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# A Multi Objective Approach to Short Food Supply Chain Management

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Conventional supply chains, involving several stages and various intermediaries, are affected by some well-known forms of inefficiencies and drawbacks. Besides the increase of market price consequent to multiple marginalization, such supply chains generally suffer of significant post-harvest losses and product waste. In this context, short food supply chains have been recently proposed as different systems capable of delivering higher quality products while promoting sustainability and efficiency. Across the EU, a growing number of consumers choose to buy food products on local farmers' markets, associating local products with higher quality standards (freshness, nutritional value), healthy eating, more environment-friendly production methods and lower carbon footprint. Such elements seem to confirm a higher performance of short food supply chains (SFSCs) compared to traditional (long) chains in terms of sustainability and quality of products. Nevertheless, the performance of SFSCs is significantly affected by the local contexts and the market situations in which they operate. In particular, although SFSCs are localized in relatively small geographical areas, the elimination of intermediaries, such as distributors/packagers, and quality preserving processes generally results in shorter shelf-life of products. The management of such systems, hence, is focused on the problem of ensuring superior quality of local product at reasonable costs, without the possibility of employing advanced packaging solutions. Therefore, due to their peculiarities, SFSCs require proper logistic policies to cope with these problems, taking into account the variability of demand and the effects of seasonality. This paper in particular focuses on the logistics of SFSCs and proposes a methodology for optimal inventory management, with the aim to preserve the shelf-life of the products, and to ensure supply chain efficiency. The methodology developed is based on a multi-objective approach to inventory management in a serial two-echelon system. A numerical application is proposed in order to prove the effectiveness of the model.

## 1. Introduction

Short food supply chains (SFSCs), as legally defined by (EU) Regulation N. 1305/13, are considered a model of agricultural production able to achieve environmental, economic and social benefits, such as the mitigation of marginalization inefficiencies, the reduction of transportation costs, $CO_2$ emissions, etc. The economic sustainability of this model is related to the possibility for farmers to receive a greater share of profit (Sage, 2003) by the elimination of the 'middleman'. Additionally, European customers tend to associate local products with higher quality standards, healthy eating, and a lower carbon footprint. For such reasons, SFSCs have spread across the European Union, assuming different configurations in order to respond to specific customers' needs. SFSCs, thus, can be classified into three types: individual direct sales, collective direct sales and partnerships. Direct sales are the simplest form of SFSC and involve a direct transaction between the farmer and the consumer. These transactions can take place inside or outside the farm, for example at farmers' markets within an individual relation with the customer or in a collective form, involving cooperatives of producers selling their products to consumer groups. SFSC can also be found in the form of partnerships between producers and consumers bound by a written agreement. Examples of these communities are: AMAP (Association pour le Maintien d'une Agriculture Paysanne) in France, GAS (Gruppi di Acquisto Solidale) in Italy, SoLaWi (Solarische Landwirtschaft) in Germany. SFSCs can also be classified in traditional and neo-traditional. Traditional SFSCs tend to be farm-based, in rural areas, and take the form of on-farm

