

The impact of the "Minimum Life on Receipt" criterion in supply chains of perishable products

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Master's Dissertation

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Abstract

The food waste produced at the hands of a retailer or at the final consumer has for long been a studied topic. The main objective of these investigations lies on the improvement of the sustainability of the supply chain, by reducing the waste. However, the existing studies do not take into account the waste generated by the players of the supply chain before the retailer.

One of the measures taken by retailers to reduce food waste at their hands was the introduction of the "Minimum life on receipt" (MLOR) criterion. It states that the retailer will only accept products from the producers, if the time elapsed from the arrival of the product to the expiration date is longer than the stipulated value for that product. This work proposes to analyse the impact that this criterion has on the supply chain, considering that the MLOR value affects directly the inventory management and the waste of both the producer and the retailer.

In this dissertation, a simulation experiment is developed with the objective of testing how a supply chain reacts to different values of the MLOR, using four products with distinct lifetimes. For each simulation run, only one type of product is considered. The impact is measured regarding costs (both specific to the players and the overall costs of the supply chain), waste generated, and the mean age of the products sold at the retailer, in order to evaluate how freshness is affected. It is found that the choice for the right MLOR depends on the objectives of the supply chain, since the different indicators analysed react distinctively with the MLOR, and the results are dependent of the lifetime of the product and even other parameters related to the supply chain.

To conclude, this work is the first study on the MLOR and the repercussions caused by it in supply chains. The main objective of this dissertation is to be the base for more specific and incisive studies on this topic.

Keywords: MLOR; supply chain; perishable products; simulation experiment.

Resumo

O desperdício alimentar produzido quer pelo retalhista, quer pelo consumidor final é um tópico já abordado por diversos trabalhos. O principal objectivo das diversas investigações sobre este tema centra-se no aumento da sustentabilidade da cadeia de abastecimento, sendo este aumento obtido por redução do desperdício. No entanto, nenhum dos estudos feitos até agora teve em consideração o desperdício gerado por outras entidades da cadeia de abastecimento que se encontram a montante do retalhista.

Uma das medidas adoptadas pelos retalhistas para reduzir o desperdício alimentar nas suas instalações foi a introdução do critério MLOR (do inglês "Minimum Life on Receipt"). Este critério estipula que o retalhista apenas aceitará receber produtos dos produtores, se o tempo entre o dia de recepção e a data de validade for superior ao valor estipulado para aquele produto. Este trabalho propõe-se a analisar o impacto deste critério na cadeia de abastecimento, visto que o valor do MLOR afecta directamente a gestão de inventários e o desperdício gerado pela cadeia.

Nesta dissertação é desenvolvida uma experiência de simulação com o objectivo de testar como uma adaptação de uma cadeia de abastecimento real reage aos diferentes valores do MLOR, utilizando para isso quatro produtos com diferentes vidas úteis. Em cada simulação será apenas utilizado um tipo de produto. O impacto do MLOR é medido de acordo com os custos (relativos às diferentes entidades da cadeia e à cadeia em si como um todo), com o desperdício gerado e com a idade média com que os produtos são vendidos no retalhista, de forma a avaliar como a frescura dos produtos é afectada. Verifica-se que a escolha do MLOR mais adequado dependerá dos objectivos que a cadeia de abastecimento define, visto que os indicadores analisados não reagem todos da mesma forma com o MLOR. Além disso, os resultados estão dependentes da duração do tempo de vida do produto e de outros factores relacionados com a cadeia de abastecimento.

Em suma, este trabalho, ao ser o primeiro estudo sobre o MLOR e as repercursões que o seu valor causa na cadeia de abastecimento, tem como objectivo ser a base para investigações mais específicas e incisivas sobre este tópico.

Palavras-chave: MLOR; cadeia de abastecimento; produtos perecíveis; experiência de simulação.

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To my grandfather and my good friend, Avô Zé

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Chapter 1

Introduction

Over the years, sustainability has become increasingly a more relevant aspect of any supply chain. Nowadays, when analysing the performance of a supply chain, companies look not only at economical indicators, but also at the overall impact that their operations have on the environment. In fact, they now aim at improving the sustainability of their supply chains, partially because they feel it is their responsibility, but mostly for marketing reasons (Jones et al., 2008).

A crucial indicator for the sustainability of fresh and frozen supply chains is the aggregate waste generated, along the different elements of it. A study from the Waste and Resources Action Programme (WRAP) estimates that, in the United Kingdom alone, annually, the food waste amounts to 1.3 to 2.6 million tonnes (Lee et al., 2015). The same report presents the food industry with simple measures to decrease these figures along its different elements: one of them is a change in the Minimum Life on Receipt (MLOR). This criterion, used by retailers, states that a certain product can only be accepted from the producer if the remaining life of the product is above a certain limit. WRAP proposed an increase of the MLOR and in 2016, Metcash, an Australian retailer, established rigid policies regarding the MLOR of their products: depending on the total life of a product, Metcash defined the respective MLOR. The main objective of this decision was to reduce the wastage of products, and other retailers followed the same path afterwards.

WRAP's study and the introduction of new policies by Metcash and others concerning the MLOR imply that an increase in this criterion will decrease the waste in the households, the last element of the supply chain. However, they do not take into consideration the waste generated upstream the retailers. If the MLOR criteria is too tight, a great amount of the products that the producers deliver might not be accepted, generating waste not at the end of the supply chain, but at the middle of it. Naturally, this scenario is not ideal and an adequate MLOR should be set, since the whole objective of reducing the food waste should be to do it along the whole supply chain, not only at one of its elements.

1.1 Motivation

A typical frozen/fresh supply chain consists of producers, distributors and retailers. The distributor plays a key role because the storage of frozen products requires complex and expensive facilities. Moreover, these facilities are usually in a central and strategic location, close to different clients. Hence, it is more profitable and convenient for the producers to store their goods in the facilities of a specialised third-party.

Due to the vast variety of stock keeping units handled by food retailers, the receiving time window for each shipment must be respected and if there are products that do not meet the requirements, they are simply not accepted. These products have to return to the distributor's facilities for posterior negotiations between the producer and the retailer. Afterwards, if an agreement is reached, the product is then shipped again to the retailer. In some cases, if the process of renegotiation and second shipping is estimated to take longer than the available saleable-life of the product, the distributor is responsible for the disposal of it.

Bearing this in mind, the focus of this dissertation is to evaluate the impact of the MLOR criterion in the supply chain. With this, it is pretended to confirm if a decrease in the value of the MLOR might improve sustainability, by reducing waste before the retailer, and reduce costs for the whole supply chain. The waste generated after the retailer is beyond the scope of this work.

Presently, for fresh or frozen goods, the retailers require a MLOR from producers of $\frac{2}{3}$ of the shelf life, a value defined by the experience and expertise of those who work daily with these products. Despite being an acceptable and manageable value for the vast majority of producers, others might find this value difficult to comply with, which leads to major disruptions in the supply chain. This project carries a study based on the characteristics of a product that has reportedly presented problems related to failures with meeting the required MLOR with retailers. A model will be developed to evaluate how the supply chain reacts to different values of the MLOR, considering overall costs and food wastage. As far as the author's knowledge, such a study has not yet been done, which enhances the relevance of this work and highlights the existing improvement opportunities in this sector.

1.2 The Mobfood project and OLANO

The Mobfood project consists of a consortium of 43 companies that constitute the agribusiness in Portugal, along with other entities that provide the scientific skills required to develop a global analysis on the current situation of the Portuguese agrifood industry. It was created with the goal of transforming the sector, making it more sustainable, efficient, safe, completely integrated and consumer-focused. To achieve this, the project is divided in eight PPS (product-process-service) projects, each of them working independently. This work is part of the Logistic PPS, whose objective is to develop a collaborative sustainable food supply chain. OLANO is an active participant on this project and is fully committed to it. Proof of that is the interest showed from OLANO's managerial chiefs in this initiative. The company is part of the French "Groupe

OLANO", even though it works independently. It is a specialist on frozen products distribution, located in Guarda. This site allows the company to operate within Southern Europe and, at the present, OLANO has the largest cold storage facilities in Portugal.

1.3 Research problem

This dissertation proposes to tackle a problem faced by many producers of frozen and fresh goods: the definition of the most adequate MLOR for the supply chain. In the frozen food sector, retailers typically require that when the products arrive at their facilities, they still have at least $\frac{2}{3}$ of their shelf life. Deliveries that do not fulfil this requirement are rejected. Because retailers, specially large ones, deal with several brands of similar products, they only suffer minor consequences from this kind of rejections. Consequently, they can afford to be inflexible and ambitious with the MLOR value, burdening the producers' supply chain.

As a result of the increasing variety offered by major retailers, the producer's power of negotiating has been reduced over time. Consequently, they might have to agree with the retailer on a MLOR that is not easy to work with. This case can generate more waste, more costs and worsen the freshness levels of the sold products. This work attempts to shed light upon the impact the MLOR has on these three aspects.

Regarding costs, it is expected to find that an increase in the MLOR criterion will incur in lower costs for the distributor, and higher costs for the retailer. As for the waste generated, it is presumed that the lower the MLOR is, the greater the amount of waste at the distributor will be created, with the opposite result for the retailer. Concerning the impact of the MLOR on the age of the sold products to the final consumer, it is predicted that it increases with an increasing MLOR. With these indicators, it might be possible for the supply chain to define a MLOR capable of benefiting all the players, through collaborations, sharing benefits, or other strategies.

1.4 Methodology

The first step of this project was to model step-by-step the supply chain of a generic fresh/ frozen product, based on a real product handled by OLANO that had been showing difficulties with complying with the MLOR criteria. From this model, with the help of the simulation software *Anylogic*, a simulator was built to run different scenarios on a supply chain comprised of a producer and distributor as the same entity (referred as distributor) and a retailer. The product has a fixed lifetime (different analysis have different values for the lifetime) and the demand was considered stochastic and time-dependent, following a weekly pattern. From the results obtained, an analysis on the impact of how the supply chain reacts to different values was made and conclusions were withdrawn.

1.5 Structure

This dissertation is divided in 5 chapters, the first being the Introduction. Chapter 2 presents a literature review on the related and relevant topics to this work. In Chapter 3 the problem studied by this dissertation is described, as well as the adjusted problem used for the simulation model. Chapter 4 details the simulation experiment and presents the results obtained. Finally, Chapter 5 presents the conclusions of this dissertation and future research possibilities.

Chapter 2

Literature Review

This chapter is divided into four sections. The first describes how perishability can be classified and the second lists the different types of demand a product can be subjected to. The objective of these reviews is to help with the definition of the characteristics of the problem in analysis. The third section details the models developed over time on perishable products inventory management, since it is important to understand the model chosen in this dissertation. In the fourth section, a short explanation on the existing types of simulation models is provided, which is crucial for the simulation experiment performed in this work. Finally, the fifth section presents the available literature on the influence of the MLOR criterion in supply chains. It is worth mentioning that the concepts discussed throughout this chapter.

2.1 Classification of perishability

The fact that a product might lose value in the future or be in worse conditions has been a concern regarding certain types of products. It is addressed as deterioration. The first analysis on this was made by Within (1957), concerning the loss of value fashion products suffer after a storage period. Later, Ghare and Schrader (1963) distinguishes products evolution over time with three categories: direct spoilage, physical depletion or obsolescence. The first is defined by the presence of damage, spoilage, vaporisation, or dryness of the stocked items (e.g. fruits and yogurts.) The second can be applied to fluids that evaporate quickly, and therefore see their potential diminished over time, such as alcohol or gasoline. For the cases where the products lose value over time while its own characteristics remain unchanged, obsolesce is the correct term (e.g. fashion items or newspapers). For this work, only the direct spoilage type of deterioration is of interest.

Nahmias (1982) reviews the existing literature on ordering policies of perishable inventories. In this review, perishability of the inventories is categorised between products with a fixed lifetime and random lifetime. The ability to know *a priori* the exact lifetime of the stock items is what differentiates them. The first category includes yogurts or frozen products, while the latter has examples such as flowers or fruits. Within the category of a random lifetime, Bakker et al. (2012), in their overall review of published articles on deteriorating inventory models, describe products

with an age-dependent deterioration rate (the lifetime follows a probabilistic distribution) and products with time or inventory deterioration rate.

Raafat (1991) presents a different classification for deteriorating items, stating that the value of a product can be a function of time. Goods are divided as (1) constant-utility perishable goods, the ones whose value remains constant while the product decays (e.g. prescription drugs), (2) decreasing-utility perishable goods, referring to goods that lose value over time (e.g. vegetables or dairy products) and (3) increasing-utility perishable goods (e.g. wine or cheese), whose value increases over time.

