from looking at Inventory Management issue from an angle which is uncommonly seen. The ability to merge two different fields with diverging objectives can shed light on existent problems, but also an opportunity to unveil possible avenues for differentiated research, as much of it is already saturated with variants seeking to maximize profit and minimize cost, rather than a focus on waste reduction.

6.1 Replenishment Model Selection

By showcasing some of the replenishment models available, a clearer picture will be drawn on some of the current models on the field and will put them through scrutiny to afterwards select the best fit for purpose model.

In this section, the models were selected as being notorious for their utilization in the replenishment of products with a short shelf-life. A quick overview of their formula will be shown, a brief explanation of the model, as well as other necessary insights and noteworthy application of the model in question for the managements of fast perishable items.

The intent of having this analysis is to have a starting point as to where it fits the purpose of this work, reducing waste of fast perishable products through a replenishment model while aligning it with the sustainability field. By going through a few of the existent models, a wider array of options is created in order to bring forth a modified version which can comply with the objective at which the work proposed.

It is worth nothing that throughout this section the model notations that have been used are similar to the ones utilized in (Christensen et al. 2020). All the models have been subjected to the same notation to allow for an easier reading and in other to present a proper platform for benchmarking and comparison purposes. Different authors utilize different notations for their models throughout the diverse literature on the topic, hence why this is needed.

$I_{p_1,t}^{available}$ = Inventory Position at time t for product p_1

$I_{j,i}^{sub.available}$ = Beginning inventory at time i for substituting product j $(p_2 \rightarrow p_x)$

$\widehat{Q}_{p_1,i}^{Outdate}$ = Estimated number to expire within review time of product p_1

$\widehat{Q}_{p_1,i,l}^{Reduced}$ = Estimated number sold at a reduced price within review time of product p_1

$\mathrm{E}\left[D_{j,i}^{sub}\right]$ = Expected substitution demand from product j $(p_2 \to p_x)$

$\mathrm{E}[D_{p_1,i}]$ = Expected demand from product p_1

SS_{p_1} = Safety Stock for product p_1

$\mathrm{Q}_{p_1,t}$ = Order Quantity for product p_1

Qf_{p_1} = Fixed order Quantity for product p_1

$\mu_{p_1|j}$ = Substitution Matrix for product $j(p_2 \to p_x)$ substituting with product when p_1

$I_{p_1,t}^{available} < D_{j,i}$

ε_{p_1} = Price Elasticity of product p_1 for price reduction when p_1 gets close to expiration

$\mathrm{Ab}_{p1,t}$ = Age of the last batch delivered of p_1

a = Unit of time defined for an age threshold policy

L = Lead Time

B = Batch size

m = Minimum Order Quantity

6.1.1 Base Stock Policy

This model and similar iterations of it throughout the years have seen ample use. As the name implies, the replenishment is done accordingly to an already pre-established amount of Safety Stock. The orders are placed regardless of expected demand.

This model entails an order to placed to match the set policy. The trigger for ordering is set when the Inventory available drops below the Safety Stock that is set. Whenever the latter happens, the order quantity will be set as the Safety Stock minus the Inventory available to replenish up to the set policy.

The formula is as follows:

If:

$$I_{p_1,t}^{available} < SS_{p_1} \tag{6.1}$$

Then:

$$Q_{p_1,t} = SS_{p_1} - I_{p_1,t}^{available} \tag{6.2}$$

Under this policy, an order placement process is triggered when the available inventory drops below the Safety Stock. The quantity to be ordered provided by this system is the difference amongst the Safety Stock policy and the available inventory at the moment that the order is triggered. In principle, this is a very basic system that just ensures that there is a supply of the product, disregarding many variables that have an impact on Inventory Management. This traditional approach does not directly consider the expiring dates on the fast perishable products on the order placement process (Lowalekar & Ravichandran 2014), as it does not take into account demand fluctuations.

This model can have its uses in other types of products where demand is very stable and that have very long shelf life. These are just two key variable considerations that can be made, but the complexity can be extended as far as storage costs or product depreciating rates. This model is just not suitable for Inventory Management of fast perishable products.

6.1.2 EWA Policy

Similar to the Base Stock Policy, the EWA policy introduced by Broekmeulen and van Donselaar in 2009 presents itself as a continuation of some of the most traditional replenishment systems, while being geared towards the handling of fast perishable products (Kiil et al. 2018). In the last years most studies for expiring products in a stochastic setting don´t seem to consider important variables that closer resemble reality (Broekmeulen & van Donselaar 2009), hence why this model was produced. Different to the traditional policies, the EWA policy places emphasis on the products about to expire and modifies the order quantity based on this premise (Kiil et al. 2018). The change from previous existing models is subtle, but it inserts a very important component into the formula, which is the consideration of expiring stock.

The authors openly state that the focus is geared towards fast perishable stock with stochastic demand and fixed shelf life (Broekmeulen & van Donselaar 2009). This was the premise in which the model was built. The inclusion made it so that it was now able to reflect better the impact that expiring stock has and thus allowing for a more accurate quantity to be advised upon order placement.

The formula is as follows:

If:

$$I_{p_1,t}^{available} - \widehat{Q}_{p_1,i}^{Outdate} < E\left[D_{p_1,i}\right] + SS_{p_1} \tag{6.3}$$

Then:

$$Q_{p_1,t} = E\left[D_{p_1,i}\right] + \widehat{Q}_{p_1,i}^{Outdate} + SS_{p_1} - I_{p_1,t}^{available} \tag{6.4}$$

One of the aims in the work was to provide a simpler model which could be used and applied in different contexts (Broekmeulen & van Donselaar 2009). This was indeed achieved by adding the expiring stock component. However, it is not without its limitations, for which posterior works came to mitigate and improve upon this model. One of these limitations, is that the model is considering expiring stock and safety stock as two different independent domains. As described by (Kiil et al. 2018), the issue encountered pertains to the fact that when dealing with products with a short shelf life the EWA will trigger order placement sooner than the Base Stock Policy to cover expiring products. This means a risk of overstock since orders will be placed sooner while the Safety Stock will remain the same. Even though the service level would clearly increase, the company utilizing the EWA policy would usually incur in extra operational costs, since high overstocks usually leads to waste in fast-perishable products.

Nonetheless, it´s a more robust and flexible model than some previous works and holds value for bringing forth the inclusion of expiring materials into the formula.

6.1.3 EWA$_{SS}$

Developed by (Kiil et al. 2018), this model seeks to improve on the former EWA model. It provides an improvement by balancing further the formula, taking a closer look into the impact of expiring materials and safety stock (Kiil et al. 2018).