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sales, roadside sales and 'pick-yourown' systems. They are usually operated by farming families and often use traditional and artisan methods. Neo-traditional SFSCs are frequently found in the form of collaborative networks of producers, consumers and institutions, sustaining traditional farming practices through new models and social innovation. This research is focused on direct sales forms of SFSCs which typically take place on farmers' markets. Customers' choice of such forms of supply chain is generally related to the fact that they deliver higher quality products compared to traditional long chains. Customers are consequently willing to pay more for such products, thus allowing producers to add a price premium (Pearson et al., 2011). Finally, SFSCs provide small growers with an opportunity to diversify and add value to their produce (Alonso, 2011). In order to achieve these objectives, however, the quality of products must be preserved from the production site to the final customer, therefore proper management policies must be established in order to deliver the products, in the right quantity, in the right condition, and at the right cost (Aghazadeh, 2004).
This paper proposes a mathematical model to determine an optimal inventory model to preserve both the shelf-life of the products, as well as to ensure supply chain efficiency. In particular, the methodology proposed aims at the determination of the optimal inventory management policy (i.e. stock levels) for a SFSC, consisting of two warehouses: one located close to the producer and the other located in the farmer's market or urban store. Such supply chain is represented as a two-echelon serial system, approached in a bi-objective formulation considering both cost and quality parameters. The research proposed falls in the theoretical framework of optimal inventory management policies for multi-echelon systems and, particularly, refers to the concept of echelon stock, first introduced by Clark and Scarf (1960). The solution method adopted takes into account the integer-ratio policy proposed by Taha and Skeith (1970), whose optimality for two-echelon systems was proved by Crowston et al. (1973) and Williams (1982).. The solution of this problem is not trivial even in the case of deterministic demand because of the complex interactions between echelons. Additionally, in the multi-objective formulation proposed, the shelf-life parameter is considered as an indicator of the quality of the product. Several researchers have investigated the reduction of the shelf-life of perishable products in time, considering different storage conditions and the effect of temperature. In particular in this research we refer to the Arrhenius model which is one of the most prevalent and widely used model to describe food quality loss reactions in time at different temperatures. The proposed methodology, hence, allows to evaluate the effects of different Inventory management policies on the cost of the supply chain and on the quality of the products, in order to analyse the trade-off between the two objectives. The decision maker can thus determine the best compromise solution once a preference scheme is introduced. The decision maker can thus identify the management policy which achieves the best compromise between the quality of delivered products and the cost of Inventory.

## 2. Methodology

A SFSC can be represented as a serial system consisting of two warehouses. The first warehouse ($W_1$) is located close to the market and its function is related product sale, while the second warehouse ($W_2$) is close to the harvesting point, and its function is to store the products harvested until they are transported to the next warehouse. Both warehouses can be equipped with a cold room or a refrigerated area, but no packaging/preservation processes are considered. The managerial challenge, hence, is to ensure a superior product quality, by employing an inventory management policy which allows to achieve a proper compromise between costs and product quality. The system described above can be represented as a simple two-echelon serial supply chain, as depicted in the following Figure 1, where the only possibility of managing the product flow is to assign appropriate Inventory levels to the warehouses. The overall Inventory Management Cost for the supply chain is related to the quantities (Inventory levels) $Q_1$ and $Q_2$ held in the warehouses. At each echelon, such cost can be expressed as the sum of an order cost, a purchase cost and an inventory holding cost.

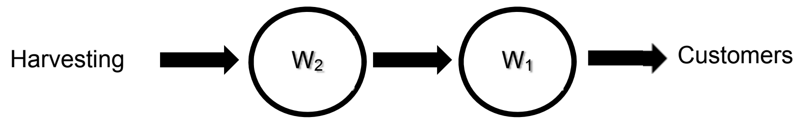


*Figure 1: Supply Chain Scheme*

Coherently with traditional deterministic inventory cost models, the order cost is assumed as a constant value per order, independent of the quantity on hand or on order, which includes the administrative costs associated with order preparation. The inventory holding cost is a function of a unit holding cost ($h_i$) and of the inventory on hand. In addition, the order quantity at the upper echelon ($Q_2$) is assumed as a multiple of $Q_1$. The ratio

$k = Q_2 / Q_1$; with $k > 1$ is therefore an integer value. The demand is considered known and deterministic, and the following assumptions are made:

- The lower echelon always replenishes its supply from the upper echelon.
- External customer demand always occurs at the lower echelon with a deterministic and constant rate of d units per year.
- Backorders and lost sales are not allowed.
- Transportation lead time does not affect the performance of the supply chain.

Also the following notation is employed:

- $h_1$ , $h_2$ : unit holding cost for warehouse 1 and 2, respectively;
- $Q_1$ , $Q_2$: order quantities for warehouse 1 and warehouse 2, respectively
- d: market demand

