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CONTENTS

Session: Food Supply Chain Design & Management

Chair: **Johan Lundin** - Lund University, Sweden

Session: Models, Tools & Devices

Chair: **Alejandro F. Mac Cawley** - Georgia Institute of Technology, USA
Pontificia Universidad Católica de Chile, Chile

Session: Agri-Food Specialties & Produce Cycle Analysis

Chair: **Maria Elisabetta Guerzoni** *– University of Bologna, Italy*

Session: Open Challenges Within Agri-Food

Chair: **Marco Bortolini** *– University of Bologna, Italy*

In Absentia

Management and optimization of perishable food supply chain: an overview

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Abstract
In the case of fresh food products, such as fresh and fresh-cut produce, fruit or meat, the supply chain design cannot neglect the perishable nature and the variability of the products entering the chain. Motivated by these considerations, in the recent papers (Dabbene et al., 2007a,b) a general framework for modeling a fresh-food supply chain and an optimization methodology to improve the performances of the network while preserving the quality of the product have been presented. The proposed approach manages a trade-off between logistic cost and some indices measuring the quality of the food itself as perceived by the consumer, such as ripeness, microbial charge or internal temperature.

The supply chain and the behavior of the product during its delivery can be described using two specific parts. The first part should take into account event-driven dynamics (typically product handling) while the second one should be devoted to time-driven dynamics (the dynamics of some parameters characterizing the food product in the supply chain). The performance of the supply chain, expressed in terms of both logistic costs and final product quality, can then be enhanced by optimization algorithms that need a model, or other description tool, to assure the feasibility of the proposed optimal solutions.

In this paper, we present an overview on the latest developments of this topic, discussing different modeling, managing and optimization approaches, and providing exemplificative guidelines on the selection of specific quality indicators for fresh-food produce.

Keywords: *Food supply chain, optimization, management, quality*

1. Introduction

The managing and the optimization of the supply chains of perishable fresh-food, as e.g. vegetables, fruits, fish, meat and dairy, from the producer to the point of sale is, in general, a complex task. This is mainly due to the following reasons:

- food quality and safety are important factors that should be continuously monitored and taken into account in decision-making processes;
- environmental conditions and duration of any storage and/or delivering phase affect the quality (and potentially the safety) of the products, with consequences on their commercial value;
- the limited shelf life of products does not allow medium/long term inventory;

In addition, productions are typically subject to seasonality and their demand and price varies with time. For this reason, the supply chain management planning is not static, but has to be continuously updated.

A supply chain represents the sequence of activities performed in order to deliver the fresh product to a destination with the highest possible quality. Any activity performed in the chain has a potential impact on the product, due to the interaction between the surrounding environment (processing rooms, storage cells, trucks etc.) and the product itself. At the same time the product affects the environment itself (see e.g. ripening phenomena as transpiration, maturing heat releasing etc.). An efficient supply chain management has to guarantee product quality specifications throughout processing/delivering conditions (mainly temperature) and durations, determining the length of any storage and transportation phase together with the appropriate temperature for the different locations and equipment. The objective is to achieve a profitable trade-off between quality preservation and logistics costs.

Aim of this paper is to give an overview of the most diffused approaches to monitor the behaviour of the products, manage and optimize the performances of a supply chain operating on fresh-food. Some previous literature reviews were published on the topic of the application of planning models to the farm operation optimization (Glen, 1987; Lowe & Preckel, 2004) and crop-based supply chain management (Lucas & Chhajed, 2004; Ahumada & Villalobos, 2009). Recently, some papers (Dabbene et al., 2007; Rong et al., 2009) have tackled this problem by operating directly on both continuous dynamics, accounting for quality behaviour, and discrete event system, i.e. logistics.

The paper is structured as follows: Section 2 presents an overview of the available tools for monitoring, control and optimization of the supply chains. A specific subsection is devoted to the reengineering of traceability systems as extended information system for decision-support tasks. Section 3 briefly resumes the very recent approach proposed by (Dabbene et al., 2007) based on hybrid models and stochastic optimization methods.