The underlying change between the EWA and this altered version pertains to the fact that it does not consider Safety Stock and expiring stock as independent elements. In the original model, the total quantity to order would equal the expiring products plus the safety stock, satisfying in this way the Safety Stock policy and covering the expected demand. In the new and remodeled version of the EWA policy, the order quantity will either match the number of products expiring, or comply with the safety stock policy (Kiil et al. 2018), whichever offers the most balanced option. It consistently scores better than the original EWA as it prevents an over-ordering situation in which too much is ordered given the forecast demand and the safety stock policy.

The formula is as follows:

If:

$$I_{p_1,t}^{available} - \widehat{Q}_{p_1,i}^{Outdate} < E\left[D_{p_1,i}\right] + SS_{p_1} \tag{6.5}$$

Then:

If:

$$SS_{p_1} < \widehat{Q}_{p_1,i}^{Outdate} \tag{6.6}$$

Then:

$$Q_{p_1,t} = E\left[D_{p_1,i}\right] + \widehat{Q}_{p_1,i}^{Outdate} - I_{p_1,t}^{available} \tag{6.7}$$

If:

$$SS_{p_1} \geq \widehat{Q}^{Outdate}_{p_1,i} \tag{6.8}$$

Then:

$$Q_{p_1,t} = E\left[D_{p_1,i}\right] + SS_{p_1} - I^{available}_{p_1,t} \tag{6.9}$$

By allowing an interdependence amongst the two variables, Safety Stock and expiring quantity, the model actual gets closer to the optimum quantity to be ordered. It contemplates the scenario in which the expiring stock is greater than the safety stock. This results in ordering the quantity going to expire soon plus the quantity needed to meet the demand requirements, which in turn accomplishes both the target of complying with the Safety Stock policy and the forecast demand. This tweak to the EWA removes one of its limitations and allows for better results, as proven in (Kiil et al. 2018).

Since the EWA$_{SS}$ is a strictly better version of the EWA, as well as having enough flexibility and simplicity to both implementation and diversity of use, it´s a rather good model for further improvements as it is done afterwards on other works.

6.1.4 EWA$_{3SL}$

One of the latest iterations on the EWA policy comes from (Christensen et al. 2020). This model takes a more in-depth turn into analysing the variables that could directly affect the actual requirements for order quantity placement. The main focus here, takes the learning from the EWA and adds another layer of variables on top, considering the customers behavior and impact on the actual demand of the product. It includes variables that consider the Supplier Fill-Rate, Price Reduction, and Substitution Demand. These inclusions on the formula are made in order to have an Inventory Management that does reflect the consumer requirements on the domains of availability and product freshness (Christensen et al. 2020).

The increase in complexity is not only seen by the increase on the number variables, but also because now there´s a multi-product approach to the replenishment models, which in turn implies that in the industry different products can have relationships of interdependence. This concept has long been known from Retail Management Theory, but now it has been applied as a concept in the development of a replenishment model.

In the efforts for closely depicting reality to provide better information, and in the same wavelength as the two previously mentioned EWA and EWA_{SS} , the EWA_{3SL} has also been constructed with the fixed review period in mind to more closely resemble what is commonly done throughout the industry (Christensen et al. 2020).

The authors developed the following decision tree for an easier understanding of how the model works:

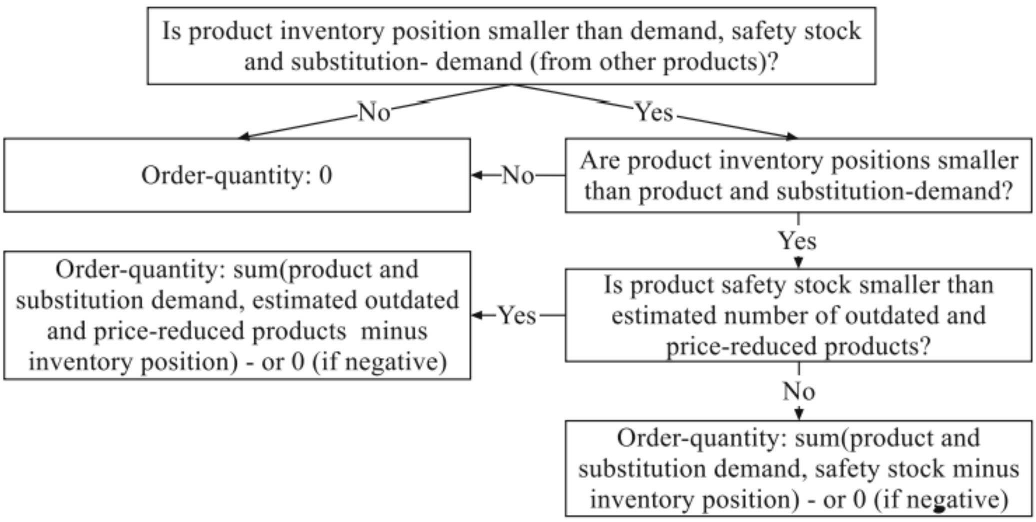

Figure 6.2: EWA_{3SL} Decision Tree - (Christensen et al. 2020)

The formula is as follows:

1) **If:**

$$I_{p_1,t}^{available} < E\left[D_{p_1,i}\right] + SS_{p_1} + E\left[D_{j,i}^{sub}\right]\mu_{p_1|j} \tag{6.10}$$

Where:

$$D_{j,i}^{sub} = 0 \text{ if } I_{j,i}^{available} \geq D_{j,i} \text{ and } D_{j,i}^{sub} > 0 \text{ if } I_{j,i}^{available} < D_{j,i} \tag{6.11}$$

$$\mu_{p_x|j} = \begin{pmatrix} 0 & \mu_{p_1 2} & \dots & \mu_{p_1 j} & \dots \\ \mu_{p_2 1} & 0 & \dots & \mu_{p_2 j} & \dots \\ \vdots & \vdots & \ddots & \vdots & \dots \\ \mu_{p_x 1} & \mu_{p_x 2} & \dots & 0 & \dots \\ \vdots & \vdots & \vdots & \vdots & \ddots \end{pmatrix} \tag{6.12}$$

Then:

$$I_{p_x,t}^{available} < E\left[D_{p_x,i}\right] \tag{6.13}$$

2) **If:**

$$I_{p_1,t}^{available} + I_{j,i}^{sub.available} < E\left[D_{p_1,i}\right] + E\left[D_{j,i}^{sub}\right]\mu_{p_1|j} \tag{6.14}$$

2a)