In the decentralized approach each warehouse is considered independently, and the optimum order quantity is calculated for the first warehouse, then for the second warehouse it is assumed to be multiple of $Q_1$

$$C_1=h_1\frac{Q_1}{2}+A_1\frac{d}{Q_1} \tag{1}$$

$$Q_1=\sqrt{\frac{2A_1d}{h_1}} \tag{2}$$

$$Q_2=kQ_1 \tag{3}$$

where k is a positive integer. Then minimizing the cost of the second warehouse:

$$C_2=h_2\frac{(k-1)Q_1}{2}+A_2\frac{d}{kQ_1} \tag{4}$$

The optimum value of k thus is:

$$k^*=\frac{1}{Q_1}\sqrt{\frac{2A_2d}{h_2}} \tag{5}$$

If $k^* < 1$ it is optimal to choose $k = 1$. If $k^* > 1$. Let $k'$ be the largest integer less or equal to $k^*$, i.e., $k' \leq k^* < k'+1$, it is optimal to choose $k = k'$ if $k^*/k' \leq (k' + 1)/k^*$, otherwise $k = k'+ 1$.

Alternatively, the centralized approach, consists employing the echelon holding costs $e_1 = h_1 - h_2$, and $e_2 = h_2$, and in taking into account both the $W_1$ and $W_2$ costs in the optimization.

$$C_2^e=e_2\frac{kQ_1}{2}+A_2\frac{d}{kQ_1} \tag{6}$$

$$C=C_1^e+C_2^e=(e_1+ke_2)\frac{Q_1}{2}+\left(A_1+\frac{A_2}{k}\right)\frac{d}{Q_1} \tag{7}$$

$$Q_1=\sqrt{\frac{2\left(A_1+\frac{A_2}{k}\right)d}{e_1+ke_2}} \tag{8}$$

$$\mathrm{C}(k)=\sqrt{2\left(A_1+\frac{A_2}{k}\right)d(e_1+ke_2)} \tag{9}$$

$$k^*=\sqrt{\frac{A_2e_1}{A_1e_2}} \tag{10}$$

If $k^* < 1$ it is optimal to choose $k = 1$. If $k^* > 1$. Let $k'$ be the largest integer less or equal to $k^*$, i.e., $k' \leq k^* < k+1$, it is optimal to choose $k = k'$ if $k^*/k' \leq (k' + 1)/k^*$, otherwise $k = k'+ 1$.

Additionally, as stated before, SFSC must be able to deliver premium quality products, therefore reducing the effects of perishability must be considered an additional objective. Generally speaking the loss of quality can be evaluated by means of a measurable parameter related to the reaction that determines the quality loss. Being q such parameter, the variation of q with time can be expressed as:

$$(\pm)\frac{dq}{dt}=kq^n \tag{11}$$

Where k is the speed and n is the reaction order of the phenomenon controlling the deterioration of the food. On the basis of these considerations it is possible to develop a kinetic-mathematical model describing the evolution of the quality index as a function of time, when the product is exposed to variable temperatures:

$$k=k_0 e^{\left(-\frac{E_a}{RT}\right)} \tag{12}$$

Where $k_0$ is a constant, $E_a$ is the activation energy of the reaction that controls quality loss, R the universal gas constant (8.31 J/ mol °K) and T is the temperature (in Kelvin). The following equation, known as Arrhenius equation, describes the dependence of the rate constant k with the temperature T (°K) and activation energy.

$$\log k_2/k_1=-E_a/R(1/T_2-1/T_1) \tag{13}$$

In addition, the $Q_{10}$ temperature coefficient is a measure of the rate of change of a biological or chemical system as a consequence of increasing the temperature by 10 °C. This parameter is adopted as the indicator of the quality change during storage, describing the relationship between temperature and reaction rate. $Q_{10}$ is an unitless quantity, as it is the factor by which a rate changes which can be calculated as:

$$Q_{10}=k(T+10)/k(T) \tag{14}$$

These typical $Q_{10}$ values allow us to construct a table showing the effect of different temperatures on the rates of respiration or deterioration and relative shelf life of a typical perishable commodity. The $Q_{10}$ can be calculated by dividing the reaction rate at a higher temperature by the rate at a 10 °C lower temperature, i.e.:

$$Q_{10}=R_2/R_1 \tag{15}$$

The temperature ratio allows to calculate the respiration rates at one temperature from a known rate at another temperature by means of the following equation:

$$Q_{\Delta T}=\frac{k_{(t+\Delta T)}}{Q_t}=Q_{10}^{\Delta T/10} \tag{16}$$

On the basis of the Arrhenius equation and knowing the $Q_{10}$ values, it is possible to predict the shelf-life variation corresponding to a ΔT of 10 °K, by means of the following equation:

$$Q_{10}=\frac{\text{Shelf life at } T\ °C}{\text{Shelf life at}(T+10)\ °C}=\frac{\theta_{xT}}{\theta_{xT+10}} \tag{17}$$

