SUPPLY CHAIN SIMULATION: A STUDY ON REORDER POLICIES FOR PERISHABLE FOOD PRODUCTS

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ABSTRACT
In this paper, we analyze three traditional reorder policies (i.e., EOI, EOQ and S,s) applied to 5 different products, in a 2-echelon supply chain. A particular attention is placed to fresh products with limited shelf life, and to the suitability of applying the inventory management policies to those products.

An *ad hoc* simulation model, reproducing the reorder process of the two supply chain players, is developed under MS Excel™ and used to simulate the low of the different products along the supply chain, according to the different reorder policies. From the simulation, the minimum cost setting is derived for all policies, together with additional performance parameters (e.g. the throughput time of items along the supply chain), which allow assessing the suitability of a reorder policy for a given product.

From the simulation outcomes, some guidelines are derived for the optimal inventory management of perishable products. Since the supply chain and product data are derived from a real scenario, it is expected that our outcomes and guidelines are of practical usefulness to inventory managers.

Keywords: inventory management, inventory policies, perishable products, simulation model.

1. INTRODUCTION
A main goals of supply chain management is to maximize customer satisfaction, at the same time optimizing demand planning and management, resource use, integration between supply and demand, and stock levels. As regards this latter point, stocks are required at any level of the supply chain, to provide a buffer between uncertain supply and demand. A proper inventory management policy is thus expected to provide uninterrupted material and product flow throughout the supply chain at the minimum cost (Waters, 2003). Inventory management has obvious impact on the supply chain efficiency, since it generates several cost components, namely the purchasing cost of items, the order cost, the inventory holding cost and the stock-out cost (Bottani and Montanari, 2011).

Inventory management models can focus either on a single-period problem, which is also known as the newsvendor problem, or on a multi-period problem. In the former case, the goal is to find the order quantity which maximizes the expected profit in a single period probabilistic demand framework (Abdel-Malek and Montanari, 2005a,b). For multi-period problems, which are the focus of this paper, specific policies, such as economic order quantity (EOQ) or economic order interval (EOI), were developed with the purpose of achieving a proper balance between the different cost components (Waters, 2003). More recently, the (S,s) policy, i.e. a periodic review policy with re-order point and order-up-to level, has been introduced as a combination of the inventory control policies mentioned above, and is currently adopted in many contexts (Silver et al., 2009). According to that policy, the stock of an item is examined at periodic review intervals, and, if the inventory position is found to be lower than reorder point *s*, an order is placed. The quantity ordered should allow raising the current stock to the order-up-to level *S*. For computational purpose, the inventory position of an item consists of the on-hand inventory plus the ordered quantities, excluding backordered quantities.

The role of inventory management in matching supply and demand and getting the right product in the right place at the right time is particularly crucial for perishable products (Deniz et al., 2004). Indeed, for those products, the economic value deteriorates significantly over time, due to the limited product shelf life (Blackburn and Scudder, 2009). This could generate further costs of shrinkage, spoilage or obsolescence (Deniz et al., 2004).

Research related to inventory management mainly focuses on the optimal determination of the control parameters of inventory policies, or on their optimality under particular operating conditions. Examples of such studies include Schneider and Ringuest, (1990), and Silver et al., (2009), for the (S,s) policy, or Ferguson et al., (2007) and Goyal (1985) for the EOQ and EOI policies respectively. Some studies for the continuous review perishable inventory models are Weiss (1980), Schmidt and Nahmias (1985), Ravichandran (1995) and Liu and Lian (1999), while available reviews of inventory models have been performed by Raafat (1991) and Nahmias (1982).

However, the studies mentioned above suffer from two main limitations. First, they concern a specific inventory management policy (i.e., either EOI, EOQ or S,s) , while comparisons among those policies are rarely available in literature. Second, the inventory management policy is examined with respect to a specific supply chain player, without considering a whole supply chain.

Our goal with this study is to compare the use of different inventory policies to manage the stock level in a supply chain of perishable goods, with the ultimate purpose of identifying the optimal policy as a function of the product examined. The policies considered and compared are EOI, EOQ and (S,s), which are the traditional reorder policies proposed in literature. We examine a supply chain composed of a distribution center, a retail store and the final customer. The reorder process of 5 perishable products, with different characteristics, is reproduced and optimized, by means of a simulation model developed under MS Excel™.