If:

$$SS_{p_1} < \widehat{Q}_{p_1,i}^{Outdate} + \widehat{Q}_{p_1,i,l}^{Reduced} \tag{6.15}$$

Then:

$$Q_{p_1,t} = max\left(\left(E\left[D_{p_1,i}\right] + \widehat{Q}^{Outdate}_{p_1,i} + \widehat{Q}^{Reduced}_{p_1,i,l} + E\left[D^{sub}_{j,i}\right]\mu_{p_1|j} - I^{available}_{p_1,t}\right), 0\right) \quad (6.16)$$

2b)

If:

$$SS_{p_1} \geq \widehat{Q}^{Outdate}_{p_1,i} + \widehat{Q}^{Reduced}_{p_1,i,l} \quad (6.17)$$

Then:

$$Q_{p_1,t} = max\left(\left(E\left[D_{p_1,i}\right] + E\left[D^{sub}_{j,i}\right]\mu_{p_1|j} + SS_{p_1} - I^{available}_{p_1,t}\right), 0\right) \quad (6.18)$$

For all:

$$I^{available}_{p_1,t} \geq E\left[D_{p_x,i}\right] \quad (6.19)$$

3)

If:

$$I^{available}_{p_1,t} + I^{sub.available}_{j,i} \geq E\left[D_{p_1,i}\right] + E\left[D^{sub}_{j,i}\right]\mu_{p_1|j} \quad (6.20)$$

Then:

$$Q_{p_1,t} = 0 \quad (6.21)$$

Even though the published material did not include an actual benchmarking against previous models, the additional variables could be seen to have a big impact on the results, if the inputs for those variables are correctly done. For example, knowing exactly the price sensitivity of a product and its impact on the product´s demand, or even the actual impact of substitution demand amongst a multi-product environment.

From a theoretical stand point this seems to be one of the best models for fast perishing products as it takes into account the behavior of one of the most important agents in the whole supply chain, the customer.

6.1.5 Old Inventory Ratio (OIR)

Presented in 2013 by Qinglin Duan and T. Warren Liao, the OIR delivers an interesting replenishment policy to address challenges dealing with uncertain demand, limited shelf life and high customer service level requirements for fast perishable products (Duan & Liao 2013). It achieves this by establishing reordering decisions that take in consideration not only available inventory, but also the expiring products within review period.

This model undergoes through two levels. Firstly, the available inventory is checked and if it is lower than the Safety Stock, then an order should be placed to meet the Safety Stock Stock policy. Secondly, if the ratio between the expiring products and the available inventory on hand goes over a given threshold, , an additional replenishment quantity – equal to the amount of expiring products – is ordered (Christensen et al. 2020)(Kiil et al. 2018).

The formula is as follows:

If:

$$I_{p_1,t}^{available} < SS_{p_1} \tag{6.22}$$

Then:

$$Q_{p_1,t} = SS_{p_1} - I_{p_1,t}^{available} \tag{6.23}$$

If:

$$\frac{\widehat{Q}_{p_1,i}^{Outdate}}{I_{p_1,t}^{available}} \geq \delta \tag{6.24}$$

Then:

$$Q_{p_1,t} = SS_{p_1} - I_{p_1,t}^{available} + \widehat{Q}_{p_1,i}^{Outdate} \tag{6.25}$$

This model similarly to the EWA$_{SS}$ can cover one of the limitations of the EWA policy. Both take into consideration the expiring products within the review period. However, it still considers an expiring stock independently from the Safety Stock policy. Since an amount of expiring stock can be ordered according to the parameters independent of the Safety Stock position, this can lead to actually over-ordering in some cases compared to the EWA$_{SS}$.

Nonetheless, the inclusion of a threshold to order quantities equal to the expiring stock can prove equally useful if adequately calculated with historical information to optimize the ordering quantity.

6.1.6 Age-and-stock-based policy

This continuous review model comes into play similarly to the the Old Inventory Ratio (OIR), however it will provide a certain amount to be ordered when the available inventory goes below a pre-established level or if the expiring stock has gone over a given time (Lowalekar & Ravichandran 2014)(Christensen et al. 2020). The order amount is fixed in this continuous review model, as the placement happens when either of the aforementioned events are met first.

The formula is as follows:

If:

$$I_{p_1,t}^{available} < SS_{p_1} \textbf{ Or } Ab_{p1,t} > a \tag{6.26}$$

Then:

$$Q_{p_1,t} = Qf_{p_1} \tag{6.27}$$

Since it´s a continuous review model, usually the Safety Stock is lower, which can pave way for certain risky conditions to arise. Highly dependent on the Lead Time for performance, this kind of model ensues that if the supply chain is not flexible enough to respond to high fluctuations in demand, out of stock situations can be a reality if not taken properly care. Specially because the formula dictates a fixed amount to be ordered. This continuous review model fits better with products which demand is stable and can accommodate responsive supply chains with adequate Lead Times for the product in question.

6.1.7 Model Selection

After reviewing some of the most prominent replenishment models in current literature, it became clear that most developed models will perform better or worse under certain specific conditions. Most of the work done by previous authors shows that different variables can have a direct impact on the results. Adding complexity to the models can depict more accurately a model closer to reality, but prove a challenge to correctly implement it with all the constraints that it ensues. Even the decision to choose between a continuous review model or a periodic one can bring different outcomes under different conditions.

From this, a simple deduction can be made - the replenishment model chosen should be the one that performs best under the given constraints, for there is not a ´best model´.

In order to choose the model in which to work further, it has to align with some criteria of that which will ultimately get to the main objective of the work depicted in the Problem Statement done previously - How to improve a model to account for the 3 sustainability pillars and thus help reduce total waste of fast perishable products?

Criteria:

- Suited for retail industry
- Ease of implementation
- Handling of fast perishable stock

After considering some of the existing models, the EWA_{SS} is the chosen model to further develop and modify for the inclusion of elements to provide a sustainably proven replenishment model.

Firstly, the EWA_{SS} complies with the criteria of suitability for the retail industry. The EWA_{SS} is a periodic review model, which is the norm across the industry for a reason. It better contemplates the inclusion of demand over a period of time in the variables, as well it will consider the supplier lead time as well as more stable Safety Stock level which ensures a higher level of service for the customer than a continuous review model.

Ease of implementation is an important requirement, as the model has to be easily implemented but also to be easily modifiable to include new elements. Increasing complexity to a model not only imposes barriers to the implementation but can be harder to maintain and control. Adding a multitude of variables has an exponential problem of issues that can arise, specially regarding the integrity and quality of all the input data which can affect the output of the model.