A different classification is proposed by Lin et al. (2006). The authors divide perishable goods in two groups: those who suffer either age-dependent or age-independent ongoing deterioration (assuming that the deterioration process is initiated after production). The first group comprises goods such as blood and fish, with radioactive materials or volatile liquids belonging to the second one. The main difference between them is that products from the second group do not have an expiry date and remain in stock indefinitely, continuously suffering natural attrition.

Based not on the quality itself, but instead on the quality level perceived of the customer, Ferguson and Koenigsberg (2007) separate goods in three types, without naming them explicitly. The first type aggregates products whose quality levels remain constant over time, even though they become unusable after some time. The authors provide airline seats as a clear example of this type of products. Another type refers to products with deteriorating quality level, reaching zero when a new version of the product is released, like newspapers or textbooks. Products belonging to the third type are characterised by having a deteriorating perceived quality level, although it does not reach zero. In this type, one can divide products whose functionality remains unchanged, such as clothes, or is gradually depreciating, such as fresh products. The third type is helpful in the introduction of the concept of shelf-life, well explained in Amorim et al. (2013). The authors state that shelf-life corresponds to the period starting right after manufacturing and ending when the product's quality is no longer sufficient for it to be saleable. However, this does not imply that the product's quality is null, only that the product's marketable or productive life has ended. Personal computers (PC) illustrate this statement: despite the conditions of a PC, due to the continuous improvement of these products and constant production of new models, a model's shelf-life is relatively short (Xu and Sarker, 2003).

To summarise and incorporate all the different concepts discussed on perishability, Amorim et al. (2013) propose a unified framework, graphically described in Table 2.1. This framework is composed of three dimensions:

- Physical Product Deterioration - asserts if the good suffers physical modifications over time or not;
- Authority Limits - refers to how strict external regulations or conventions are to the product. In the case of blood banks, authorities set strict shelf-lives to ensure the quality of the stock, whereas for vegetables and fruits these regulations are more loose, due to the randomness of the deterioration of the products and to the smaller risks involved;

- Customer Value - relates to the customer's willingness to pay for a certain good.

Table 2.1: Framework to classify perishability (Amorim et al. (2013))

		Authority Limits			
		Fixed		Loose	
Physical Product Deterioration	Yes	e.g. Human Blood	e.g. Yoghurt	e.g. Cheese, Gasoline	e.g. Fruits, Radioactive Materials
	No	<i>Not-realistic</i>	e.g. Daily Newspapers	<i>Not-perishable</i>	e.g. Haute-Couture Fashion Clothes
		Constant	Decreasing	Constant	Decreasing
		Customer Value			

To conclude, the different classifications of the perishability related to a product are essential to the definition of the problem in analysis. Afterwards, one has to characterise the demand and how it can be described mathematically. In this work, adopting the framework of Table 2.1, a product suffering physical deterioration with a fixed lifetime and a constant customer value over time is studied.

2.2 Classification of demand

Besides the product's deterioration rate, the demand it is subjected to is also a defining parameter for the model's construction, since it can be deterministic or stochastic. In the first case, the demand is already known at the time of planing, whereas in the second, one can only know the probability distribution that the demand follows. For planning with the second type of demand, only an approximate prediction of the demand is obtainable. Janssen et al. (2016) catalogue the articles published by the demand distribution functions: demand is most commonly assumed to be uniform/constant, stock-level dependent, time-varying, price-dependent and age-dependent. Only 25 of the 283 articles analysed consider that the demand is dependent on other factors.

The demand for the studied product in this work is stochastic and time-varying, following a Gamma distribution defined with a mean μ and a variance σ .

2.3 Models developed on managing perishable inventories

The first study on optimal ordering policies of perishable products with periodical review was carried out by Van Zyl (1964). The author investigated a two period lifetime product with zero lead time. The considered issuing policy is First-In-First-Out (FIFO), justified by the base example used, a blood-bank. Regarding the lifetime of the product, it is restricted to two periods, in order to reduce the complexity of the problem.

Nahmias (1975) and Fries (1975), built on the work produced by Van Zyl (1964) and investigated optimal ordering policies of products with m periods of lifetime. Since these models record the inventory's distribution age in a $(m-1)$ vector, the computational complexity of their utilisation is too great, when m takes up large values.

As a result of this growth in complexity, simpler replenishment policies were investigated. The most studied one corresponds to the single critical number ordering policy, which states that when the inventory position is below a previously defined and static critical number, a replenishment order is conducted (Cohen, 1976). Brodheim et al. (1975) based their work on a constant order policy following a Markov-chain process, also very popular due to its simplicity during application.

Even though Nahmias (1976), Nandakumar and Morton (1993) and Cooper (2001) conclude that the critical number policy produces near optimal results, they assume that the lead time is zero, demand is always fulfilled and replenishment follows a FIFO policy. In the case of a retailer, these assumptions should not be made. Firstly, the lead time is always bigger than zero. Secondly, if demand is larger than the retailer's inventory at that the moment, customers will simply choose another similar product, meaning a lost sale for the first. Finally, despite FIFO being the best issuing policy for the retailer, the decision on the issuing policy is made by the customer. Because of this, Last In First Out (LIFO) is a more realistic policy (Pierskalla and Roach, 1972).

Regarding the age distribution of inventory, Nahmias (1977) shows that collecting partial information on the age distribution of the inventory at the moment of reordering improves the performance of the system. This is concluded after comparing the performance of an approximated heuristic with the original optimal policy of Van Zyl (1964) and the base-stock approximation of Nahmias (1976). Haijema et al. (2007) utilise two critical ordering numbers: one for the total inventory and the second for "young" inventory. With this separation, it is possible to distinguish and fulfil the demand for young products and the demand regardless of the products' age. These works consider FIFO withdrawal, no lot sizing and no weekly pattern, an important factor in the demand distribution in retail.

The work of Ferguson and Ketzenberg (2005) contemplates lot sizing, lost sales, and stochastic demand. The lead time and the review period are of one day and it attempts at modelling a supply chain with a producer and a retailer. The objective is to understand how sharing information between the two players improves the freshness of products. This is achieved by allowing the retailer to know the age distribution of the producer' inventory, before the retailer issues a replenishment order. Although being complete, it requires the full demand distribution of the retailer and does not consider a weekly pattern for demand.

In Broekmeulen and Van Donselaar (2009), the authors develop a simpler heuristic than Ferguson and Ketzenberg (2005), to provide an easy to implement and adaptable policy. It sets a constant safety stock and uses only the expected demand. The lead time, the review period, and the weekly pattern are input parameters.

Minner and Transchel (2010) presented a model to determine dynamic order quantities that satisfy service levels constraints. It assumes a system with periodic review, random demand and

positive lead time (the possibility of the producer delivering products before they are issued is rejected). The model allows for intra-period demand, replicating demand over a day in a retailer, and the order quantity is defined by the maximum value between: (1) the minimum required so that the probability of the demand not being met is bigger than the non-stockout probability and (2) the minimum required so that the fill rate is complied with. This model continues the work of van Donselaar et al. (1996), who also considered the stockout probability as a constraint.

Granted that Minner and Transchel (2010) is thorough in its description of the replenishment process, it is overly complex and complicated to be implemented in real life by a retailer. It is important to bear in mind the considerable variety of products dealt by a regular size retailer. Therefore, the heuristic presented in Broekmeulen and Van Donselaar (2009) is adopted in this work to describe the replenishment policies used by both the retailer and the distributor. The model is described in Section 3.2.3.

2.4 Types of simulation models

Simulation models can be categorised into four types: (1) spreadsheet simulation, (2) system dynamics, (3) discrete-event dynamic system and (4) business games. (1) consists of models built in spreadsheets: they are fairly simple and thus, very popular, but too simple for replicate supply chains. (2) works primarily with input flows, such as production, sales or others, and output flows, mainly performance metrics of the supply chain analysed. The evolution of the model is dependent of changes in rate variables, for example the rate of production, which induce changes in the flows. (3) makes use of individual events, as the arrival of an order, and is capable of incorporating variability. (4) attempts to model human behaviour, by letting the user interact with the simulation between rounds. They are useful to train and educate users Kleijnen and Smits (2003).

Type (1) is too simple to model a supply chain and type (4) is not appropriate for the objective of this work. According to Van Der Vorst et al. (2009), system dynamics models produces qualitative results, whereas discrete-event simulations provide quantitative results. Therefore, type (3) is the most adequate simulation model type for this problem.

2.5 The minimum life on receipt

The Minimum Life on Receipt (MLOR), sometimes quoted as Remaining Life (RL), is a criterion widely used by retailers. Essentially, it states that, in order to be accepted, the product must still have an agreed number of days before its own expiration date. This value is typically set as a proportion of the lifetime of the product. This criterion was adopted by retailers in order to ensure that there is time for a product to be sold before it reaches the expiration date.

Although being a specification of every fresh/cold supply chain, it has not yet been studied thoroughly. Lee et al. (2015) suggests that if the supply chain were to increase the shelf-life of perishable products by one day, by improving its own efficiency, the waste both at the retailer's

shelf and at the hands of the customers would be significantly reduced. This increase in the shelf-life would be obtained through a rise in the MLOR, from 75% to 85%. The report presents estimations of the quantity of waste prevented by applying this measure, but they are only based on very simple calculations.

The work of Kaipia et al. (2013) analyses the supply chains of three different types of products, proposes changes in their processes and measures the reduction in waste, as well as other parameters of the supply chain itself, such as the MLOR. The authors indicate a correlation between the increase in the MLOR and the waste reduction, but not causality. This idea of rejecting causality is reinforced by Amani and Gadde (2015). Their study presents the example of a dairy product that suffered improvements in the supply chain, extending the shelf life by three times. This meant that the majority of the issued products were shipped before their "saleable date", meaning that an increase in the MLOR was indirectly achieved. This work found that, contrary to the expectations of zero waste between the producer and the retailer, there was still a considerable amount of waste being generated (over three tons of waste per year).

The example provided in Amani and Gadde (2015) can be interpreted as the introduction to a part of the problem analysed in this work, which has not yet been investigated: how does the MLOR impact waste generation along the supply chain?

Chapter 3

Problem description and methodology

This chapter provides firstly the context of the problem in analysis, followed by a section in which the model built to simulate the supply chain is described. This second section explains the assumptions considered, the structure on which the model is based on and the inventory management policy adopted by the distributor and the retailer.

3.1 The MLOR criterion and the operations of OLANO

OLANO is a specialised company in the storage and distribution of frozen and fresh food. This type of business has flourished, because the operations involved with frozen products have to be done with temperature control at all times, meaning that a great amount of energy to maintain low temperatures is required, as well as appropriate equipment (vehicles) and facilities. All of this translates into very high fix costs, independent of the volume of production. As a result, producers are keener to resort to the services of a third-party logistic (3PL) provider specialised on this industry. With this, producers only need to store a small amount of products (the ones out of the production line), allowing them to focus on production. The 3PL company, by holding inventories of several producers and working with economies of scale, can build a profitable business. All this, while offering a less expensive service for the storage of goods, when compared to the case where the producer also manages the storage and distribution of their products. In the aftermath, the overall cost of the supply chain is reduced.

Despite simplifying the operations of the producer, this strategy can cause great entropy in the system. The physical detachment from the products may induce in a disregard for the inventory management, leading to poor results of the global operation.

As a result, the amount of products in storage that do not comply with the MLOR criteria increases. Owing to the fact that the product is not a property of OLANO, the product will stay in storage and often will be shipped to the retailer (by direct order of the producer). When the product arrives at the retailer, it is rejected and has to return to OLANO's facilities. Depending on the age of the product, it can be stored again or disposed/destroyed by OLANO with direct orders from the producer to do so, considering that the expiration date is too close for the product

to repeat the shipping process. In the case of re-storage, the producer contacts the retailer to reach an agreement on the terms of a second delivery. Afterwards, the product is shipped again to the retailer.

Bearing in mind that an essential part of OLANO's operations is distributions/transportation, if a product is rejected by the MLOR and has to return to OLANO, the vehicle carrying the outdated product cannot be used for other operations. Subsequently, a different lorry has to be sent, meaning that the effectiveness of the operations is affected. Because avoidable distances are driven, OLANO's operating costs increase. In the end, OLANO's supply chain becomes less sustainable.

Thus, OLANO felt that an analysis of the impact of the MLOR ought to be conducted, in order to better grasp what can be done to avoid this type of situation, recurrent with some clients. It is relevant to understand that without the role of the distributor in this supply chain, this problem would never arise: it only became a realisation that this was a problem transverse to all types of products, by observing that different and independent clients suffer from this problem and by noticing its recurrence.