2. Tools for fresh-food supply-chain management and optimization

Efficient fresh-food supply-chain management has to deal with different aspects at the same time, so to simultaneously satisfy distinct types of specifications and/or constraints. The first aspect concerns the shelf life of the product, both in terms of food quality and of food safety. To this extent, it is first necessary to find precise (and valuable) indices able to properly quantify product quality (see e.g. Watada & Qi ,1999; Piagentini et al., 2005, for the case of fresh cut produce) together with specific models for the description of the behaviour of such indices on the basis of environmental/processing conditions (Verdijck et al., 2002). The second point is related to the logistic and economic performances of the network. The joint control and optimization of these two subjects requires updated information from the process, that could be obtained from dedicated monitoring systems and/or from extended traceability system.

2.1 Cold chain monitoring and management

Ad-hoc monitoring systems are crucial for those products that, due to the absence of an inactivation step before delivering and - in most cases - consumption (see e.g. fresh cut produce, sushi, raw meat etc.), are subject to an increased risk of exposure to human pathogens. Raw products can become contaminated at any point of the supply chain. In the case of produce, for example, this occurrence may happen from the cultivation (because of contaminated manure, sewage or irrigation water), from the harvesting and the processing to the handling and distribution. Strict control of storage conditions (mainly temperature and humidity) can slow down the development of pathogens and/or spoilage bacteria, minimizing the risk of food-borne illness. Low temperatures typically help maintaining optimal product quality, since most part of physiological activities (e.g. respiration and transpiration) is reduced, and the growth rate of spoilage microorganism is partially inhibited.

In both cases, these phenomena can be associated to kinetics that depends on the time-temperature path of the product during storage and handling. Practical and cost-effective tools to individually monitor the temperature condition of chilled (or frozen) products throughout supply chain are for instance Time Temperature Integrators (or Indicators) – TTI (Giannakourou & Taoukis, 2002; Giannakourou & Taoukis, 2003). Given a specific product, if its shelf life (or any quality index) can modelled by reliable kinetics models, then TTI can be used not only to monitor the cold chain of distribution, but also as effective decision-support tool (Bobelyn et al., 2006 ; Giannakourou & Taoukis, 2002; Labuza & Fu, 1995). The availability of TTI allows moving from standard FIFO (First In First Out) warehouse management to more sophisticated and performing control algorithm as, for example, LSLFO (Least Shelf Life First Out) (Kouki et al., 2010).

Temperature monitoring can also be performed using data loggers (see e.g. Farquhar, 1982 ; Redies et al., 2009), wireless networks of sensors (Ruiz-Garcia et al., 2008) and RFID devices (Ngai & Riggins, 2008 ; Jedermann et al., 2009).

2.2 Traceability and safety issues

The base scope of traceability, i.e. the ability of registering and tracking parts, processes and materials used in production, by lot or serial numbers, can be extended to give to firms a tool for improving the management of their logistics, reducing handling costs, optimizing

inventories and minimizing errors related to the whole production and distribution. As a first benefit, a traceability system can constantly monitor the whole production, detecting if something goes wrong and determining at which stage and at which time instant the error has occurred. This knowledge can then be applied to improve the inventory management in the supply chain, leading to a more efficient use of the warehousing spaces, reducing inventory levels and errors (Alfaro & Ràbade, 2009).
In general, the role of a well-organized traceability system can be extended, using it as the information system that provides the necessary information about the process (as product and activities) to the decision-support system of the supply chain (Bevilacqua et al., 2009). In this case traceability information can be used, for example, to plan the production in order to minimize the amount of product to be recalled in the unfortunate case when a batch of product results unsafe or inadequate to the firm quality standards (Dabbene & Gay, 2011; Wang et al., 2010) or influence the logistics on the base of the expiring date of the products (East, 2011 ; Rong et al., 2009).

2.2 Supply chain optimization approaches

Perishable food have, by definition, a limited lifetime. For this reason, product behaviour dynamics, accounting for quality/safety, cannot be treated separated from logistics (Ahumada & Villalobos, 2009). In (Rong et al., 2009) an integrated approach for production and distribution planning of food distribution systems is developed, aimed at minimizing the degradation of food quality. In particular, the quality degradation of food products in storage (or transport) is modelled by an ordinary differential equation of the form

$$\frac{dy(t)}{dt} = ky^{\alpha}(t). \tag{1}$$

where the product quality $y(t)$ is assumed to be dependent on storage time t, storage temperature T, and various constants (e.g., activation energy, gas constant). Then, the authors develop a design approach based on integer linear programming, introducing an objective function aimed at minimizing a linear combination of production costs, cooling costs and transportation costs, storage costs and waste disposal costs. Constraints are introduced so to guarantee inventory balances, retailer demand and quality requirements.