Lastly, the ability to handle fast perishable stock implies that the model is already taking into account expiring material over the review period, and not only looking at the dual plane of Inventory availability vs Stock Policy.

After going through the literature it is also easy to find evidence to strengthen this choice. For example the simulation that was done in which six different replenishment models were compared. The results have shown that the EWA was the best performing periodic review policy for fast perishable products (Lowalekar & Ravichandran 2014). Given that the EWA_{SS} is indeed a strictly better model than the predecessor it makes sense to choose it over other periodic review models.

Summary

As far as replenishment models go, some of the most preeminent are displayed and explained to provide an understanding on the topic, but also to give a bedrock as for which to construct a different model with a different approach of that which has been commonly seen.

In this chapter while going through all of the models is was possible to engage with different topics on Inventory Management, specially pertaining to the different compositions of the models and how they work under different conditions. Additionally, what they can bring in different scenarios, as each different model brings its own advantages/disadvantages, and any choice made from any company to utilize a replenishment model has to take into account the whole environment and a myriad of variables that have direct impact on the correct choosing of a model.

At the end the model chosen for the purpose was the EWA_{SS}. It has shown to be the most compliant with the criteria defined and has been shown in the current literature to outperform other models under the specific constraints that this work requires.

The next chapter will then put under more scrutiny the model in order to better understand the areas of improvement and what can be modifiable to accommodate the elements that ensure sustainable solution for a new replenishment model.

6.2 Model Analysis

In this section the focus shifts towards going into the selected model and analysing the different elements that constitute the formula. By assessing the variables at play and the different impacts that they can have, it is possible to withdraw a clearer view on what can be improved upon to reach the objective of this work. Ultimately, delivering information that enables the construction of a model that has at its core the aim to minimize waste while adhering to the ever more important sustainability concepts.

The selected model to work on was the EWA_{SS} as it is a better fit for purpose in this work. (Kiil et al. 2018) developed the EWA_{SS} to properly consider the volume of available inventory in relation to the expiring products within the review period (Christensen et al. 2020). The whole work has been developed for an improvement upon the work of (Broekmeulen & van Donselaar 2009) on the EWA policy, and making it a proven strictly better version of it by displaying better results when applied in simulation. This has been done considering fast perishable products within a fixed review period which reflects the ongoing activities of the industry in general.

(Christensen et al. 2020) sheds light on a new angle by utilizing a multi-product approach to the EWA policy, since most models are limited in their analysis to a single product. EWA_{SS} does not stray from this as well, and is only considering a single product. It is worth noting that this is only a limitation if the variables considered are a reflection of reality for whatever product is being considered. Meaning that it all depends on the constraints and assumptions at play. If a certain product does not have a direct substitute within the shop floor then substitution demand would be rendered to 0, or even if the pricing strategy of the company does not allow for reduced prices on expiring stock then price sensitivity is not affected. Obviously, including these variables in the formula for multi-product consideration offers more flexibility and can extend a model to a larger number of products, however, it only performs better under certain assumptions.

Ultimately the EWA_{SS} is one of the best replenishment model options for a single fast perishable product with fixed shelf life, while considering a fixed review period and stochastic demand. This as been set as the basis for the formula to work on.

6.2.1 EWA_{SS} Formula Composition

The formula is as follows:

If:

$$I_{p_1,t}^{available} - \widehat{Q}_{p_1,i}^{Outdate} < E\left[D_{p_1,i}\right] + SS_{p_1} \tag{6.28}$$

The trigger to place an order is seen in this line. The trigger is when the available inventory cannot both satisfy the forecast demand and the safety stock policy when deducting expected expiring stock from the available inventory. The order placement happens then because either the Demand will not be satisfied and thus reducing the service level, or not complying with the Safety Stock which in turn places the company liable to out of stock situations if there is a sudden surge in demand in which the Safety Stock is not able to cover.

After this condition is met, then the formula bifurcates into two separate scenarios. Only one of them can be met mathematically given that the first one is true. Meaning the order quantity provided by the model will be given by either one of those scenarios, whichever becomes true first.

If:

$$SS_{p_1} < \widehat{Q}^{Outdate}_{p_1,i} \tag{6.29}$$

Then:

$$Q_{p_1,t} = E\left[D_{p_1,i}\right] + \widehat{Q}^{Outdate}_{p_1,i} - I^{available}_{p_1,t} \tag{6.30}$$

One of the scenarios stipulates that if the Safety Stock is less than the expiring stock, then the ideal order quantity provided by the model would be the total amount of forecast demand plus the expiring stock, while obviously deducting the available inventory. This leaves out the Safety Stock out of consideration. However, by utilizing this formula, the system is actually complying with the Demand requirements and since the expiring stock is higher than the Safety Stock, the available quantity when the order is received will also have the Safety Stock covered.

This is key to understanding why the EWA$_{SS}$ outperforms the EWA, and why often it will not cause an overstock that could otherwise be provoked by utilizing the EWA.

or **If:**

$$SS_{p_1} \geq \widehat{Q}^{Outdate}_{p_1,i} \tag{6.31}$$

Then:

$$Q_{p_1,t} = E\left[D_{p_1,i}\right] + SS_{p_1} - I_{p_1,t}^{available} \tag{6.32}$$

On the other scenario possible, the consideration will rely on if the Safety Stock is actually higher than the expiring stock. Given that this condition is true, the formula will entail that the ideal quantity to be ordered will be composed by the forecast demand plus the Safety Stock, while deducting the available inventory in the equation. In turn, this does not consider the number of expiring stock. It does not need to, as both conditions for compliance with the service level as well as the Safety Stock are met. Bringing a theoretical balance in which it would have the optimized amount to meet demand and also the stock holding policy.

6.2.2 EWA_{SS} Waste Scenario

The formula has been deconstructed and each element has been analysed so far. To answer the Problem Statement it is needed then to actually look at what could provoke a situation of waste in the formula. This means going through and taking a closer look at how the variables work and how could a potential waste situation arise.

From the formula it can be deduced that there will be waste when the following is true:

$$0 < \widehat{Q}_{p_1,i}^{Outdate} \tag{6.33}$$

Logically, when the expiring material is higher than 0 there will be a waste situation.

$$I_{p_1,t}^{available} - \widehat{Q}_{p_1,i}^{Outdate} < E\left[D_{p_1,i}\right] + SS_{p_1} \tag{6.34}$$

This is further shown when looking into the condition that needs to be met to trigger an order placement, it can be seen that even if the expiring stock is higher than 0 it does not necessarily mean that an order will be placed. It can be the event that there was a drop in demand from the last review period and there is nothing to do in that case, and there will be a waste situation even if no order is placed from the replenishment system. In some variables like Demand, the forecast can be off the actual real number, given that it is based on stochastic demand.