The loss of quality corresponding to subsequent time intervals at different temperature is given by:

$$\frac{dq}{q^n}=-\sum(k_i\Delta t_i)_{T_i} \tag{18}$$

It is therefore possible to calculate the fraction of consumed shelf life ($f_c$) and residual shelf-life ($f_t$) as:

$$f_c=-\sum_{i=1}^{n}\left(\frac{\Delta t_i}{SL_i}\right)_{T_i} \tag{19}$$

$$f_t=1-f_c \tag{20}$$

The above equations allow to evaluate the residual shelf-life on the basis of the time/temperature history.

## 3. Numerical application

The case presented is referred to the peaches of the variety “elegant lady” grown in Sicily and appreciated as a premium quality product (Aiello et al., 2012). For such product, we considered a shelf-life of approx. 22 days at the temperature of 0.5 °C, and an activation energy ($E_a$) of 0.9 kJ/mol, which is coherent with parameters reported in the literature (Testoni et al., 2007). $Q_{10}$ and the shelf-life values are given in Tables 1 and 2.

*Table 1: $Q_{10}$ values at different temperatures*

| | T=10 | T=20 | T=30 |
|---|---|---|---|
| Q10 | 2.5 | 2.5 | 2.0 |

*Table 2: Shelf life (h) at different temperatures*

| | 0 °C | 5 °C | 7 °C | 10 °C | 20 °C | 25 °C | 30 °C | 35 °C |
|---|---|---|---|---|---|---|---|---|
| Shelf-life (h) | 528 | 334 | 278 | 211 | 84 | 60 | 30 | 24 |

The following parameters have also been considered: d=50 pc/day; $A_1$=600 €, $h_1$=0.8/pc/year; $A_2$=1800 €, $h_2$=0.2/pc/year. Thus: $e_1 = h_1 - h_2 = 0.6$; $e_2 = h_2 = 0.2$. According to Eq. 9 the value of k can be calculated:

$$k^* = \sqrt{\frac{A_2 e_1}{A_1 e_2}} = 3 \tag{21}$$

Consequently, referring to Eq. 6 and Eq. 3, the optimum order quantities are: $Q_1$= 316 $Q_2=3Q_1$=948 and the corresponding annual inventory costs are:

$$C_1^e = \frac{e_1 Q_1}{2} + \frac{A_1 d}{Q_1} = 189.74 \text{ €/year} \tag{22}$$

$$C_2^e = e_2 k \frac{Q_1}{2} + A_2 \frac{d}{kQ_1} = 189.74 \text{ €/year} \tag{23}$$

$$C_{TOT} = C_1^e + C_2^e = 379.48 \text{ €/year} \tag{24}$$

Finally, the average logistic lead time for the warehouses and for the entire supply chain is:

$$T_1 = \frac{Q_1}{2d} = \frac{316}{100} = 3.16 \text{ days} \tag{25}$$

$$T_2 = \frac{Q_2}{2d} = \frac{948}{100} = 9.48 \text{ days} \tag{26}$$

$$\text{Total Logistic Leadtime} = T_1 + T_2 = 3.16 + 9.48 = 12.64 \text{ days} \tag{27}$$

Once the average stocking periods have been calculated, the consumed shelf-life can be determined. In order to demonstrate the importance of a proper stock management policy in the context of SFSCs, the total cost of inventory management and the shelf-life consumed have been calculated for different values of the inventory levels. Additionally, to demonstrate the sensitivity of the solution to the warehousing conditions, two different configurations are considered. In the first configuration (SC1), the first warehouse is at 7 °C, while the second warehouse is at 10 °C. In the second configuration (SC2), the temperatures are 5 °C and 20 °C, respectively.