The remainder of the paper is organized as follows. In the next section, we provide an overview of the supply chain examined and of the data collection phase. In section 3, we describe the development of the simulation tool and we detail the simulations The main results, in terms of the optimal inventory management policy as a function of the product considered and of the supply chain player, are proposed and discussed in section 4. In the last section, we summarize the key findings of the study and indicate future research directions.

2. THE SUPPLY CHAIN EXAMINED

The present study examines a real supply chain, composed of a distribution center, a retail store and the final customer (see Figure 1).

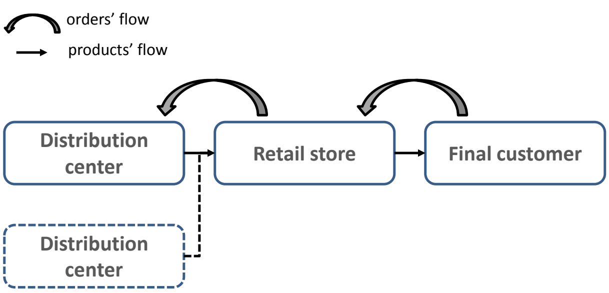

Figure 1: the supply chain examined

The distribution center considered is a warehouse of a main Italian retailer, and is located in northern Italy, near Reggio Emilia. It is specialized in the distribution of perishable products, such as fish, fruits, vegetables, milk derivatives and dairy products. Overall, the distribution center handles approx. 800 different items per day.

The retail store is a hypermarket, located near Mantova (Italy). It receives fresh products from the distribution center mentioned above, while the remaining product categories (e.g. grocery, beverage, health and beauty care, frozen foods, paper) are supplied by a different distribution center (dashed line), which is not considered in this study.

With respect to the perishable products, the current inventory management of the retail store and of the distribution center is as follows. The retail store places orders to the distribution center according to a proposal formulated by the company's information system, taking into account the final customer's demand. Typically, the product ordered are supplied within one or two days. The retail store does not own a refrigerated warehouse, so that the product received are immediately located on the store shelves. In the case the fresh product is not immediately sold, and its shelf life is expiring, the distribution center will pick up the product from the retail store, to send it to an alternative channel before it expires.

The distribution center receives the orders from several retail stores (besides the one considered in this study) and fulfills them primarily by using the available stock. Moreover, orders are collected to derive an aggregated demand, which will be processed by the warehouse management system to compute the product quantity to be ordered to manufacturers. Product ordered are available within some days; the specific lead time varies depending on the product considered.

Both the retail store and the distribution center were visited with, and people in charge were interviewed to derive the relevant pieces of information related to the current inventory management process. Moreover, store's managers were asked to indicate 5 perishable products, with different characteristics, whose reorder process could be investigated and optimized through simulation. The products chosen for the analysis, as well as their relevant data, are provided in Table 1. The following nomenclature is used for products: 1-Fresh milk; 2-Mozzarella cheese; 3-Yoghurt; 4-Plum pulp; 5-Royal jelly.

As can be seen from Table 1, for each product we collected data related to the total product shelf life, which is shared between the distribution center (for approx. 1/3) and the retail store (for 2/3). The "residual shelf life for picking up" represents the residual shelf life of the product which is collected from the retail store, to be sent to different channels.

Table 1: the products investigated

Product	**1**	**2**	**3**	**4**	**5**
Total shelf life [days]	7	19	35	365	720
Shelf life for distribution center [days]	2	5	8	80	158
Shelf life for retail store [days]	3	9	15	163	322

Residual shelf life for picking up [days]	2	3	3	5	10
Procurement lead time for distribution center [days]	0	1	1	5	8
Number of deliveries per week [delivery/week]	6	5	4	1	1
Procurement lead time for retail store [days]	1	2	2	2	2
Maximum number of items on the shelf [items]	70	54	21	12	24
Number of items per case [items/case]	6	-	6	-	-

Further data collected from the interviews with the distribution center and retail store's managers refer to holding cost, stock-out cost and order cost of the product examined. They are proposed in Table 2. As can be seen from that table, the order cost is the same for all products considered, since it only depends on the cost of manpower dedicated to the order process, while it is not affected by the product type. The stock-out cost and the cost of holding stock, instead, are specific for the product considered in the case of the retail store, while the same cost is assumed for the distribution center. Indeed, the cost of holding stock for the distribution center is specific for a given product category, since the product category may generate different cost components (e.g. energy, facility maintenance, or plant amortization). As the product considered in this study belong to the same category (i.e., fresh products), the same holding cost results. Finally, the stock-out cost is derived by multiplying the cost of stocks by a suggested factor of 20.