The same unpredictability factor goes into the Safety Stock, as it becomes the variable that tries to mitigate errors and account for other unexpected occurrences, as demand fluctuations or even product spoilage derived from other factors.

On one side there are variables which are known at the beginning of the review period, such as the available inventory and the expiring stock. On the other hand there are the forecast demand and the Safety Stock threshold which are not static nor can reflect 100% reality, thus providing a margin of error which can often translate into either waste or even shortages in the handling of fast perishable products.

This theoretical imbalance is easily observed, because if the forecast demand was always on point with reality and Safety Stock demonstrated the accurate risk for each review period, then the order placement would be optimized and there would be no waste nor shortages. As each order would have precisely the exact amount it needed to satisfy the demand, complying with the service level, and the Safety Stock would ensure that any of the unpredictable spoilage or variations would be accounted for without impacting the inventory availability to satisfy demand. Unfortunately, there´s no guessing the future and all the assumptions are based on historical data and behaviour.

$$Q_{p_1,t} = \frac{E\left[D_{p_1,i}\right] + SS_{p_1} - I_{p_1,t}^{available}}{B} \tag{6.35}$$

$$Q_{p_1,t} = \frac{E\left[D_{p_1,i}\right] + \widehat{Q}_{p_1,i}^{Outdate} - I_{p_1,t}^{available}}{B} \tag{6.36}$$

Above it shows the two equations that provide the order quantities for both scenarios in the formula. In these two there is now an element that was not in the original paper from (Kiil et al. 2018) and was added now to reflect reality as it does have an impact on waste since it is the object of study. The B is the batch size that the supplier can provide the product. What ends up often happening is that the order is rounded up so that service level is not impacted and the Safety Stock Policy is followed. The excess usually places the product in an overstock position, which can then lead to waste situations.

However, there is yet another aspect of reality that is often overlooked and that could skew the results. Which is the integration of the Minimum Order Quantity. Every product has a minimum order quantity, even if it is just 1 unit, that is the minimum, as realistically speaking it should not be possible to order half a unit or a third of a unit. So in reality these formulas would appear as the following:

If

$$\frac{E\left[D_{p_1,i}\right] + \widehat{Q}_{p_1,i}^{Outdate} - I_{p_1,t}^{available}}{B} > m \tag{6.37}$$

Then

$$Q_{p_1,t} = \frac{E\left[D_{p_1,i}\right] + \widehat{Q}_{p_1,i}^{Outdate} - I_{p_1,t}^{available}}{B} \tag{6.38}$$

Else

$$Q_{p_1,t} = m \tag{6.39}$$

In turn the other scenario follows the same idea:

If

$$\frac{E\left[D_{p_1,i}\right] + SS_{p_1} - I_{p_1,t}^{available}}{B} > m \tag{6.40}$$

Then

$$Q_{p_1,t} = \frac{E\left[D_{p_1,i}\right] + SS_{p_1} - I_{p_1,t}^{available}}{B} \tag{6.41}$$

Else

$$Q_{p_1,t} = m \tag{6.42}$$

The latter inclusions show a closer depiction on reality and something that is not often seen within the replenishment models. With this in place, what is happening is that to comply with the demand and the implemented stock holding policy, companies would actually have to order even if it meant that the demand in place would be inferior to the MOQ, generating a scenario where unwanted waste is a possibility since it creates a position of overstock.

Chapter 7

Solution

In this chapter a solution is provided to reduce total waste through a sustainability proven replenishment model.

7.1 Model Modification

In the previous sections the work went through a replenishment model selection and then an analysis on the chosen model and its variables. Some insights could be retrieved, specially regarding on what can cause waste in the chosen model, as well as some of the implications that reality has on the model itself.

In the development of the modification some considerations have been made, and the conclusion was to tackle unnecessary waste that could originate from the model. There was a situation that became evident in the previous analysis, that the modification tries to tackle and address. The MOQ, as seen in the previous chapter, is a constraint that is often present and should be considered.

Currently, when applying these constraints to the EWA_{SS} model, the formula looks like the following:

If

$$I_{p_1,t}^{available} - \widehat{Q}_{p_1,i}^{Outdate} < E\left[D_{p_1,i}\right] + SS_{p_1} \tag{7.1}$$

Then

If:

$$SS_{p_1} < \widehat{Q}_{p_1,i}^{Outdate} \tag{7.2}$$

Then

If:

$$\frac{E\left[D_{p_1,i}\right] + \widehat{Q}_{p_1,i}^{Outdate} - I_{p_1,t}^{available}}{B} > m \tag{7.3}$$

Then

$$Q_{p_1,t} = \frac{E\left[D_{p_1,i}\right] + \widehat{Q}_{p_1,i}^{Outdate} - I_{p_1,t}^{available}}{B} \tag{7.4}$$

Else

$$Q_{p_1,t} = m \tag{7.5}$$

Or

If:

$$SS_{p_1} \geq \widehat{Q}_{p_1,i}^{Outdate} \tag{7.6}$$

Then

If:

$$\frac{E\left[D_{p_1,i}\right] + SS_{p_1} - I_{p_1,t}^{available}}{B} > m \tag{7.7}$$

Then

$$Q_{p_1,t} = \frac{E\left[D_{p_1,i}\right] + SS_{p_1} - I_{p_1,t}^{available}}{B} \tag{7.8}$$

Else

$$Q_{p_1,t} = m \tag{7.9}$$

The modification proposes the inclusion of a variable that takes into account the difference between the actual requirements to fulfill demand and the physical order placement constraints that are imposed on the MOQ. This variable acts as a decision maker to place or not the order. The actual value is a percentage attributed beforehand that could differ according to different polices. The variable has been denominated as η and is included as follows:

If

$$I_{p_1,t}^{available} - \widehat{Q}_{p_1,i}^{Outdate} < E\left[D_{p_1,i}\right] + SS_{p_1} \tag{7.10}$$

Then

If:

$$\frac{I_{p_1,t}^{available} - \widehat{Q}_{p_1,i}^{Outdate}}{B} < \eta \cdot \mathrm{m} \tag{7.11}$$

Then

$$Q_{p_1,t} = 0 \tag{7.12}$$

Else

$$SS_{p_1} < \widehat{Q}_{p_1,i}^{Outdate} \tag{7.13}$$

Then

If:

$$\frac{E\left[D_{p_1,i}\right]+\widehat{Q}_{p_1,i}^{Outdate}-I_{p_1,t}^{available}}{B}>m \tag{7.14}$$