The objective of this work is to understand how the supply chain is affected by the MLOR. Analysing the impact of the MLOR on each player, one can conclude that: from OLANO's perspective, a change in the MLOR is irrelevant, at first sight, since the company does not have any interest in the product's age. On second thought, because rejections affect OLANO's operations, this conclusion might not be so straightforward. Regarding the perspective of the producers that are not able to comply with the agreed MLOR, a relaxation on its value can be extremely helpful, because products are not outdated so frequently. With this, bigger and less periodical batches can be produced, reducing costs. From the retailers' point of view, a relaxation in the MLOR might not be welcomed. Instinctively, retailers might feel that such a measure affects the control they have on the product and that the probability of selling the product before the expiration date might diminish.

3.2 Modelling the problem

The best strategy to evaluate the impact of any parameter in a supply chain, such as the MLOR, is to modify its own value and register the possible changes originated from that modification. With the computing tools available, resorting to a supply chain simulator provides satisfactory results without harming the actual supply chain in the process. For this work, the software *Anylogic* was used to build the model and to run the event-based simulations.

3.2.1 Assumptions of the problem

The model built in a simulator cannot replicate perfectly the actual supply chain. There are always assumptions or modifications that need to be made. For this problem, the following assumptions are made:

1. A product is characterised by its own production date, lifetime, selling price and quantity/amount;
2. The supplier and the distributor are represented by the same entity, since the distributor does not influence the product. This unified entity is referred as distributor;
3. The distributor has an infinite production and transportation capacities;
4. The MLOR verification is done in the distributor. If the product cannot comply with it, it is removed from the inventory and considered as waste;
5. Products issued in the distributor follow a FIFO policy, whereas in the retailer they follow a LIFO policy;
6. Backlog is allowed for the distributor. In the case of the retailer, if demand is higher than the available inventory, the unmet demand translates in lost sales;
7. The product's quality remains intact and its levels constant until the expiration date is reached. By then, quality levels are considered zero and the product cannot be sold;
8. The inventory management policies in use are based on periodic review.

With assumption 4, the case where a rejected product forces a trip to the distributor's base and the utilisation of another lorry is eliminated. This situation does not happen every time there is a rejection, since it depends on the daily operations of the distributor regarding other clients and products. Thus, to maintain the certainty of the results produced, it is assumed that a product is never sent to the retailer if its own lifetime is over the MLOR.

3.2.2 Building the model

The base of the model lies on the path the products follow over time. Figure 3.1 illustrates this path, also explained below:

- Production - Due to assumption 3, independently of the total amount produced, the product remains at this stage for an amount of time equal to a fixed lead-time. Fix and quantity-dependent costs are considered at this stage. If the distributor is unable to meet demand, the production cost of the unmet demand is given with a backlog cost;
- Inventory at distributor - The product stays at the distributor until it is either: (1) issued to the retailer in FIFO order (moving to the stage "Transportation"); (2) it can no longer comply with the MLOR (moving to the stage "Rejected by MLOR"). Holding costs are included in the operations costs;
- Transportation - As a result of assumption 3, there is a fixed lead-time between the distributor and the retailer, during which the product remains at this stage. Picking and fixed transportation costs are taken into account;

- Storage at retailer - This stage represents a shelf in a retailer: products at this stage are withdrawn by customers by LIFO order. A customer will only withdraw products from a different pack than the most recent one if the amount of the latter reaches zero. If the expiration date is reached before the product is sold, at the beginning of the next day the product is removed (moving to the stage "Rejected by Expiration"). Holding costs at the retailer's facilities are included in this analysis.

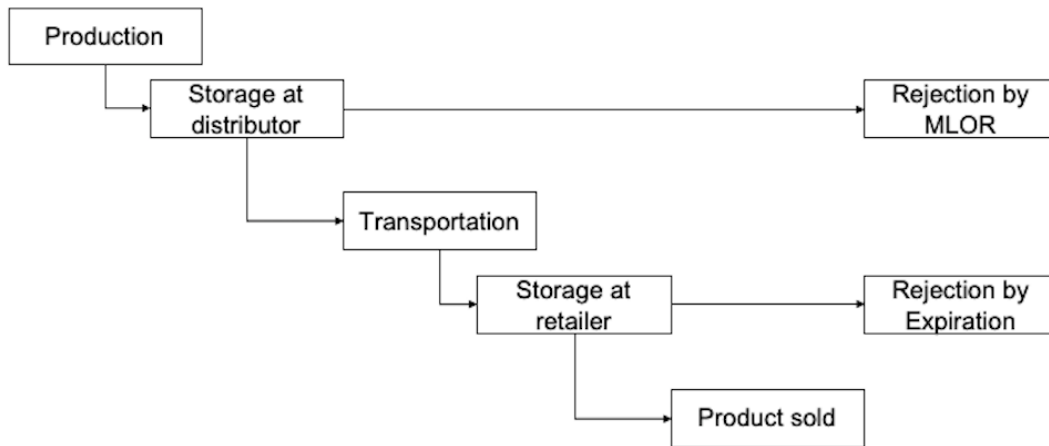


Figure 3.1: The different stages of a product

There are two players in the simulation: a distributor and retailer. As mentioned, both hold inventories to guarantee the success of operations. Both inventories are managed by the heuristic developed by Broekmeulen and Van Donselaar (2009), presented in Section 3.2.3, although some minor adaptations are necessary for the distributor.

Concerning the main discrete events that govern the simulation, it only requires the action of three:

- Production - responsible for the triggering of the production orders. It occurs periodically, according to the distributor's review period;
- Selling - responsible for simulating the demand of customers. Occurs daily and the output value produced is a function of the day of the week and the weekly demand;
- Ordering - controls the issuing of orders from the retailers to the distributor, namely its amount. It occurs periodically, according to the retailer's review period.

3.2.3 Inventory management heuristic

Broekmeulen and Van Donselaar (2009) developed the following heuristic with the objective of providing a replenishment policy for perishable products, different from the automated one in place for non-perishable products. It takes into account the age of the inventory and only requires

simple calculations, making it easy to implement. The model makes use of the age of the different products in inventory and, with this, estimates the amount of products that will become outdated. This value is then used for the calculation of the order quantity.

In this work, the policy is applied to both the distributor and the retailer. Consequently, it may be required some modifications to the original heuristic. The adapted heuristic uses the following assumptions and notation:

- Only one type of product with fixed lifetime of m days is handled. The lifetime is defined as the number of days during which the product's quality is constant. After m days from the production date, the product cannot be sold;
- Demand at the retailer is probabilistic and is calculated for the week. The daily demand is obtained with a time-varying pattern. To avoid amplification of variability of the demand of the distributor (the issuing orders of the retailer) by calculating it with arbitrary values, an initial warm-up period is used, during which the values of the issuing orders are recorded. In the end, a custom probability distribution is created. During the initial warm-up period, a "make-to-stock" replenishment policy is used for the replenishment of the distributor.
- The inventories are managed with a periodic review system: for the retailer, the review period is equal to R^r ; for the distributor, the review period is equal to R^d ;
- At the distributor, production comes in the form of batches of fixed initial amount C , whereas at the retailer the initial quantity is a pack of P amount. The amount existent in the batch/pack number g at the start of day t is equivalent to B_{tg} ;
- There is a lead-time L^d for production at the distributor and a lead-time L^r for the retailer's replenishment order to arrive;
- W_{tg} represents the amount withdrawn from batch/pack g at day t . Products with a remaining shelf-life of 0 cannot be sold the next day and their quantity makes up for the outdated quantity O_t at day t ;
- The distributor's and the retailer's Safety Stock, represented by SS^d and SS^r respectively, remain constant over time;
- n_t corresponds to the number of batches/packs to be produced/ordered at period t .

The reorder level s_t is the reference value for the inventory. If and only if the inventory position is below the s_t at a periodic review moment, shall a replenishment order be created. The value for s_t is obtained with equation 3.1, with SS as the safety stock and $\sum_{i=t+1}^{t+L+R} E[D_i]$ as the expected demand during lead/time plus review period.

$$s_t = SS + \sum_{i=t+1}^{t+L+R} E[D_i]; \quad (3.1)$$

With the value of s_t , the inventory position IP_t , the *estimated* amount of outdating $\sum_{i=t+1}^{t+L+R-1} U_i$ and the batch/pack size Q , it is possible to calculate n_t , as shown in equation 3.2.

$$\text{if } IP_t - \sum_{i=t+1}^{t+L+R-1} U_i < s_t \text{ then } n_t = \left\langle \frac{s_t - IP_t + \sum_{i=t+1}^{t+L+R-1} U_i}{Q} \right\rangle \quad (3.2)$$

The notation $\langle x \rangle$ rounds up x to the nearest integer.

To obtain the estimated outdating quantity, firstly, it is necessary to describe the withdrawal behaviour. Equation 3.3 describes the FIFO issuing present at the distributor, while equation 3.4 represents the LIFO withdrawal at the retailer.

$$W_{tg} = \text{Min} \left\{ B_{tg}, D_t - \sum_{i=1}^{g-1} W_{ti} \right\} \quad g = 1, \dots, m \quad (3.3)$$

$$W_{tg} = \text{Min} \left\{ B_{tg}, D_t - \sum_{i=g+1}^m W_{ti} \right\} \quad g = m, m-1, \dots, 1 \quad (3.4)$$

After each day in the case of the retailer and each retailer's review period in the case of the distributor, the quantities of the different batches/packs are updated according to equation 3.5. This calculation takes into consideration the ageing, the withdrawal and the outdating of the batches/packs.

$$B_{t+1, g-1} = B_{tg} - W_{tg} \quad g = 1, \dots, m \quad (3.5)$$

The batches/packs with 0 days of remaining shelf-life see their quantities update following equation 3.6.

$$O_t = B_{t,1} - W_{t,1} \quad (3.6)$$

Finally, to calculate the estimated outdating quantity required in equation 3.2, the following procedure must be carried (i ranges from $i = t + 1$ to $i = t + L + R - 1$): firstly the estimated withdrawal for period i is calculated, with equations 3.3 or 3.4. It is assumed that the demand in period i is equal to the estimated demand. Secondly, the batches'/packs' quantities and the estimated outdating are updated, according to the recursive equations 3.5 and 3.6. It is assumed that withdrawal in period i is equal to the withdrawal calculated in the previous step. To conclude, $i = i + 1$ for the retailer and $i = i + L'$ for the case of the distributor.

With this, the number of batches/packs n_t is calculated and the replenishment orders can be created.

Chapter 4

Results and discussion

In this chapter, the simulation experiment developed in this work is described, along with the expressions to obtain values and the input parameters. Then, the results obtained are presented, discussed, and analysed.

4.1 Simulation experiment

For this dissertation, the simulation software "Anylogic" was chosen as the tool for the analysis. The aim of this section is to provide a brief and explanatory description on how some indicators are obtained and the parameters used.

In the experiment, the time-unit utilised was the day. Simulations were run for 300 days and four products with different lifetimes. Regarding demand, it is calculated weekly and multiplied by the corresponding value of the weekly pattern, depending on the day t . Comparing with Broekmeulen and Van Donselaar (2009), the weekly demand is obtained similarly, although the values chosen for this experiment are higher. The parameter "Daily safety stock" (SSd), along with the review period (R), sets the safety stock in use, according to Equation 4.1.

$$SS^d = SSd^d * R^d \quad \text{and} \quad SS^r = SSd^r * R^r \quad (4.1)$$

With respect to costs, they are firstly separated by players: the distributor has production, transportation, and inventory costs, while the retailer deals with ordering and inventory costs.

Production costs (Cp) are a function of the number of batches (n_t^d) to be produced, the amount of products in backlog (nb_t^d), and the costs of the operation Cp_f , Cp_v , and Cp_b , representing the values for the fix, the variable and the backlog production costs. It is described in Equation 4.2.

$$Cp_t = (n_t^d - nb_t^d) * Cp_v + nb_t^d * Cp_b + Cp_f \quad (4.2)$$

Shipment costs (Ct) are detailed in Table 4.1. For an amount higher than 15 packs, the distributor considers that a vehicle is sent, irregardless of whether its capacity is complete or not.

Due to confidentiality reasons, all values are presented as function of the cost of sending a vehicle, x . The same applies to the distributor's picking cost and the distributor's inventory cost.