Table 2: unitary costs used in the simulation

Product	1	2	3	4	5
stock-out cost for distribution center [€/case/day]	0.44	0.44	0.44	0.44	0.44
stock-out cost for retail store [€/item/day]	2.38	2.66	3.08	3.48	2.32
cost of holding stock for distribution center [€/day/case]	0.022	0.022	0.022	0.022	0.022
cost of holding stock for retail store [€/day/item]	0.0119	0.0133	0.0154	0.0174	0.0116
order cost for distribution center [€/order]	6.8	6.8	6.8	6.8	6.8
order cost for retail store [€/order]	0.954	0.954	0.954	0.954	0.954

3. SOFTWARE MODELLING

3.1. Overview

As previously mentioned, multi-period inventory policies for perishable goods (i.e., EOI, EOQ and S,s) were studied using a simulation model, developed under MS Excel™.

Specifically, discrete event simulation has been used to reproduce the reorder process of the supply chain, in order to obtain a sufficient amount of observations on the performance of the system.

The simulation model consists of MS Excel™ file which reproduces the flow of orders related of a given product, according to a specific reorder policy. Both supply chain players (i.e., retailer and distributor) are considered in the file. For each product, we simulated the use of the three reorder policies, except for fresh milk. Indeed, from the interviews carried out with the store representatives, it emerged that the EOQ policy does not seem to be suitable to be used for that product, given its very short shelf life. Overall, we thus have 3 (policies) x 5 (products) – 1 = 14 MS Excel™ simulation files. Each simulation file reproduces, by means of as many spreadsheets, the two supply chain players.

3.2. Reorder policy settings

We start by simulating the flow of orders and products of the retail store, starting from the (known) customer's demand. For each product, this latter was generated as a random variable, whose parameters were suggested by the retail store representatives on the basis of the daily sales of the product. The simulation of retail store and distribution center were performed with different settings of the reorder policies. More precisely, the reorder policies considered are characterized by different operating leverages, as indicated below.

- For the EOQ policy, operating leverages are:
  - EOQ, i.e. the fixed quantity of product ordered to order [units]; and
  - order point (OP), i.e. the level of inventory at which the supply chain player will make an order to suppliers [units];
- For the EOI policy, operating leverages are:
  - EOI, i.e. the time interval between two subsequent orders [days];
  - order up to level (OUTL), i.e. the level of stock to recover when ordering [units].
- For the (S, s) policy, operating leverages are:
  - s, corresponding to the order point of the policy [units];
  - S, corresponding to the order up to level of the policy [units]; and
  - ΔT, i.e. the time interval between two subsequent controls of the stock level [days].

The basic idea of the simulation was to express one of the operating leverages of each policy as a function of the required level of safety stocks (*k*); in this way, a direct relationship between the total costs and achieved level of customer service was obtained and analyzed. The operating leverages that we chose to express as a function of *k* are OP for the EOQ policy, OUTL for the EOI policy, and s for the (s, S) policy.

The mathematical relationships which expresses one operating leverage as a function of the customer service *k* are shown below:

$$OP = LT \times \bar{d} + k\sigma\sqrt{LT} \quad (1)$$

$$OUTL = \bar{d} \times (EOI + LT) + k\sigma\sqrt{EOI + LT} \quad (2)$$

where LT is the order lead time [days], $\bar{d}$ is the average demand of the product [units/day] and σ is the standard deviation of the demand [units/day]. The formula for the OP is used for both the EOQ and (S,s) policies.

Through the simulation, a range of values has been assigned to *k* and to the remaining operating leverage(s) of each policy. Hence, during this preliminary simulations, the model was exploited to examine different settings of the operating leverages of each policy, with the purpose of identifying the *minimum cost* setting of each policy. Further input data used in the model were the order lead time and the maximum capacity of the store shelf, which is assumed as the S in the (S,s) policy.