Then

$$Q_{p_1,t}=\frac{E\left[D_{p_1,i}\right]+\widehat{Q}_{p_1,i}^{Outdate}-I_{p_1,t}^{available}}{B} \tag{7.15}$$

Else

$$Q_{p_1,t}=m \tag{7.16}$$

Or

If:

$$SS_{p_1}\geq \widehat{Q}_{p_1,i}^{Outdate} \tag{7.17}$$

Then

If:

$$\frac{E\left[D_{p_1,i}\right]+SS_{p_1}-I_{p_1,t}^{available}}{B}>m \tag{7.18}$$

Then

$$Q_{p_1,t}=\frac{E\left[D_{p_1,i}\right]+SS_{p_1}-I_{p_1,t}^{available}}{B} \tag{7.19}$$

Else

$$Q_{p_1,t}=m \tag{7.20}$$

The trigger for this modification idea to the model was to think of an extreme scenario where an automated replenishment system using the EWA$_{SS}$ would actually place an order if the following statement were to be true $I_{p_1,t}^{available}-\widehat{Q}_{p_1,i}^{Outdate}<E\left[D_{p_1,i}\right]+SS_{p_1}$.

Theoretically it makes sense, but it could happen that it would be just 1 unit short triggering the order. Since in reality there are MOQ´s in place and rounding values for the batches, the company cannot just order 1 unit of the product. The automated system would just place the order to the nearest possible value - the MOQ. Depending on whatever was agreed on the contract with the supplier this difference could be negligible or might be rather large. The point to make is to not allow such extreme situations to happen, as something like this could actually mean an overstock that in turn could become unnecessary waste.

It could be argued that the issue could be solved by a rounding down or up application, but that is an oversimplification of the issue. Studying the right threshold for this variable across multiple products, with different suppliers, could avoid unnecessary waste and environmental impact when extrapolated to a whole portfolio.

7.2 Sustainability Screening

One of the intents of this work is to create a bridge between replenishment model theory and Sustainability as whole, looking deeper not only in the efficiency of the models and their fit for the companies, but the inherent implications they might have otherwise in real life applications.

Integrating these concepts together, while having a multi-disciplinary approach can help mitigate issues that are being reverberated across our society. It is important to stray away from a somewhat silo mentality and blend ideas from different fields for sustainable growth.

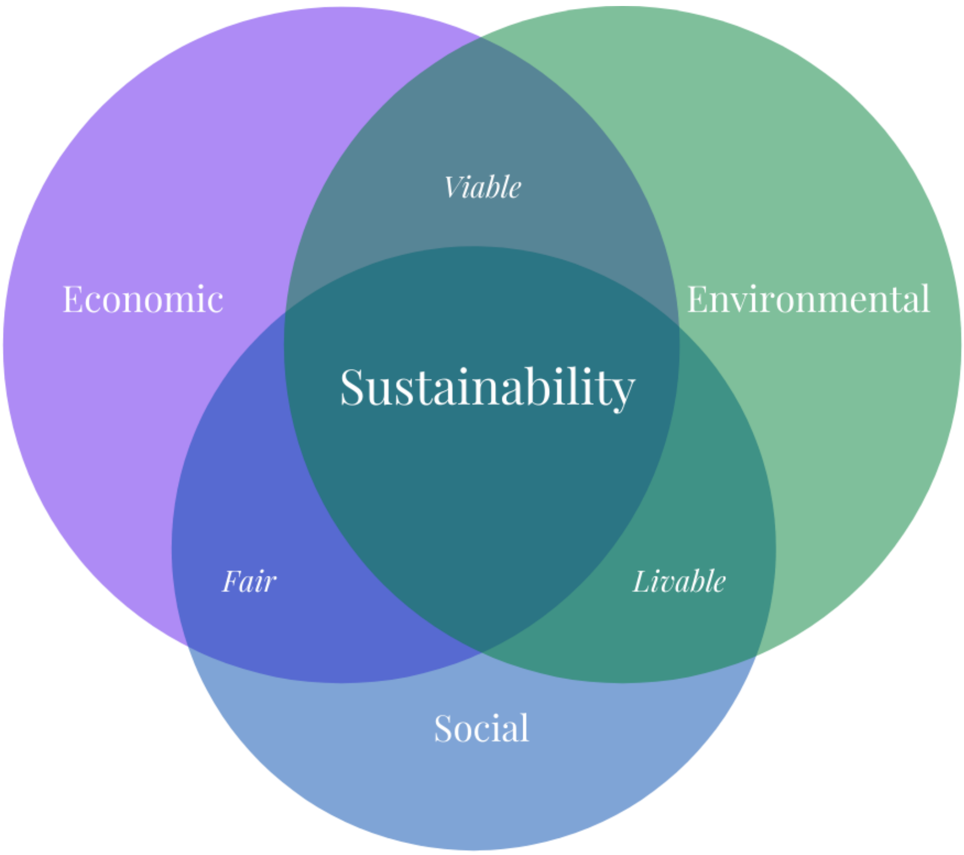

Figure 7.1: 3 Pillars of Sustainability

With the model produced in the latter section, it is now possible to pass it through a sustainability screening in order to observe the model and its impacts on real life applications. For this purpose, the 3 Pillars of Sustainability will be important and they will be used as the indicators on how this new model can perform.

Many of the concepts and impacts that these Pillars have on a food supply chain, were shown upon the Literature review. These insights allow an understanding on how having sustainable solutions within a food supply chain, no matter how small, can directly impact society. In this case, it can be even observed how can waste reduction have an impact and actually help achieve the SDG 12.3.

As (Garcia-Garcia et al. 2016) described, developing alternative paths in food management that directly produce less waste and that maximize economic and social benefits, while minimizing environmental effects, is indeed adhering to the concept of sustainability. Specially in a world where more than a third of the food going downstream on the supply chain is spoiled before it could ever reach the consumer(Garcia-Garcia et al. 2016) (FAO 2013).

Before delving into the Pillars and how the new model connects with the subjects, it is necessary to explain a bit further in what ways does the model impact reality.

This new modification to the model will strictly avoid overstock situations, thus decreasing the risk of waste. This addition does not allow a scenario where there would be more overstock than before with the previous version of the model. Meaning that either the total waste will remain the same as the predecessor or it will actually drop.