Table 4.1: Shipment costs

Number of packs	Cost (per pack)
1	$0.116*x$
2-3	$0.092*x$
4-6	$0.077*x$
7-10	$0.062*x$
11-15	$0.054*x$
Cost of vehicle	x

The distribution costs are a function of the transportation costs (Ct) and the picking costs (Cpk) related to the operations within the distributor. Because the considered values of Ct and Cpk are the values OLANO charges its own clients, the distribution costs are only a fraction of the amount charged. This fraction is assumed to be the complementary of the gross profit margin of the cold/fresh distribution businesses. According to SBC (2019), this sector works with margins of up to 24% in business-to-business operations. Equation 4.3 details the calculation of the distribution costs.

$$Cd = (Ct + n_t^r * Cpk) * (1 - 0.24) \quad (4.3)$$

Inventory costs are calculated in Equation 4.4, with the letters d and r representing the distributor and the retailer respectively.

$$Ci^d = \sum IP_t^d * Ci^d \quad \text{and} \quad Ci^r = \sum IP_r^r * Ci^r \quad (4.4)$$

Ordering costs (Co) for the retailer have an analogous formulation, with the difference of not allowing backlog. It is as function of the number of packs ordered (n_t^r) and the fix and variable ordering costs, (Co_f and Co_v respectively) (Equation 4.5).

$$Co_t = n_t^r * Co_v + Co_f \quad (4.5)$$

The values of the input parameters used in the simulation experiments are presented in Table 4.2.

Table 4.2: Input parameters for the simulation experiment

Input parameter	Values
Product lifetime, m	{ 13,20,28,42 } (days)
Product's selling price Sp	3.5
Inventory	
Retailer's weekly demand	Gamma(100,1,80)
Weekly pattern	{ 0.12;0.13;0.13;0.16;0.18;0.18;0.1 }
Batch, C	60 (units)
Pack, P	10 (units)
Distributor's lead time, L^d	2 (days)
Distributor's review period, R^d	10 (days)
Distributor's daily Safety Stock, SSd^d	24 (units)
Vehicle's capacity	33 (packs)
Retailer's lead time, L^r	1 (days)
Retailer's review period, R^r	3 (days)
Retailer's daily safety stock, SSd^r	20 (units)
Costs	
Fix production cost Cp_f	70 (per order)
Variable production cost Cp_v	0.5 (per unit)
Backlog production cost Cp_b	1 (per unit)
Distributor's picking cost Cpk	Confidential (per unit)
Distributor's inventory cost Ci^d	Confidential (per unit per day)
Fix ordering cost Co_f	40 (per order)
Ordering cost Co_v	2.5 (per unit)
Retailer-s inventory cost Ci^r	0.0017 (per unit per day)

It is relevant to mention that, beside the MLOR, all the values of the input parameters are kept constant throughout the simulations. Whenever there are changes in the values, these are expressed.

4.1.1 Warm-up period

The initial period in the simulation of any supply chain is never a smooth period, producing rather extreme results. To avoid their inclusion in the final results, a warm-up period of 130 days was considered for this simulation experiment. In the first 100 days, a Make-To-Stock policy is used to maintain the distributor's stock level with reasonable values, while the distributor's demand during

that period is recorded. With these values, a probability distribution function is constructed. The final 30 days of the warm-up period are used with the intent of allowing the supply chain to adapt itself to the inventory management policy described in Chapter 3.

The Make-To-Stock policy is based on Equation 4.6, in which n_t^d is calculated. The term q represents the quantity of the latest order from the retailer.

$$\text{if } (L^d + R^d) * \frac{q}{R^r} + SS^d > IP_t^d \text{ then } n_t^d = \left\langle \frac{(L^d + R^d) * \frac{q}{R^r} + SS^d - IP_t^d}{C} \right\rangle \quad a \in \mathbb{N} \quad (4.6)$$

4.2 Results and discussion

The results obtained from the simulation runs for the different lifetimes are presented and discussed in this section. The analysis is divided by indicators, with the objective of explaining clearly the impact the MLOR criterion has in each one. The analysed indicators are: costs, generated waste, and freshness.

It is of the utmost importance for a correct interpretation of the results that the reader retains this aspect: the line of thought of the analysis was based on the path the products follow over time. Therefore, in an attempt to simplify the interpretation, the results are presented as function of the maximum number of days that products are allowed to remain at the distributor's facilities (*maxdays*). This variable is related to the MLOR through Equation 4.7, meaning that, in the results presented, the MLOR is decreasing from left to right.

$$\text{maxdays} = m - \text{MLOR} \quad (4.7)$$

In addition, with this approach, it is possible to compare the impact of the MLOR on different products from an operational perspective: in terms of holding and shipping products, the age of the product itself is irrelevant. However, the number of days that a product remains in inventory is crucial for operations and is independent of the product's lifetime, meaning that comparisons between different products can be made and generalist conclusions can be drawn.

The last value in each product of *maxdays* represents the case where the retailer does not specify a lower limit on the remaining lifetime of the product. It is always equal to the total lifetime of the product subtracted by retailer's lead time.

4.2.1 Costs

An analysis to the costs involved in a supply chain is one of the most common approaches to evaluate its performance. This section presents and discusses the impact the MLOR has on the different costs of the supply chain, concluding with a global analysis. The main focus is on the tendencies and on the effects caused by changes in the MLOR, meaning that little attention is

given to the values themselves. Nonetheless, the values are presented and they represent monthly costs.

4.2.1.1 Production and Distribution Costs

Production and distribution are the main parcels affecting the operational costs of the distributor. Figure 4.1, shows how these costs are affected by the maximum day allowed for products to remain at the distributor. Production costs decrease at similar rates, independently of the product's lifetime. This is due to the fact that for high MLORs, the amount of "outdated" products at the distributor is larger than for the cases where the MLOR is lower, meaning that, to maintain the inventory levels constant, a larger quantity of produced items is required. As for distribution costs, they increase slightly with *maxdays* for products with a lower lifetime, while for products with a lifetime of 28 or 42 days they remain constant. The reason for this difference is that the amount of outdated products at the retailer is higher in the first two cases, because the relative age of arriving products at the retailer is also higher. With this, a larger number of deliveries is required, increasing the distribution costs.

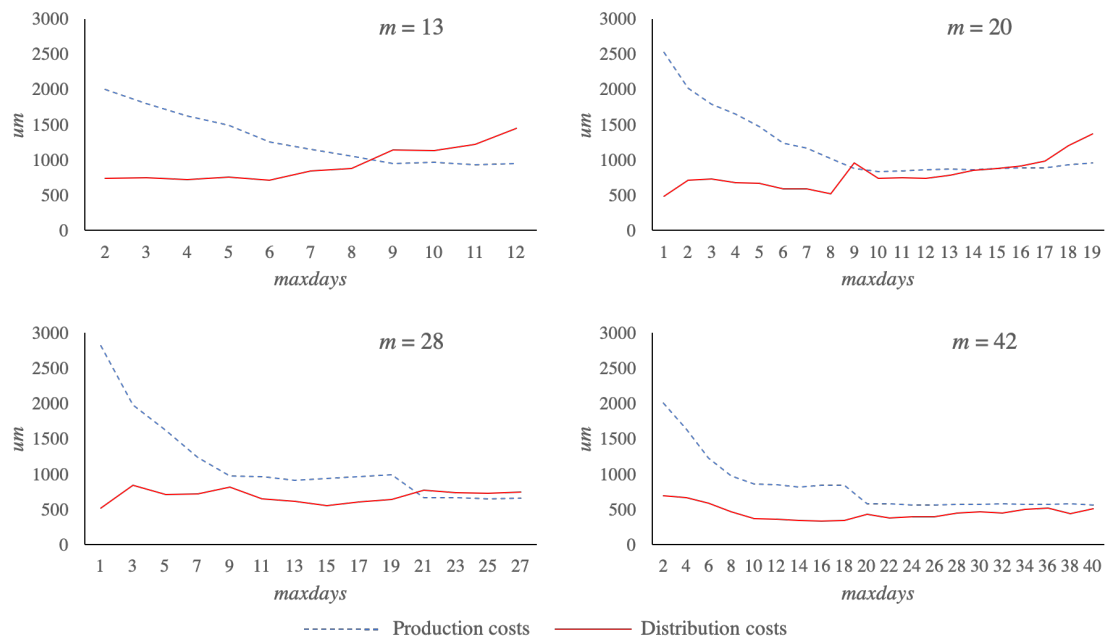


Figure 4.1: Production and distribution costs for products with different lifetimes (m)

The MLOR criterion, from the distributor's perspective, can be compared to the expiration date. Because the distributor's review period sets the frequency of production, affecting the age of the products in inventory, influence of this parameter in this analysis is critical.

The distributor's review period does not affect the behaviour of these costs. Figure 4.2 illustrates the production and distribution costs for a product with a lifetime of 28 days. Their

tendencies are similar, although there is a propensity for gradation in production costs as the review period increases. This applies to the other products with distinct lifetimes (Appendix A).

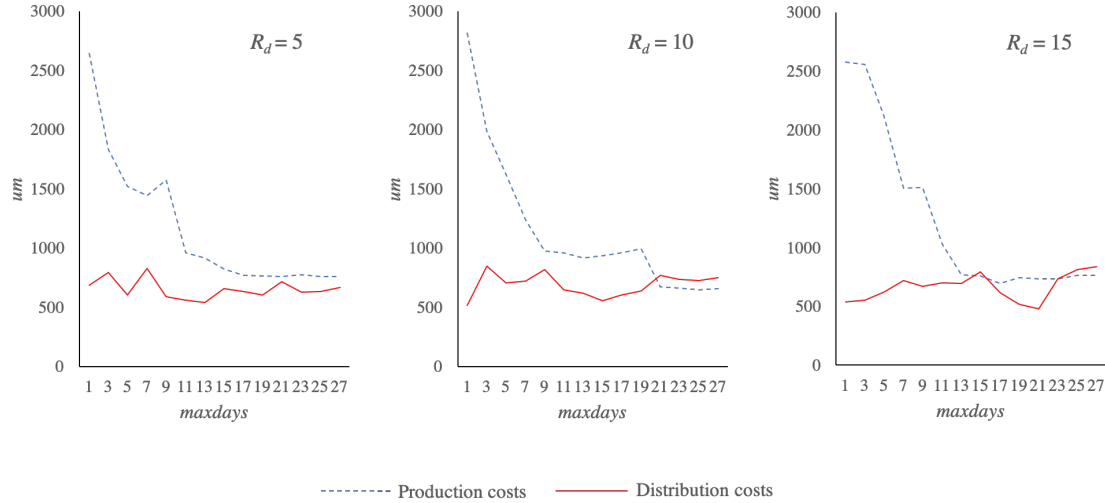


Figure 4.2: Production and distribution costs for products with a lifetime of 28 days

4.2.1.2 Ordering cost

Ordering costs represent a large percentage of the total costs of a retailer. Figure 4.3 represents the ordering costs, along with the sales profit, in order to have a comparable term and to allow interpretation of the impact of the MLOR in the operations of the retailer. From these results, the impact of the MLOR on ordering cost can be divided in three stages: in the first, the ordering costs increase with *maxdays* (decreasing with an increasing MLOR); during the second, the ordering costs are constant and below the sales amount, generating profit; in the third, only existent in the products with a lower lifetime ($m = 13, 20$) the ordering costs increase with the MLOR and surpass the sales amount.

The results displayed in Figure 4.4 shows that the first period mentioned above is dependent of R^d . For the same R^d , the different products have similar behaviours during this period.

Conjugating the two analyses, it can be concluded that:

- The first period terminates when the *maxdays* reaches R^d minus one or two days. This is due to two reasons: firstly, if the *maxdays* is significantly lower than R^d , independently of the quantity produced, there is always a time period during the production cycle in which the distributor will not be able to fulfil the demand from the retailer. Because the products in the distributor's inventory are considered "outdated" *maxdays* after the production day, they are removed, the inventory (IP_t^d) reaches zero and no products are shipped to the retailer. Therefore, the ordering costs are lower, since the number of shipments and even the amount shipped is lower. Secondly, because the inventory management policies in use have a safety

stock, allied to the fact that the distributor allows for the backlogging of demand, both the distributor and the retailer can reduce the impact of the tight *maxdays* criterion and restore the equilibrium in the supply chain in the mentioned one or two days. The sales amount is also lower, due to the first reason presented above. Even though the customers' demand at the retailer is the same, there is a lack of products at the retailer's inventory. As such, the lost sales have the complementary behaviour of the sales amount, reaching values of zero in the second period.