*Table 3: Results for supply chain configuration 1*

| $Q_1$ | $Q_2$ | $T_1$ (h) | $T_2$(h) | $T_{tot}$ | $C_1$ | $C_2$ | $C_{tot}$ | %$SL_1$ | %$SL_2$ |
|---|---|---|---|---|---|---|---|---|---|
| 316 | 948 | 75.84 | 227.52 | 303.36 | 189.74 | 189.74 | 379.48 | 29% | 116% | 145% |
| 200 | 600 | 48 | 144 | 192 | 210 | 210 | 420 | 18% | 73% | 92% |
| 150 | 450 | 36 | 108 | 144 | 245 | 245 | 490 | 14% | 55% | 69% |
| 100 | 300 | 24 | 72 | 96 | 330 | 330 | 660 | 9% | 37% | 46% |
| 50 | 150 | 12 | 36 | 48 | 615 | 615 | 1230 | 5% | 18% | 23% |

*Table 4: Results for supply chain configuration 2*

| $Q_1$ | $Q_2$ | $T_1$ (h) | $T_2$(h) | $T_{tot}$ | $C_1$ | $C_2$ | $C_{tot}$ | %$SL_1$ | %$SL_2$ |
|---|---|---|---|---|---|---|---|---|---|
| 316 | 948 | 75.84 | 227.52 | 303.36 | 189.74 | 189.74 | 379.48 | 24% | 268% | 291% |
| 200 | 600 | 48 | 144 | 192 | 210 | 210 | 420 | 15% | 169% | 184% |
| 150 | 450 | 36 | 108 | 144 | 245 | 245 | 490 | 11% | 127% | 138% |
| 100 | 300 | 24 | 72 | 96 | 330 | 330 | 660 | 7% | 85% | 92% |
| 50 | 150 | 12 | 36 | 48 | 615 | 615 | 1230 | 4% | 42% | 46% |

The results show that inventory levels drastically influence the performance of the supply chain since the shelf life varies between 40 % and 150 % in SC1 and between 50 % and 300 % in SC2. The corresponding inventory costs can vary between 400 €/year and 1300 €/year. The choice of the best compromise solution is therefore a critical issue for the supply chain management. Additionally, the set of non-dominated solutions which constitute the Pareto-Frontier is represented in Figure 2.

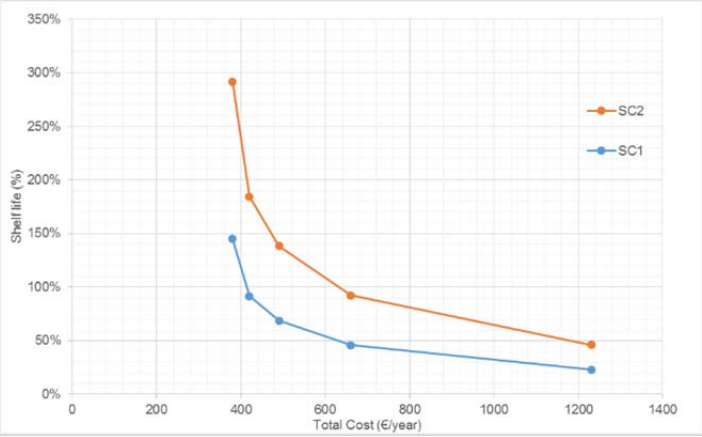


*Figure 2: Pareto Frontier for the supply chain in the two configurations considered.*

## 4. Conclusions

The research has focused on the management of SFSC, which, in order to be adequately profitable and sustainable, must be able to deliver superior quality products at affordable cost. The Inventory management policies are critically important in this context, since the absence of intermediaries typically hinders the possibility of adopting advanced packing solutions and quality preservation processes. The problem has been approached in a general Multi Objective methodology, taking into account the minimization of the inventory management costs and the maximization of the quality of products. The effectiveness of this approach has been demonstrated by means of a numerical application, which allowed to calculate the cost/quality tradeoff for different supply chain policies. A limitation in the approach proposed is related to the simplifying assumptions, which however are coherent with similar approaches in the literature. Further developments may also address the variability of demand and the effects of seasonality.

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