3.3. Simulation procedure

A specific procedure was followed during the simulations. In particular, for a given product, we first simulated the order flow of the retail store, according to the different reorder policies investigated. As mentioned, different settings were used for the parameters of the reorder polies, with the purpose of identifying the *minimum cost* setting. We then collected the main performance parameters of each policy, in terms of the total cost (TC, expressed in [€/units/day]) of the policy and the throughput time (TT, expressed in [days]) of the product at the retail store. The total cost takes into account the cost of holding stocks, stock-out and order for each product examined. In turn, the cost of holding stocks and the stock-out cost are simply determined starting from the unitary costs shown in Table 2 and on the daily stock level of the retail store, while the order cost is calculated considering the number of orders made. The TT is computed, for each supply chain player, as

$$TT = LT + \frac{\bar{\imath}}{\bar{d}} \quad (3)$$

being $\bar{\imath}$ the average stock level [units] of the product for the player considered. In this study, the TT is a relevant performance indicator, because the products simulated have different shelf life characteristics. Moreover, some of them have very limited shelf life, and thus they should reach the final customer is a short time.

On the basis of the outcomes (i.e., TC, TT and the minimum cost setting of the policy), we assessed the *suitability* of each policy for each product. By suitability, we mean that the resulting optimal setting should comply with the product characteristics (i.e., its shelf life) or to the store constraints (i.e., the amount of shelf space). For instance, the minimum cost setting of the EOQ policy for a give product could generate an EOQ which could not be compatible with the amount of shelf space the particular product is given. Under this circumstance, the optimal setting of the EOQ policy is not suitable to be used for that product. Whenever the minimum cost setting of a policy turns out to be unsuitable for a given product, this policy will not be considered for that product. Among the suitable policies, we finally chose the *optimal* one, on the basis of the TC it generates.

The order flow of the retail store resulting under the optimal policy is used as input (and, in particular, as the demand) for the simulations of the distribution center reorder process. Again, all the reorder policies are simulated for this player, with different settings, and the same procedure described above is repeated for the selection of the optimal policy.

4. RESULTS AND DISCUSSION

Following the procedure described in section 3.3, we obtained, through simulation, a *minimum cost* reorder policy for each actor (i.e., retail store and distribution center) and for each product considered (from product 1 to product 5). However, as remarked, the minimum cost solution could be not suitable for application to a given product because of its characteristics, such as shelf life or store constraints. The *optimal* policy, i.e. the minimum cost policy which is also suitable to be applied to a given product, is highlighted in bold in Tables 3 and 4, respectively for the retail store and the distribution center. For each policy, we provide the resulting total cost [€/day/unit], the cost composition (in percentage) and the operative leverages set to obtain the minimum cost scenario, according to the description in section 3.2. The remaining outcomes (e.g., the TT) are directly derived from the simulation.

As regards the notation used, it should be remarked that, for simplicity, results are referred to “units” for both the distribution center and the retail store. The meaning, however, is different, since, by “units” we mean product “items” in the case of the retail store, and product “cases” in the case of distribution centers.

4.1. Retail store results

As regards the retail store and starting from the product with the shortest shelf life (i.e., product 1), it can be seen from Table 3 that the EOI policy appears as the minimum cost one, but it is not suitable to be adopted for this product, since it does not meet the shelf life and the store constraints (i.e., the store facing): in particular, the store facing for product 1 is 70 items, while, adopting EOI, the resulting OUTL should be significantly higher (232 items). For the same product, the (S,s) policy (which is the *optimal* one, because of the incompatibility between EOI and the product characteristics) generates a significant increase in the total cost, compared to EOI. This is mainly due to high stock-out cost resulting under the (S,s) policy, and indicates that, under that policy, the retail store experiences significant stock-out situations.

Specifically, stock-out cost accounts for 34% of the total cost resulting under (S,s) policy. From the above outcomes, two possible approaches can be suggested for the optimal management of product 1 at the retail store.