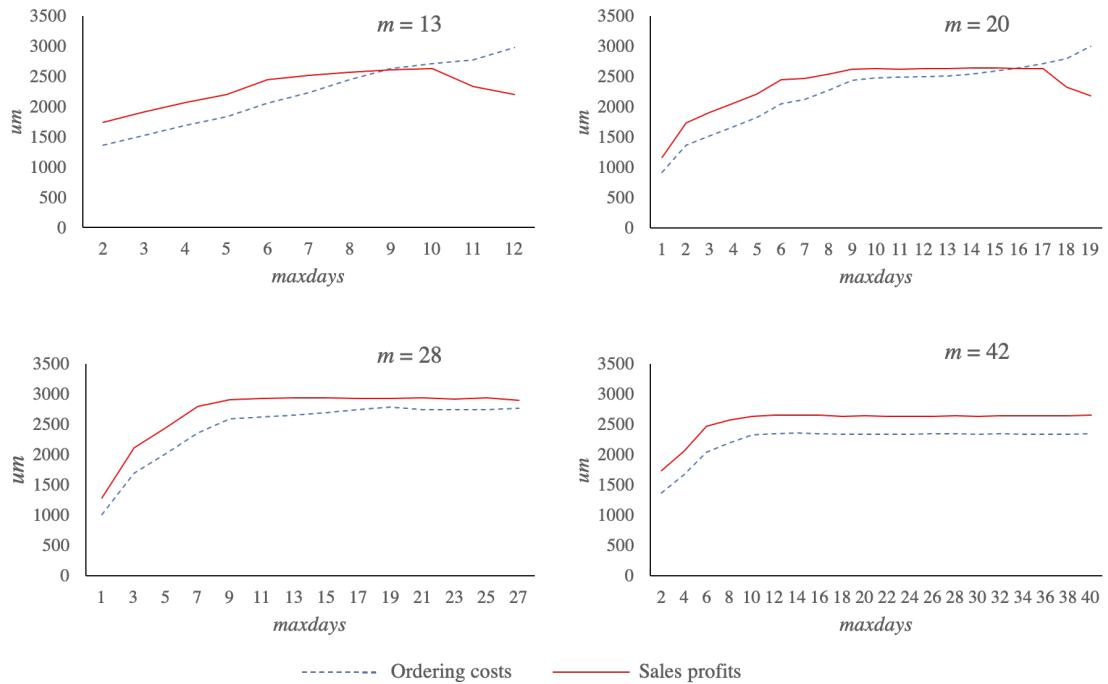


Figure 4.3: Ordering costs and sales profits for products with different lifetimes (m)

- The second period is representative of a balanced supply chain. Demand at the retailer is fulfilled (lost sales have a residual value), service levels are close to 1 and the retailer is able to generate profit. This profit is characterised by very small margins (3%-5%), just like the ones retailers work with in reality, which attests to the validity and adequacy of the input parameters.
- The third period, existent for the products with lifetime ($m = 13,20$) and for the product with a lifetime of 28 days with a distributor's review period (R^d) of 15 days, is caused by the growth in waste at the retailer when the *maxdays* criterion is close to m . Because issuing at the distributor follows a FIFO order and at the retailers follows a LIFO order, the older products at the distributor will be shipped (if they comply with the MLOR), but the withdrawn products at the retailer will be the younger ones. This increases waste at the retailer, implying that higher quantities of products have to be ordered, when compared to the scenarios with lower *maxdays* (higher MLORs).

These conclusions also apply to the other products with distinct lifetimes (Appendix A).

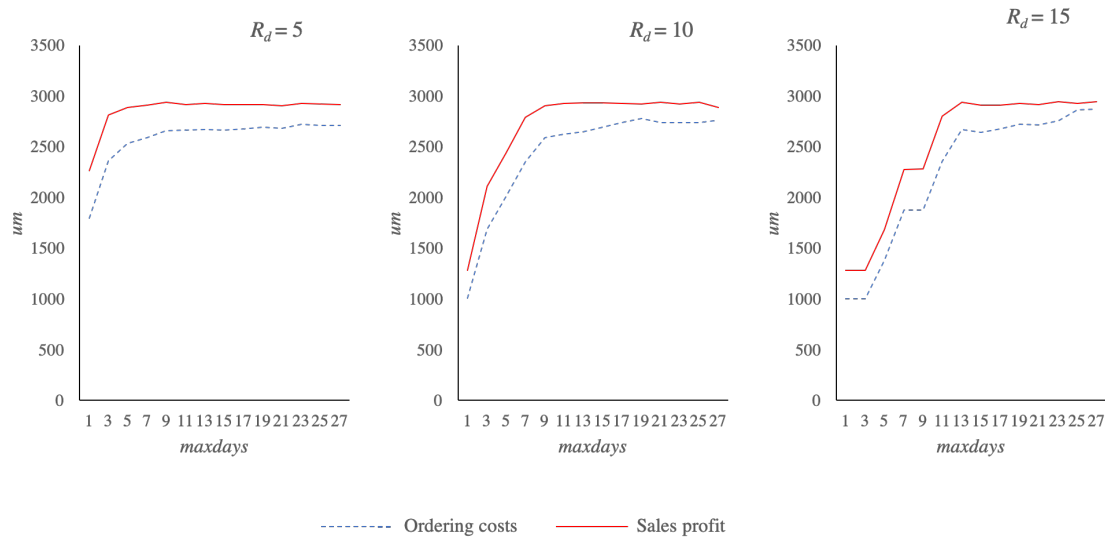


Figure 4.4: Ordering costs and sales profits for products with a lifetime of 28 days

4.2.1.3 Overall supply chain costs

An analysis on the global costs of the supply chain, in order to evaluate the global economic impact of the MLOR, culminated in the results exhibited in Figure 4.5. These costs are the sum of production, distribution, and holding (almost negligible) costs for the distributor and the sum of the ordering and holding (almost negligible) costs for the retailer.

It is observable that the distributor's combined costs for the products with lower lifetimes have a minimum around values of $maxdays$ equal to half the lifetime of the product, explained by the increase in distribution costs detailed in Section 4.2.1.1. For the products with longer lifetimes, the distributor's combined costs decrease continuously with an increase in $maxdays$ (a decrease in the MLOR), although the increase is characterised by a very small rate. This result confirms the predictions in Section 3.1.

Regarding the retailer, since the influence of inventory costs in the overall costs is practically nonexistent (representing 2,5% to 4% of the combined costs), the interpretation of the obtained results is the same for the ordering costs, explained above. Apart from the case with products of m of 13 days, the obtained values indicate that the MLOR's financial impact on the retailer is only disadvantageous for short $maxdays$, contrary to what was expected. After that, it is neutral to the retailer's costs.

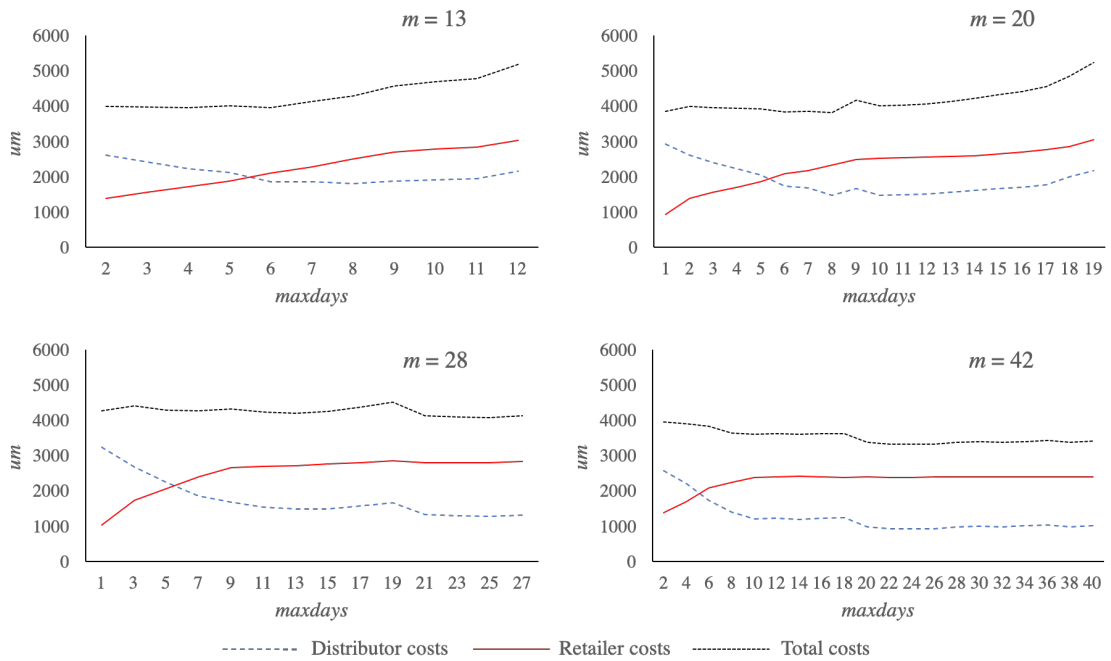


Figure 4.5: Overall costs for products with different lifetimes (m)

Figure 4.6 describes the overall costs of the supply chain as a function of the distributor's review period (R^d). From the obtained results, the global costs of distributor and the retailer are independent to R^d .

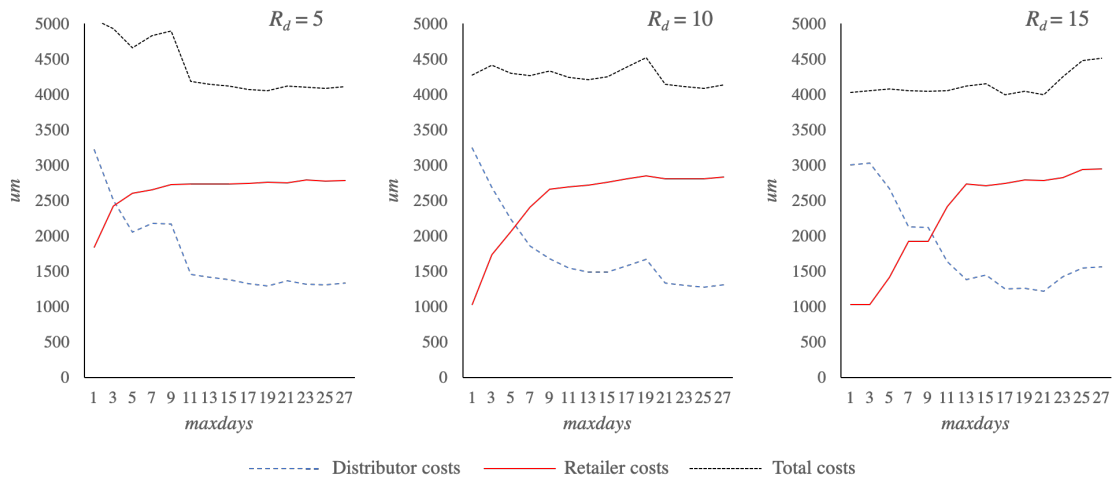


Figure 4.6: Overall costs for products with a lifetime of 28 days

As for the global costs of the supply chain, the results demonstrate the following:

- For products with short lifetimes, the overall costs remain constant with low and moderate values of $maxdays$. When $maxdays$ is low (the MLOR is high) the overall costs show a

linear increase with it. The transition value of *maxdays* from constant to growing global costs decreases with increasing R^d .

- For products with long lifetimes, the results suggest that a decrease in the MLOR might be beneficial to the supply chain, since the global costs tend to decrease at a very small rate. As the R^d increases, this relation tends to fade, meaning that the overall costs become independent of the MLOR.

In conclusion, the results obtained show that the global costs of the supply chain are maintained constant for moderate values of the MLOR. For low *maxdays* (high MLORs) the total costs of the supply chain are higher, except for fast perishable products. On the opposite side, a permissible MLOR from the retailer (high *maxdays*) will incur on a more expensive supply chain, when dealing with products with short and medium lifetimes. Comparing the costs of the different types of products, products with shorter lifetimes have more expensive supply chains, since the products become outdated much faster and, therefore, in bigger amounts. These conclusions also apply to the other products with distinct lifetimes (Appendix A).

4.2.2 Waste

As mentioned in Chapter 1, waste and sustainability is becoming a relevant indicator in the evaluation of the performance of any supply chain. As so, an analysis on the waste generated along the different players is appropriate.

Figure 4.7 shows the amount of waste created monthly by the distributor and the retailer, as well as the monthly quantity produced, with the objective of providing context to the values of the waste. It is clear that the amount of waste at the distributor is much larger than at the retailer. For all types of products, waste at the distributor decreases significantly with increasing *maxdays*. For products with longer lifetimes (m equal to 28 or 42 days), this waste can be considered nonexistent for values of *maxdays* larger than 21. Regarding waste at the retailer, its amount is zero for values of *maxdays* lower than 10, rising marginally after that and reaching maximums in the cases of m of 13 and 20 days when the *maxdays* reaches its maximum as well. For the lower values of *maxdays*, the waste generated reaches proportions of 85% of the quantity produced.

As shown in Figure 4.8 variations in the distributor's review period lead to different behaviours by the waste produced at the distributor. However, the reasons behind these differences are not straightforward, since in the scenarios with R^d of 5 and 15 days, the drop in waste is much more abrupt than in the case with R^d of 10 days. The quantity of the batch and other factors might be influencing the waste in an unknown way. Because of this, direct conclusions about the distributor's review period and the waste generated at the distributor should not be drawn.