The drop in total waste is the main benefit of the inclusion. The next logical question is - how is this accomplished? Well, the modification makes it so that the systems would place less orders than it would normally place before, by comparing the volume required to meet demand and the Safety Stock versus the MOQ. This entails a reduction in resource usage from the predecessor model, meaning that there are additional efforts on resource usage being done to decrease total waste. This an important conclusion to consider for the next sections.

7.2.1 Environmental Implications

Environment is the area most commonly associated with sustainability, hence why it is the most amply researched out of the pillars throughout the years (Ohlsson 2014) (Carson 1962).

The benefits of the model in this area are quite obvious, namely in the impact that it could have in resource usage. As previously explained, the new model achieves a reduction in waste without needing additional resources to achieve this. However, this is not the biggest contributor to environmental sustainability, the actual reduction in the number of orders will bring forth the biggest impact.

The point to be made is that the new modified model has a positive impact because it stretches throughout the whole chain. Even more when it can be considered that if applied to a larger portfolio, the order number drop actually extrapolates and reverberates through the chain causing considerable positive impacts, specially given the already enormous strain that the food industry places on our already finite resources.

Very much as a bullwhip effect, the demand signal coming from the end of the chain will dictate the required production required upstream. Since the scrap percentages are so high and one third of the food is lost along the chain, even a small decrease in the demand signal could have serious impacts on the environment since all the negatives effects of production that would otherwise be in place will be gone.

When applying the model in a food supply chain for a diverse portfolio is difficult to track every single benefit due to the complexity and specificity of each company´s supply chain. However, the negative effects of food production are well documented.

Since there will be less need for production with the reduced amount of orders, energy requirements will drop. This is significant when it is considered that food production takes about 20% (Sonesson 2011) of all energy consumption. Water usage will most likely drop as well, since food production also consumes about 70% of all freshwater (Ohlsson 2014). The possible list of impacts is rather extensive, and it can include, but not restricted to, positively affecting carbon-dioxide emissions, methane emissions, landfills, loss of biodiversity or mono-culture activities.

7.2.2 Economic Implications

Currently it is estimated that about 750 Billion dollars worth of food production is spoiled every year in the supply chain (FAO 2013). This amount of waste clearly has negative implications for all agents in the chain, from the producer to the consumer (Ribeiro et al. 2018). The unnecessary amounting operational costs of waste handling from product loss carry on from agent to agent, since with each step the price tends to increase. This has a big impact on the economical area of the industry. Due to the complexity of the chain and the difficulty to handle such products, such amount of waste is understandable, but food chains are in no way efficient and are in dire need to change paradigm.

After consideration, there are only two agents in the chain that should benefit economically from a replenishment model like this at the end of the supply chain, namely the retailer and the customer.

The retailer will have decreased the operational costs upon usage of the model, as it will avoid the actual waste handling that otherwise could be in place. This is a direct reflection of becoming more efficient. By inference, the consumer might experience a drop in price given that the retailer will now earn higher margins on its portfolio.

However, the drop in orders will actually negatively impact the rest of the supply chain from an economic perspective, given that the other agents will not attain higher efficiency levels and will continue with the same waste rates. For the rest of the chain it just means lost sales.

One of the facets of economic Sustainability pertains with trying to ensure a just and equitable distribution of revenue amongst the different agents in the chain (Ohlsson 2014). The introduction of the developed model might not reach all the agents, but it does improve the conditions for sustainable economical living of the retailer and, most likely, the consumer as well.

7.2.3 Social Implications

In the Social Pillar there are also contributions to be made from developing a model focused on reducing total waste. This domain has its own set of unique issues to address, that can can range from the impact of a single individual to worldwide reach. Often we can find items about the sustainability of a supply chain regarding human rights, discrimination, child labor or minority rights (Ohlsson 2014).

The new developed model improves on the social perspective by contributing to a more socially conscious supply chain. Around 2 Billion people live currently with difficult access to food or even hunger conditions (UNDP 2015), from a moral and social standpoint it is almost a duty to try and reduce waste to the best of the abilities. Is not only immoral but also wrong to deliberately allow waste to happen in detriment of other interests that do not take in consideration Social Sustainability.

Mirroring the Environmental impact due to the reduction of waste throughout the chain due to the reduced number of orders, the model not only stops waste at the retailer level, but also suppresses on other levels. This extrapolation exercise enables a view of how important it is to reduce waste and how small correctional actions can have an impact.

There is another point to speak about in which the model helps directly with the local waste reduction. It is a problem which is very specific to the food industry, but it happens as a symptom of the core waste issue. Retailers often are under fire for this. With the high amounts of generated waste, there are individuals who try to salvage the food from the disposal containers and consuming it, often putting their health at risk. By having a local waste reduction, this kind of behaviour could be suppressed.

Chapter 8

Discussion

The discussion chapter will include insights and a discussion about the newly developed model as well the relationship with the Sustainability field.

Replenishment Model Risk

During the elaboration of the new model, the benefits of having reduced waste through a change in order placement have been brought forward. However, it is now worth trying to show the risks associated with proceeding with this model.

The model assumes a new decision variable to check if an order is worth placing given the quantity required and what is established in the MOQ. The trigger for order placement is when Available Inventory becomes lower than the forecast demand and the Safety Stock. When this happens there is clearly an imbalance that needs to be fixed or a shortage situation might occur. The problem is when the imbalance is so negligible that is actually better to not order than to order the MOQ leaving a situation of overstock that could prove to be even worse.

By not placing an order, the available inventory for that review period will be lower than demand and the Safety Stock policy in place. One of the risks is that in one situation the inventory level can incur in overstock, in the other a shortage situation where there is unmet demand has a higher chance of happening, due to the imbalance that was there in the first place.

If the forecast is accurate, then the Safety Stock can accommodate the risk of having less inventory than expected until the next review period. Obviously, a lot would depend on the actual variables at play. Does the company run a low Safety Stock or prefers to be well stocked? Is the forecast historically accurate? What´s the MOQ?

Since the model deals with stochastic demand, the risk of overstock or shortage will always be present. It is the optimization of the variables to the policy in place that will dictate how well will the model perform.

Model Viability

Developing a replenishment model that can help with reducing waste, while making the whole order placement process more efficient from a supply chain point of view, has to obey to some constraints that make the model viable.

Since a replenishment model adheres to a mathematical formula, the variables can be changed to suit whatever is the objective. In this case it was to reduce total waste. Total waste is not a variable in this case since we´re dealing with an order placement process, but the variables at play can definitely have an impact in the amount of waste produced.

The viability of a model can be looked at through how well it adapts to reality, how well the constraints are in place, how easy it is to implement and then how it performs.