- A first approach could be to manage product 1 adopting the EOI policy with k=1.5 and EOI=4 days, which is the *minimum cost* setting. Since such setting does not met the constraint of the store facing, the retail store should consider to increase the amount of shelf space for this product, raising it to approx. 230 items;
- Alternatively, product 1 could be managed according to the (S,s) policy, with k=1 and ΔT=1 day. This would lead to a higher total cost, but all the problem constraints are satisfied. The main issue with the (S,s) policy is that the retail store experiences numerous out of stock situations, meaning that the number of items available for purchase is too low. However, since product 1 has a very limited shelf life, the lack of the product on the shelf could also be acceptable, since it means that there will be no product shrinkage, and thus no cost for product disposal will arise. This could be an interesting business strategy that the retail store could consider. Under this scenario, sale losses should be avoided by offering alternative products to customers once product 1 is out of stock.

Looking at the mozzarella cheese (product 2), we can see that the most severe constraint is given by product shelf life (9 days), which should be lower than the TT. On the basis of this consideration, the EOI policy turns out to be the only suitable policy for that product, since both EOQ and (S,s), with minimum cost setting, generate excessive TT. However, it should be remarked that, no matter the policy, the way product 2 is currently managed by the retail store is probably inefficient: in fact, the store facing (54 items, as indicated in Table 1) is too high, compared to the product demand (approx. 1.60 items/day). With those settings, all the reorder policies simulated generate somehow inconsistent results, and can be hardly adapted to the real scenario.

Because of the same reason, i.e. the inconsistency between the shelf facing and the daily demand, only the (S,s) policy is suitable to be adopted for product 3 (yoghurt), since its minimum cost setting meets all the problem constraints. This policy, although optimal, generates higher total cost, compared to EOI or EOQ.

An opposite situation occurs for product 4 (plum pulp): in this case, the daily demand is high and the shelf facing (12 items) of the product is probably undersized. It is thus likely that this product experiences stock-out situations. For product 4, the minimum cost policy resulting from the simulation is EOQ, which is also compatible with the product characteristics and is thus the optimal one. Similar considerations hold for product 5 (royal jelly): EOQ turns out to be the minimum cost policy, and is also compatible with the product characteristics. It should be noted, in this regard, that both products 4 and 5 have less severe constraints in terms of shelf life (163 days and 322 days, respectively), thus all inventory management policies can be easily adapted to those products, via appropriate settings. As a result, no relevant incompatibilities between these products and the reorder policies emerge from Table 4.

Table 3: retail store results

	Product 1-MILK (Shelf life 3 days) (đ = 44.52 units/day)		
	EOQ	EOI	**(S,s)**
Average total cost [€/day/unit]		2.675 (stock out cost 0.60%) (cost of holding stock 36%) (order cost 63.40%)	**10.241 (stock out cost 34%) (cost of holding stock 0%) (order cost 66%)**
k		1.5	**1**
TT [day]		2.81	**1.749**
Operative leverage		EOI = 4 OUTL = 232	**ΔT = 1 S = 70 s = 48**
	Product 2-MOZZARELLA CHEESE (Shelf life 9 days) (đ = 1.60 units/day)		
	EOQ	**EOI**	(S,s)
Average total cost [€/day/unit]	0.589 (stock out cost 0%) (cost of holding stock 55%) (order cost 45%)	**1.145 (stock out cost 0.30%) (cost of holding stock 15%) (order cost 84.70%)**	0.635 (stock out cost 0%) (cost of holding stock 70%) (order cost 30%)
k	1.7	**1**	1
TT [day]	15.3	**9**	20.5
Operative leverage	EOQ = 40 OP = 6	**EOI = 7 OUTL = 17**	ΔT = 1 S = 54 s = 5
	Product 3-YOGHURT (Shelf life 15 days) (đ = 1.83 units/day)		
	EOQ	EOI	**(S,s)**
Average total cost [€/day/unit]	0.617 (stock out cost 0%) (cost of holding stock 32%) (order cost 68%)	0.736 (stock out cost 0.15%) (cost of holding stock 28%) (order cost 71.85%)	**0.815 (stock out cost 0%) (cost of holding stock 15%) (order cost 85%)**
k	1.9	1	**1**
TT [day]	10.34	10.68	**7.1**
Operative leverage	EOQ = 30 OP = 6	EOI = 13 OUTL = 30	**ΔT = 1 S = 21 s = 5**
	Product 4-PLUM PULP (Shelf life 163 days) (đ = 0.30 units/day)		
	EOQ	EOI	(S,s)
Average total cost [€/day/unit]	**0.274 (stock out cost 1%) (cost of holding stock 43%) (order cost 56%)**	0.382 (stock out cost 3%) (cost of holding stock 17%) (order cost 80%)	0.282 (stock out cost 0.25%) (cost of holding stock 46%) (order cost 53.75%)
k	**1**	1	1
TT [day]	**27.26**	16.08	29.79
Operative leverage	**EOQ = 6 OP = 2**	EOI = 1 OUTL = 2	ΔT = 3 S = 12 s = 2
	Product 5-ROYAL JELLY (Shelf life 322 days) (đ = 0.70 units/day)		
	EOQ	EOI	(S,s)
Average total cost [€/day/unit]	**0.339 (stock out cost 0%) (cost of holding stock 43%) (order cost 57%)**	0.465 (stock out cost 0%) (cost of holding stock 16%) (order cost 84%)	0.346 (stock out cost 1%) (cost of holding stock 43%) (order cost 56%)
k	**1**	1	1
TT [day]	**20.36**	11.59	20.86
Operative leverage	**EOQ = 24 OP = 3**	EOI = 1 OUTL = 3	ΔT = 3 S = 24 s = 3