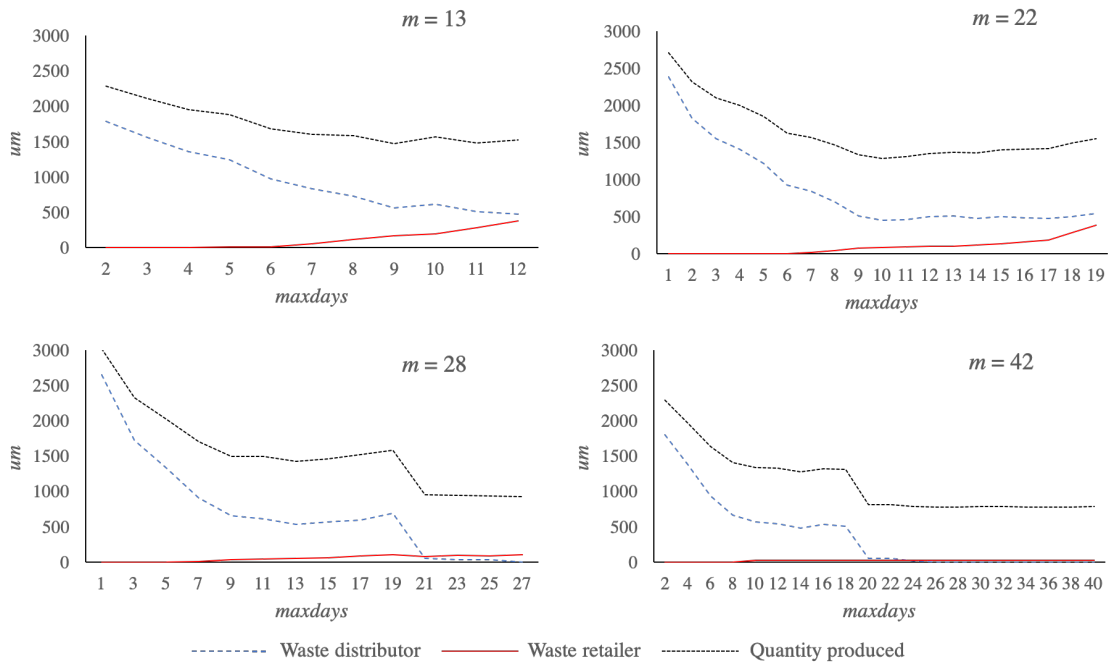


Figure 4.7: Waste generated and quantity produced of products with different lifetimes (m)

Concerning the waste at the retailer, the amounts represented in Figure 4.8 indicate that it is independent of R^d . Therefore, for the products whose perishability is less severe, the waste created at the retailer has as only cause the discrepancies in the estimated demand and the actual demand at the retailer.

These conclusions are corroborated by the results concerning products with distinct lifetimes (Appendix A).

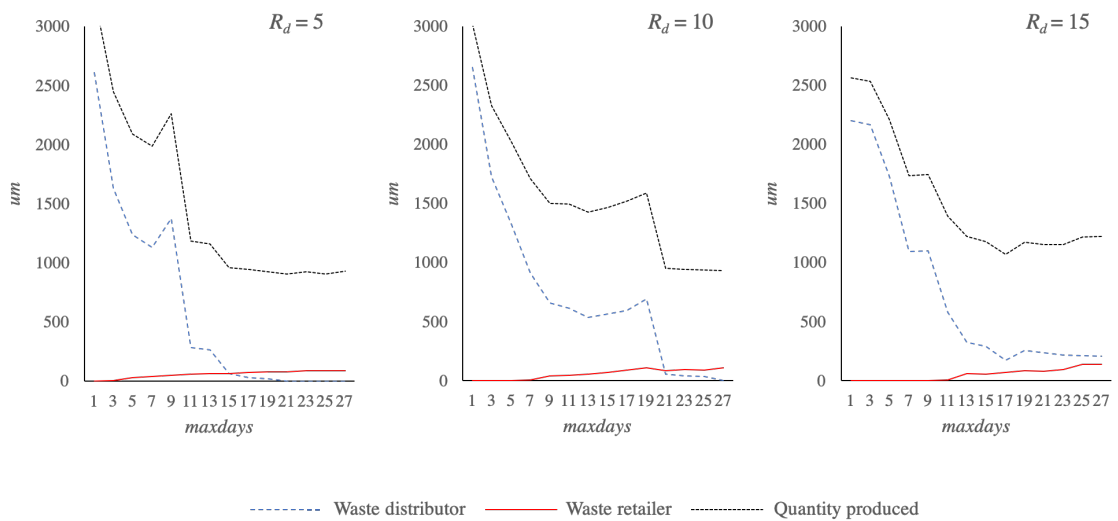


Figure 4.8: Waste generated and quantity produced of products with a lifetime of 28 days

4.2.3 Age of sold products at the retailer

The average age of the sold products, also referred as the freshness of products, is one of the most relevant aspects of a perishable product at the moment of purchase by a client. Figure 4.9 shows the mean age of sold products for different lifetimes. Furthermore, this indicator has a direct impact on the possible waste generate at the households (Lee et al., 2015). If the age of the sold product increases, the probability of that product becoming outdated increases as well.

For a lifetime of 13 and 20 days, the relationship between this parameter and the *maxdays* is almost linear, which explains the larger values of waste at the retailer when *maxdays* is close to *m*: for these cases, the mean relative age of the sold products can reach 90% of the lifetime of the product. Considering that customers choose products by a LIFO order, the mean age of the products in inventory in these cases is even higher. For the scenarios with higher lifetimes, the behaviour of this indicator is more complex: in both cases, the mean age increases linearly *maxdays* up to a certain point. Afterwards, it remains constant for the rest of the values of *maxdays*.

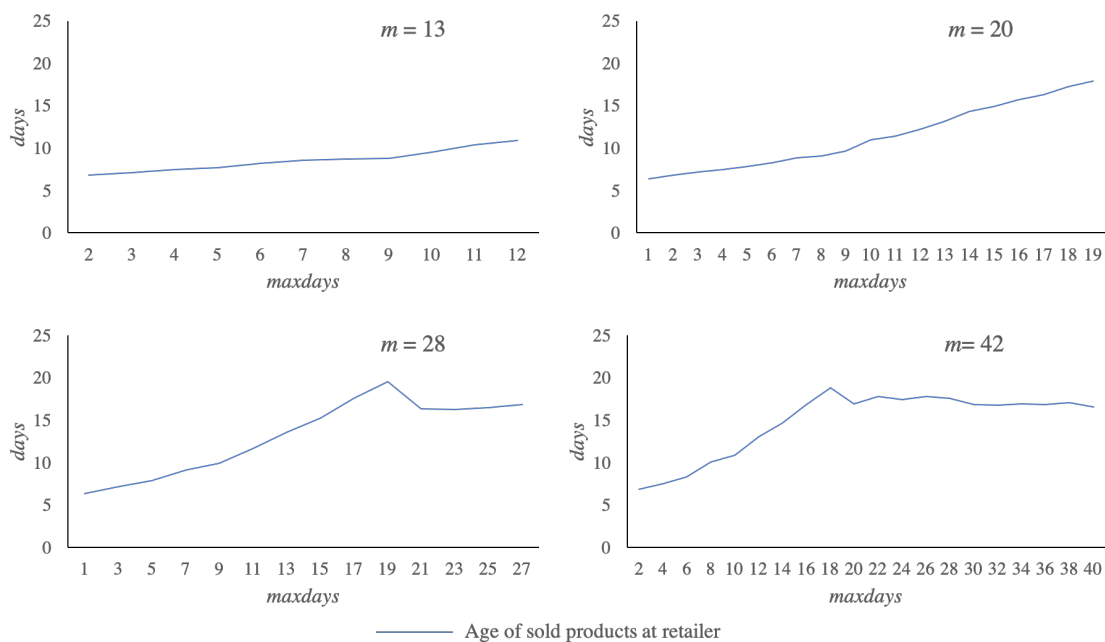


Figure 4.9: Mean age of sold products at the retailer with different lifetimes (*m*)

With Figure 4.10, it is safe to conclude that the mean age of sold products is affected by the distributor's review period: the higher the R^d , the later products are sold, something considered undesirable for perishable products. While in the scenarios of R^d equal to 5 and 10 there is a period during which the mean age remains constant, this is not the case when R^d equals to 15. In the first case, for a lifetime of 28 days, the maximum mean age of sold products is of 14,4 days. In the second it is of 19 days and for the last the maximum corresponds to 22,4 days, a value that represents 80% of the total lifetime of the product. All of these values are obtained when *maxdays*

is at its maximum or close (a very small MLOR). A similar analysis can be made with products with distinct lifetimes (Appendix A).

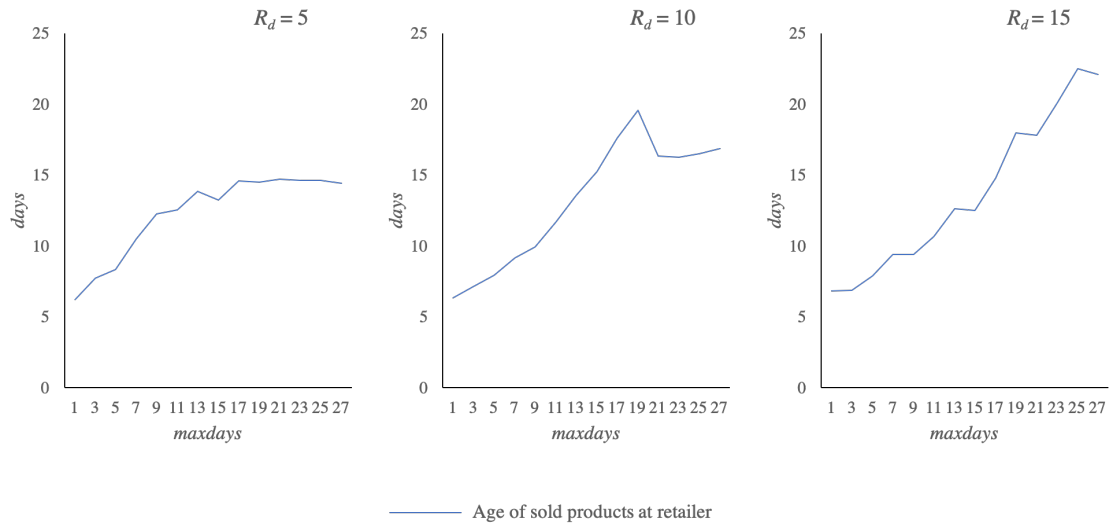


Figure 4.10: Mean age of sold products at the retailer with a lifetime of 28 days

It is important to emphasise that the values of the mean age of the sold products have great impact on the supply chain: demand at the retailer might be affected (customers might not buy a product if they believe that it will not be consumed before the expiration date) and the waste generated at the households will increase with high *maxdays* (low values of the MLOR). Although this last indicator is not analysed in this work, it should be taken into account when evaluating the sustainability of the supply chain.

Chapter 5

Conclusions and future research

This work represents the very first effort to investigate the impact that the MLOR criterion has on a supply chain of perishable products. Despite being put in practice by retailers for quite some time, it has still not been studied properly. The values set as the MLOR of products are either set by the experience and expertise or by copying blindly the value for the criterion from other products, whose lifetime might not even be comparable.

This dissertation studies a real life problem with some modifications. The original problem was presented by OLANO. The problem is modelled in the simulation software "Anylogic", with the objective of running simulations and recreating different supply chains using all the possible MLORs. The model is detailed, as well as the assumptions and the parameters it is built on.

With the results obtained, is possible to conclude that the MLOR, in the general cases, does not impact the overall costs of the supply chain. Although having a clear impact on the players participating in the supply chain, the overall costs usually remain constant. This is something that can facilitate and motivate cooperation between the elements when agreements of the MLOR are being made. Regarding the waste generated in the supply chain (without taking into consideration the waste at the households), it is concluded that the majority of it is produced in the distributor and it increases significantly with an increasing MLOR. Even though the waste created at the retailer increases with lower MLOR, its quantities are not as critical as the distributor's. Finally, the freshness of the products is also studied, with an analysis on the mean age of the sold products at the retailer. This indicator can be used as an indirect measure of the potential waste at the households. It is confirmed that increasing the MLOR improves the freshness of products bought by consumers. However, for low values of the MLOR, the freshness of products can be considered to remain constant.

Globally, it can be concluded that the MLOR is a critical aspect in the supply chains of products with short lifetimes and that the value of $\frac{2}{3}$ of the total life is appropriate. For products with longer lifetimes, the results show that a more permissible MLOR would not affect negatively the supply chain, giving more flexibility to the distributor's operations.