The developed model is certainly viable and valid for use. Previous models of the same sort were not including batch size or MOQ in the considerations. Also the process is easy to follow and to input it into a system without too much complexity.

But it is a model with certain limitations, as it is developed for general use across an undefined portfolio of fast perishable products. It is a model for a single-product approach and not multi-product as for example the one developed by (Christensen et al. 2020). It does not account for some variables that can occur in reality, hence it might not be suitable for every product. However, these inclusions are all slightly relative.

Under certain contexts some variables work better and depict reality better, thus providing a more reliable system. This is the part of the adaptation to reality and the assumptions made that has to be taken carefully. The EWA_{3SL} is considering Price Sensitivity and Substitution Demand into the formula. But if the company has a pricing policy in which it does not drop prices for expiring products, or even that for certain products there was no direct substitute once a product goes out of stock, the variables would be nullified.

The viability and application of the model will always have to consider the reality in which it is to be inserted in. Some models for fast perishable products can look absurdly different and both be efficient, take replenishment models for blood management in hospitals versus food retail. Even within the same industry they can look different, as it will highly depend on the company´s business model, environment and processes.

Sustainability Compliance & Impact

Coming up with a solution that accommodates all the Sustainability Pillars can be challenging. Not only should the solution be able to reduce total waste, but contemplate all the possible consequences throughout the supply chain. This requires and inherent knowledge of different Supply Chain concepts, but also retrieving concepts from different fields of study.

One common misconception is that just by reducing waste, whatever solution that led to it is a sustainable solution. Attention needs to be focused on how the reduction was accomplished.

- If waste is minimized by having a Just in Time model in which every hour there is an almost empty truck making deliveries, is it environmentally or economically sustainable?
- If waste is minimized by ordering below demand requirements and letting the product go out-of-stock, is it economically sustainable?
- If waste is minimized by sourcing from a supplier that violates human rights, is it socially sustainable?

The model developed has shown to comply in the three areas of Sustainability. Obviously, there´s more emphasis and impact on one area than another. However, it will not stray from the fact that it does comply with the Sustainability narrative.

The biggest impact would be felt on the environmental field, due to the bullwhip effect that would be felt from downstream to upstream in the shape of the demand signal. So many different variables and impacts would be at play that it is even hard to contemplate all. But this is the kind of approach that will help achieve the SDG 12.3.

For the company employing the model, the economic pillar would have a big weight on the decision to use it, but it still holds value to consider it. At least it strays from the common narrative where the optimization of systems is geared towards maximizing profits. Utilizing this model which aims at reducing total waste, operational costs would actually go down.

These Sustainability concepts are ever more important, clients are ever more concerned and conscious of their purchase decisions. There are even companies that focus on studying and tracking whole supply chains to identify negative activities in order to improve them from a sustainability perspective. This is particularly useful when trying to deal with suppliers and know every step of the chain to make sure there is nothing wrong or immoral that could jeopardize in any way the company. It´s no longer just a social responsibility, it can actually affect the business.

Chapter 9

Conclusion

Food waste is becoming an even more critical issue than ever due to the constantly growing globalized supply chains and the finite resource availability problem. Considering the three pillars of sustainability, all of them have substantial implications regarding food waste. Environmental impacts such as the GHG emissions connected to the food production and consumption, the economically damaging and polluting nature of final disposal and the depletion of the finite natural resources are major concerns.

Meanwhile, food waste has also economical impacts for all actors of the supply chain, connected to all the operational costs that stem from it. There are also considerable issues from the social perspective, between the inequality of the growing population and the vastly diminishing natural resources, as well as food poverty and the food wastage.

This work took an investigative path on inventory management, trying to connect the concept of replenishment models with the aforementioned sustainability aspects of food waste. These Replenishment Models have been changing throughout the years, differing in structure as well as applications in different industries. With an increasing need to be more efficient and sustainable, the pressure on the models to bring better results has been quite high. This kind of models are of utmost importance for the order placement process and can really bring value and even competitive advantages if properly implemented.

In the development of this work it was displayed the difficulty to shape a model to real life constraints, even more when several repercussions have to be considered for each variable that is added to the formula, thus increasing the level of complexity of the task at hand exponentially. However, replenishment models keep getting developed in both academia and in the business world, all it is needed is to find the right level of balance of execution.

This work has reached a final solution in the shape of a replenishment mode that adhered to the 3 Pillars of Sustainability, even contributing for the achievement of SDG 12.3. This solution was constrained by limitations and still presented some risks of usage, but it has enough validity to stand on its own as a valid alternative to some other replenishment models. Specially, when considering that the objective of reducing total waste is seldom used, as well as taking the Sustainability concept into account in the building of the model. Most other models are taking into consideration the economical benefits and usually aim at profit maximization, however this is not a sustainable way of thinking if the other aspects of Sustainability are not considered, or worse, disregarded.

Chapter 10

Reflection

Model Selection

When reviewing the Literature existent in the field, a lot of different replenishment models came up. It is worth considering that only a handful of them were selected to be included in this work. Some might have been missed that could be a better fit overall to include and could provide more valuable insights.

Model Variables

Upon the construction of the model there were some variables that could have been added to make the model more robust. The model is considering the MOQ and if to order or not. The same thought process could have been utilized to extend to formula to similar issues with the Batch Size and its rounding values. It could have given a better answer as to order the batch size rounded up or below according to the whatever policy was determined.

Another variable that was not included, but was under consideration, was the inclusion of substitution demand. This would make the single-product approach into a multi-product approach. It would add another layer of complexity to the model that would closer reflect reality.

Sustainability Concepts

Sustainability is such a broad term that harbors a lot of concepts and definitions such as sustainable development or even economic sustainability. Many times these concepts are used interchangeably, however they do not exactly mean the same. This even allows stakeholders to use the term most beneficial according to their political agenda. Almost four decades of intense discussions can be seen with concerted efforts by national governments, international agencies, public organizations, and thousands of committed activists and academics, however, still without conclusions (Shkliarevsky 2015), (Guardian 2012).

To avoid misconceptions, the narrowest definition of sustainability has been used in this study. However, utilization of only the Sustainability Pillars to assess the model might have been short-sighted. The thesis was developed for the Operations and Supply Chain Management program and not the Sustainability field, hence some more important concepts and insights might have been missed as well. The aim was to try and congregate different fields, since that is what happens out of the academic context.

Further Research

This model could use further research and it feels it could be improved even more. It is at a stage where it has general applications and could easily be modified to fit better a certain scenario for fast perishable products.

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