4.2. Distribution center results

Results related to the distribution center are proposed in Table 5.

The main outcome from Table 5 is that, for 3 out of 5 products simulated, none of the reorder policies considered turns out to be suitable for implementation. The products for which we were unable to find a suitable reorder policy are milk (product 1), mozzarella cheese (product 2) and yoghurt (product 3). The main reason for unsuitability is that the distribution center TT is always higher than the product shelf life, which, as already observed, is particularly short for those products. To reduce the TT, at the same time avoiding product expiry, from a practical perspective it can be suggested that products 1, 2 and 3 should be supplied to the retail store through direct deliveries.

The remaining products, as already remarked, are less problematic in terms of their shelf life; thus, all the reorder policies simulated generate an acceptable scenario and the optimal policy is simply the minimum cost one. In particular, for both products 4 and 5, the optimal solution is given by the (S,s) policy.

Table 5: distribution center results

	Product 1-MILK (Shelf life 2 days) ($\bar{d}$ = 4.45 units/day)		
	EOQ	EOI	(S,s)
Average total cost [€/day/unit]		0.398 (stock out cost 0%) (cost of holding stock 40%) (order cost 60%)	2.13 (stock out cost 58%) (cost of holding stock 2%) (order cost 40%)
k		1	2.8
TT [day]		2.94	2.32
Operative leverage		EOI = 4 OUTL = 22	ΔT = 4 S = 23 s = 3
	Product 2-MOZZARELLA CHEESE (Shelf life 5 days) ($\bar{d}$ = 0.20 units/day)		
	EOQ	EOI	(S,s)
Average total cost [€/day/unit]	0.105 (stock out cost 10%) (cost of holding stock 55%) (order cost 35%)	0.167 (stock out cost 0.10%) (cost of holding stock 18%) (order cost 81.90%)	0.48 (stock out cost 0.6%) (cost of holding stock 98%) (order cost 1.4%)
k	1	1	1
TT [day]	15.27	9.54	112.42
Operative leverage	EOQ = 5 OP = 1	EOI = 3 OUTL = 2	ΔT = 5 S = 43 s = 0
	Product 3-YOGHURT (Shelf life 8 days) ($\bar{d}$ = 0.30 units/day)		
	EOQ	EOI	(S,s)
Average total cost [€/day/unit]	0.151 (stock out cost 8%) (cost of holding stock 64%) (order cost 28%)	0.147 (stock out cost 0%) (cost of holding stock 34%) (order cost 66%)	0.11 (stock out cost 0%) (cost of holding stock 56%) (order cost 44%)
k	1	1	1.2
TT [day]	16.27	10.78	13.77
Operative leverage	EOQ = 7 OP = 2	EOI = 2 OUTL = 3	ΔT = 8 S = 6 s = 1
	Product 4-PLUM PULP (Shelf life 80 days) ($\bar{d}$ = 0.045 units/day)		
	EOQ	EOI	**(S,s)**
Average total cost [€/day/unit]	0.073 (stock out cost 27%) (cost of holding stock 54%) (order cost 19%)	0.054 (stock out cost 0%) (cost of holding stock 60%) (order cost 40%)	**0.049** **(stock out cost 0%)** **(cost of holding stock 56%)** **(order cost 44%)**
k	1	1	**1**
TT [day]	48.76	49.28	**49.44**
Operative leverage	EOQ = 3 OP = 1	EOI = 11 OUTL = 2	**ΔT = 21** **S = 2 s = 0**
	Product 5-ROYAL JELLY (Shelf life 158 days) ($\bar{d}$ = 0.06 units/day)		
	EOQ	EOI	**(S,s)**
Average total cost [€/day/unit]	0.072 (stock out cost 0%) (cost of holding stock 75%) (order cost 25%)	0.06 (stock out cost 0%) (cost of holding stock 54%) (order cost 46%)	**0.053** **(stock out cost 0%)** **(cost of holding stock 75%)** **(order cost 25%)**
k	1	1	**1.1**
TT [day]	55.33	42.84	**60.76**
Operative leverage	EOQ = 3 OP = 2	EOI = 1 OUTL = 2	**ΔT = 25** **S = 4 s = 1**