Since this is the first work on this topic in the literature, the main objective was to set the starting point to more incisive analyses on the impact of the MLOR. Considering the available time

to produce this work, it was only possible to investigate a small number of scenarios. Furthermore, several assumptions were taken into account, the most prominent of them being the impossibility of the distributor shipping products with a remaining life lower than the MLOR. In addition, it should be mentioned that, for the analysis of the generated waste, it was not considered the waste created at the hands of final consumers. These examples are representative of the limited breadth of this work and therefore, there are many possibilities for future researches: developing models that consider the limitations presented, studying of the influence of the production batch, the development of a fully cooperative supply chain, or even the utilisation of different inventory management models, starting with using dynamic safety stocks, are examples of such possibilities.

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Appendix A

Results obtained with products having different lifetimes

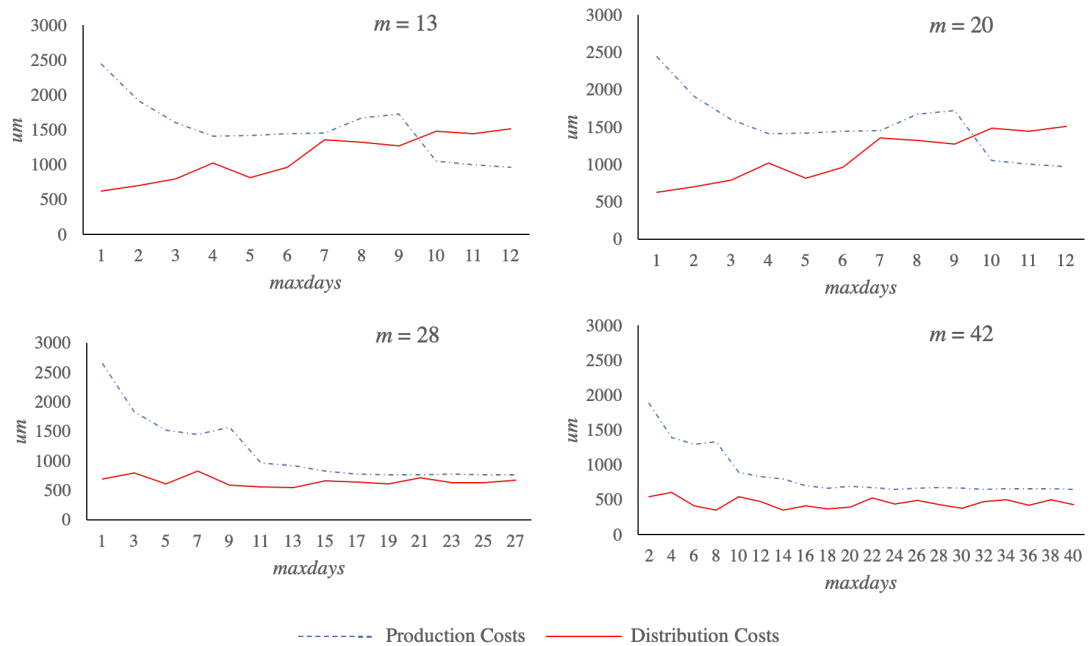


Figure A.1: Production and distribution costs for products with different lifetimes (m) and $R^d = 5$

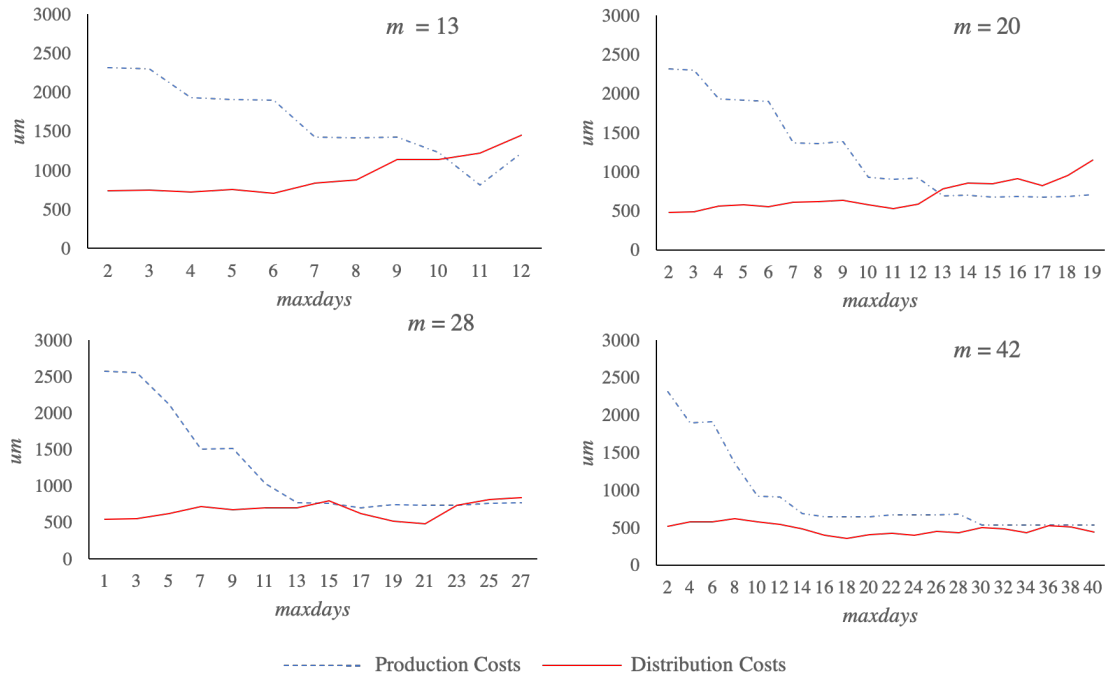


Figure A.2: Production and distribution costs for products with different lifetimes (m) and $R^d = 15$

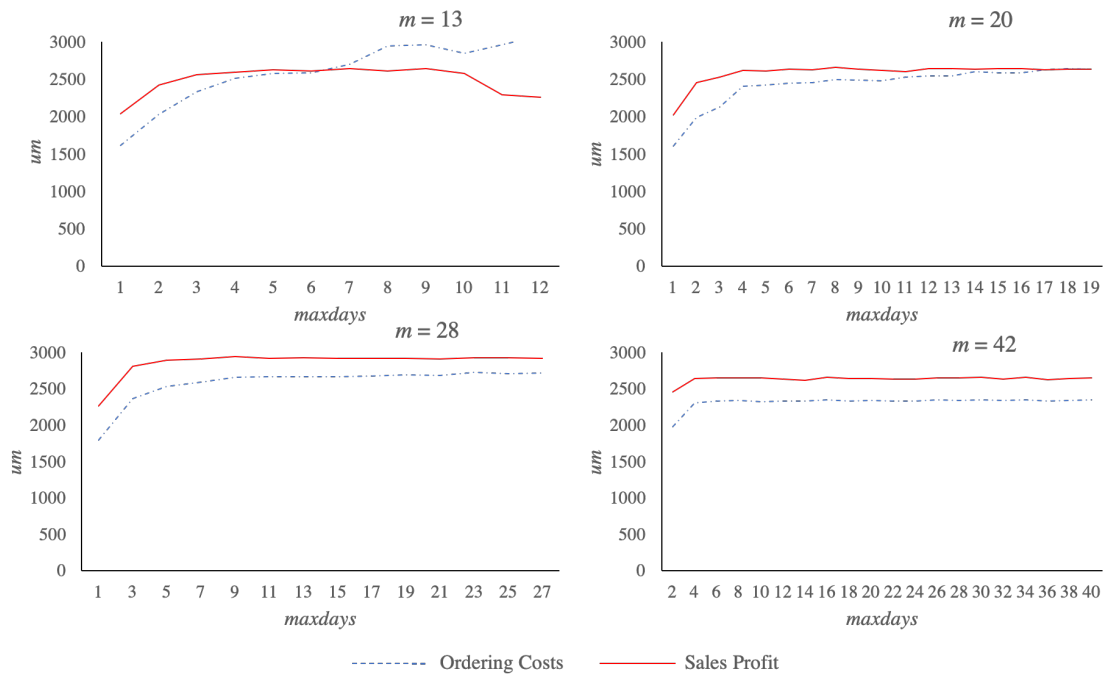


Figure A.3: Ordering costs and sales profits for products with different lifetimes (m) and $R^d = 5$

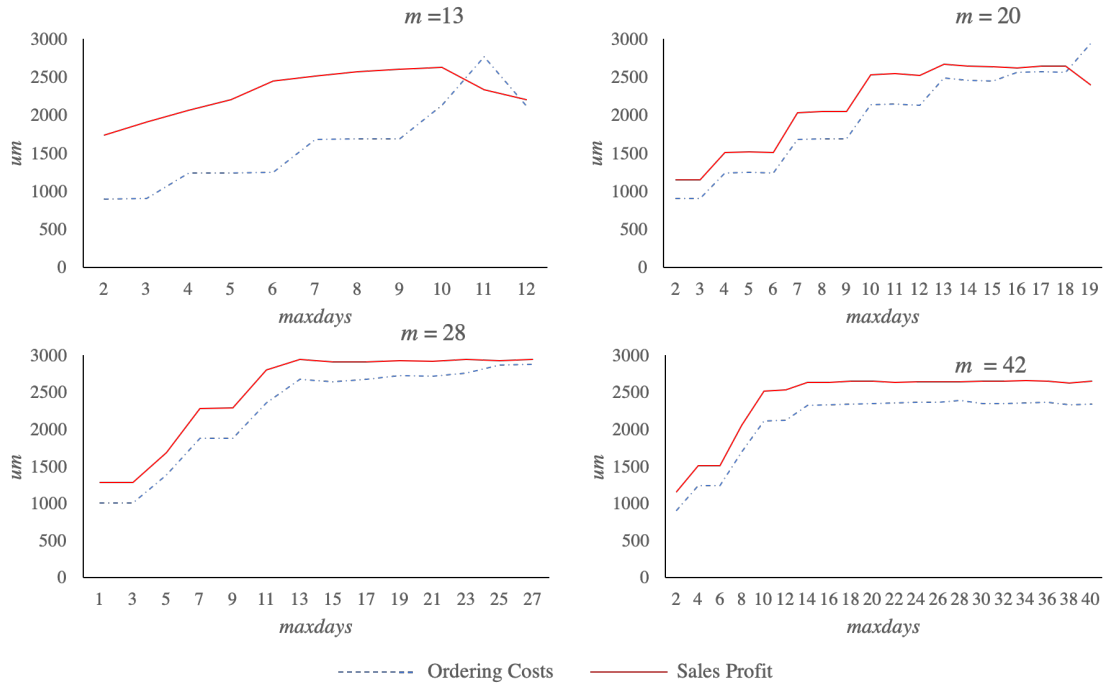


Figure A.4: Ordering costs and sales profits for products with different lifetimes (m) and $R^d = 15$