5. CONCLUSIONS

Inventory management is a basic element of competition in order to increase company's efficiency and profitability.

In this paper, we analyzed, through simulation, 3 traditional reorder policies (i.e., EOI, EOQ and S,s) applied to a 2-echelon supply chain, with the purpose of identifying the optimal one with respect to the characteristics of a given product. A particular attention has been paid to fresh products with limited shelf life. As a result, we provided the optimal inventory management policy, its optimal setting, and the resulting total cost, as a function of the product considered and of the supply chain player examined.

The outcomes obtained lead to the following major conclusions. A first consideration is that, for products 4 and 5, which do not fall into the category of fresh products, no significant problems emerge as regards the compatibility of the reorder policies with the product characteristics. Conversely, the correct management of products 1, 2 and 3, which have limited shelf life, is more problematic, and it emerged from our analysis that reorder policies cannot always been adapted to those products. For those products, some practical guidelines can nonetheless be suggested on the basis of the outcomes obtained. As a matter of fact, it seems that the current way such products are managed is inefficient and could be improved. For product 1, the current store facing of 70 items allows satisfying the product demand of less than 2 days (being the daily demand approx. 44 units). No matter the reorder policy applied, this setting always leads to numerous out-of-stock situations. Although stock-out situations could be accepted, because no cost of product disposal arises, they should be properly managed by the retail store. For products 2 and 3, on the contrary, the current store facing is oversized compared to the daily demand of the product at the retail store. For instance, the store facing accounts for 54 items for product 2, while the daily demand is approx. 1.60 items/day. No matter the reorder policy applied, those settings generate a very high TT, which leads to incompatibility with the short product shelf life. Such scenario could be improved by reducing the store facing of those products.

The main contributions of this study can be summarized as follows. First, from the methodological point of view, we compare the different inventory policies to manage the stock level of products, instead of focusing on the optimization of only a specific policy (which is common among the studies available in literature). Second, inventory management policies are examined with respect to a whole supply chain, even if the optimal solution is given separately for each supply chain player. Future research could consider be oriented toward the optimization of the whole supply chain cost. Third, a real supply chain has been chosen for the analysis, so that the outcomes obtained describe are useful to derive practical guidelines for supply chain managers in real scenarios.

Some limitations of the work should be mentioned. One is related to the simulation model developed, which is susceptible to be improved. In fact, under some scenarios (and, in particular, when the real scenario shows some inconsistencies), the simulations performed were ineffective in finding suitable reorder policies. In those cases, the user should change the operating leverages of the reorder policies manually to derive useful results. Moreover, the model omits some specific cost components, such as the disposal cost of expired goods or the cost for checking the stock level, which should be considered for some reorder policies. The cost of disposal was not introduced in the model because of lack of information in this regard. Specifically, it is not know which supply chain player has to pay such cost. Conversely, the cost for checking the stock level has been voluntary omitted, because typically its amount is very limited compared to the remaining cost components. Nonetheless, on the basis of the considerations above, some improvements will be introduced in the model in future studies.

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