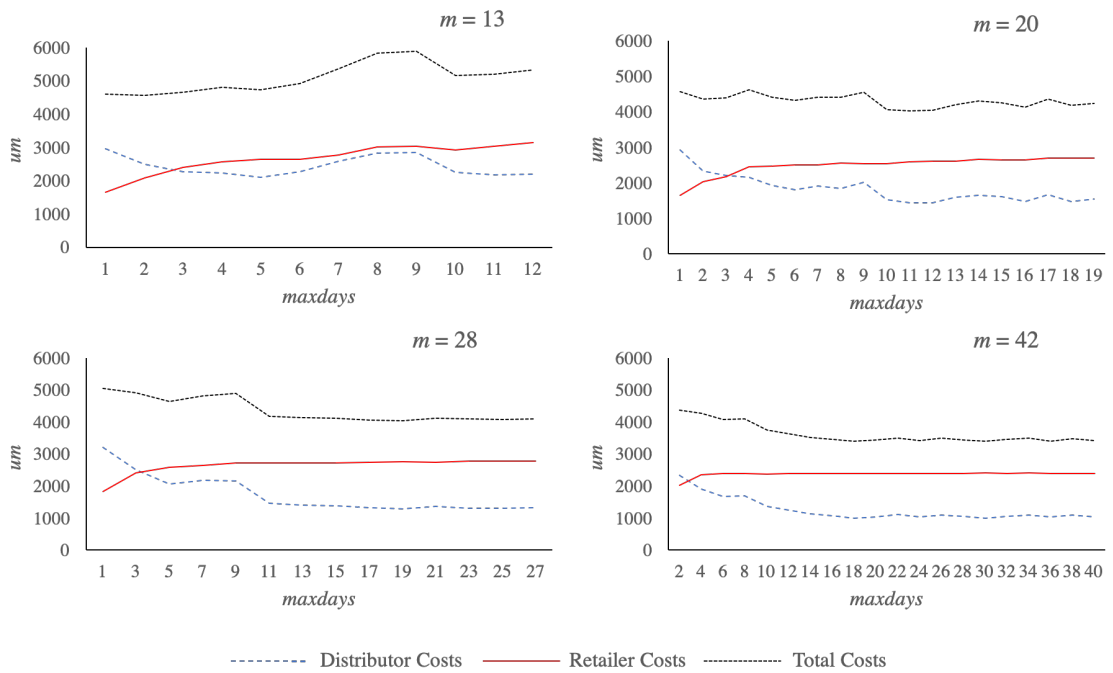


Figure A.5: Overall costs for products with different lifetimes (m) $R^d = 5$

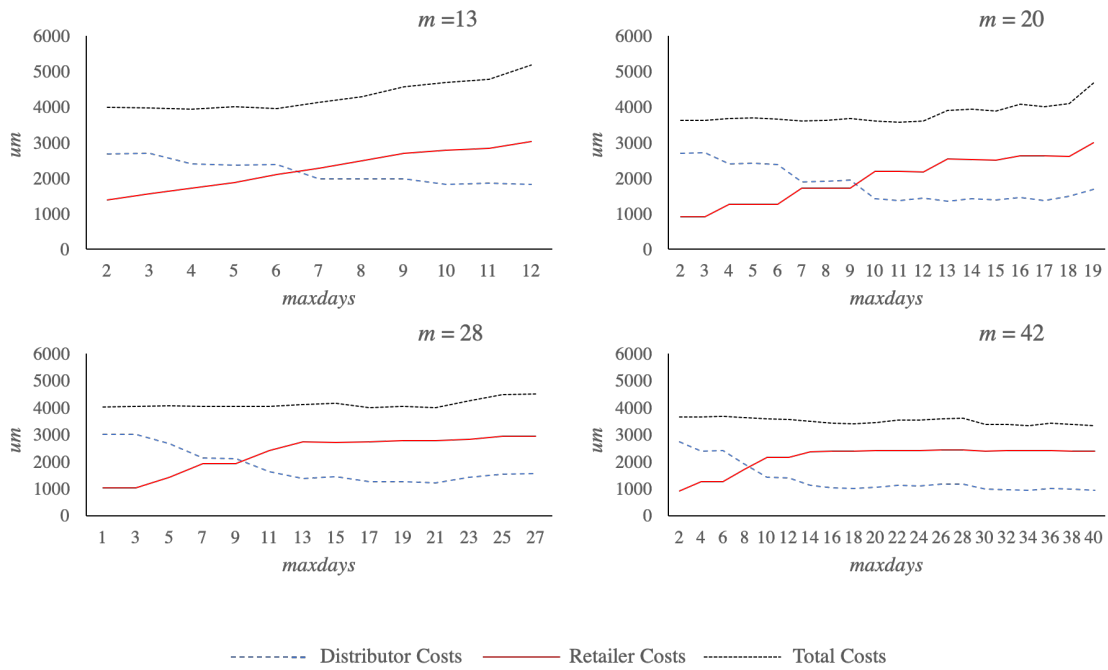


Figure A.6: Overall costs for products with different lifetimes (m) $R^d = 15$

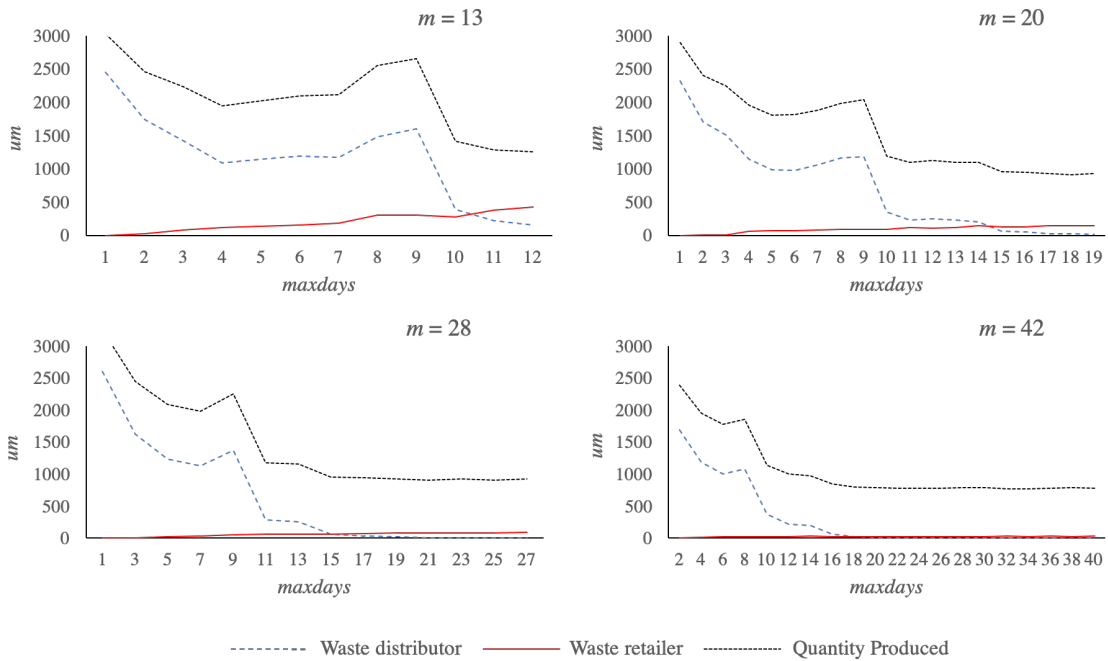


Figure A.7: Waste generated and quantity produced of products with different lifetimes (m) and $R^d = 5$

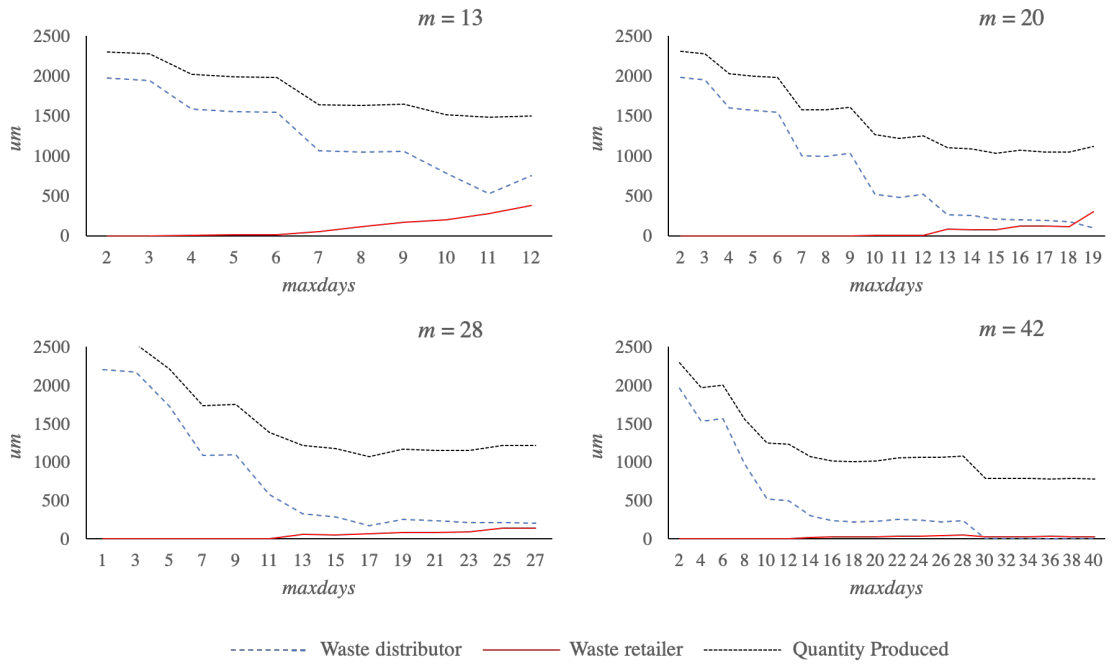


Figure A.8: Waste generated and quantity produced of products with different lifetimes (m) and $R^d = 15$

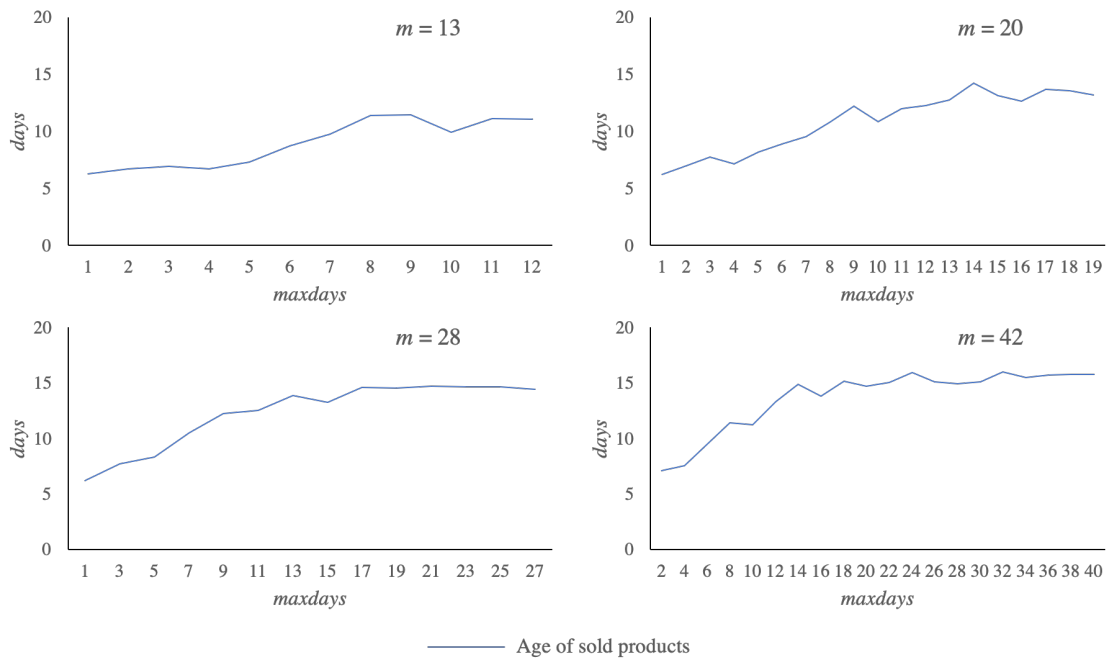


Figure A.9: Mean age of sold products at the retailer with different lifetimes (m) and $R^d = 5$

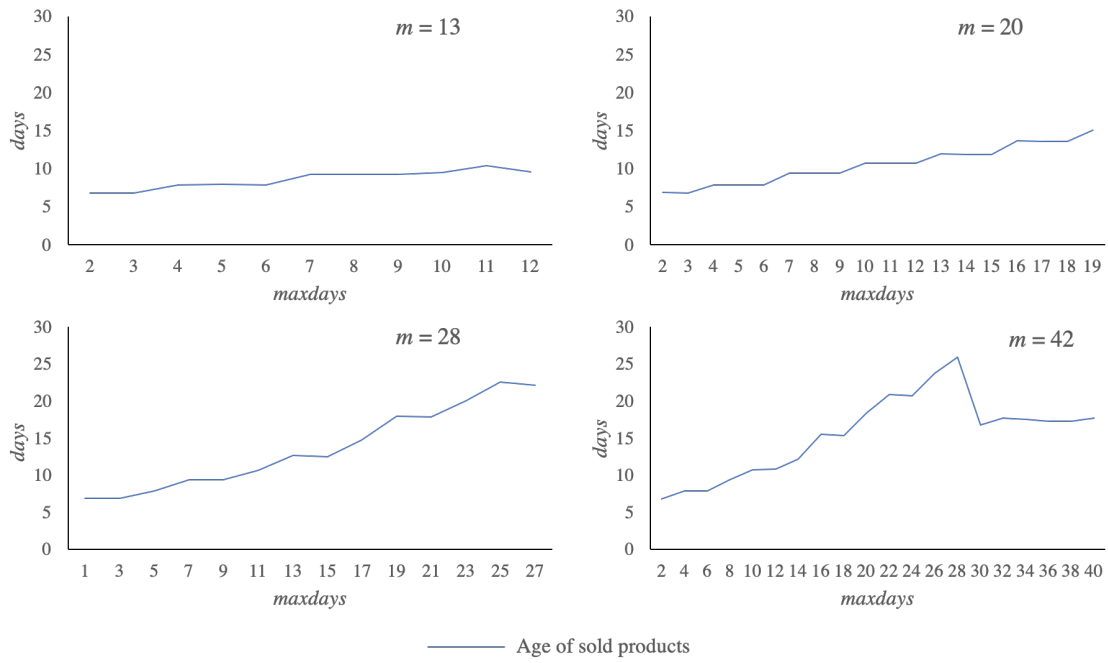


Figure A.10: Mean age of sold products at the retailer with different lifetimes (m) and $R^d = 15$