3. An hybrid model based approach

In the approach developed in (Dabbene et al., 2007), the food supply-chain is modeled as a network formed by *n* successive nodes, in which *m* batches of product are processed in a sequential way. The products enter the first node at different instants in time, and are processed sequentially from node 1 to node *n*. Both cases of nodes with finite and infinite process capacity are addressed in the paper. In the first case, every node can process simultaneously any number of batches, and a batch can immediately leave a node and enter the next one as soon as it has been processed. In the second case any new batch has to wait in the preceding node until another batch leaves the node it wants to enter.
In (Dabbene et al., 2007), as a representative of the product quality (e.g. internal temperature, firmness, ripeness, microbial charge, etc.), to the i^{th} batch it is associated a

quality attribute $y_i(t)$. These attributes vary in time according to a differential equation which depends on the operating conditions of the network and on the different j^{th} node where the batch is being processed at time t, similarly as what is assumed in (1).
To describe the operating conditions, the supply-chain is characterized by a vector of parameters $\theta \in \mathrm{R}^q$. In the paper, a clear distinction is made between physical parameters, which represent some physical properties of the nodes in the network (such as power of a refrigeration cell or air composition in controlled atmosphere environments) and the logistic parameters of the chain, describing the way the various products move into the chain. To this end, the vector $\theta \in \mathrm{R}^q$ is partitioned in the following way

$$\theta = \begin{bmatrix} \omega \\ \mathrm{T} \end{bmatrix}, \quad \omega \in \mathrm{R}^{q_\omega}, \quad \mathrm{T} \in \mathrm{R}^{nm}, \quad q = q_\omega + nm. \tag{2}$$

where ω is the physical parameters vector and T is the logistic parameters vector, which is given by the vector of time intervals $\mathrm{T} = [\mathrm{T}_1^1 \ \cdots \ \mathrm{T}_1^n \ \cdots \ \mathrm{T}_i^j \ \cdots \ \mathrm{T}_m^1 \ \cdots \ \mathrm{T}_m^n]^T$, where T_i^j represents the time spent by the batch i in node j.
Moreover, some of the parameters of the supply chain can be freely chosen by the network operator, while others are imposed by the chain itself. For this reason, in (Dabbene et al., 2007) a clear distinction is made between controllable parameters θ_C and uncontrollable parameters θ_{NC}. An important point that should be also considered is that the uncontrollable parameters are usually not perfectly known, but may vary according to a known distribution. This is formalized assuming

$$\theta_{NC} = \overline{\theta}_{NC} + \nu \tag{3}$$

where $\overline{\theta}_{NC}$ represents the (known) nominal value of the uncontrollable parameters, while ν is a random vector with zero mean and known probability density.

3.1 Discrete-event dynamics

The dynamics of the discrete-event system are described introducing the event-occurrence times τ_i^j, that represent the time instants in which the i^{th} batch leaves the j^{th} node. These times are gathered in vectors $i = 1, \ldots, m$ relative to the switching times of the i^{th} batch, and then into the composite vector $\tau = [\tau_1^T \ \tau_2^T \ \ldots \ \tau_m^T]^T$. Then, the discrete-event dynamics is formally stated by means of the following recursion, for $i = 1, \ldots, m$ and $j = 1, \ldots, n$

$$\begin{aligned} \tau_i^j &= \tau_i^{j-1} + \mathrm{T}_i^j \\ \tau_i^0 &= a_i \end{aligned} \tag{4}$$

where a_i denotes the arrival time of the i^{th} batch in the first node. Equation (4) is valid in the case of infinite capacity, the formula complicates in the case of finite capacity, and the term T_i^j is replaced by a logistic function $s_i^j(\mathrm{T})$, see Section 2.3.2 of (Dabbene et al.) for further discussions. Equation (4) is instrumental to the introduction of the two main parameters describing the logistic behavior of the net: the position $p_i(t)$ as the node in which the i^{th} batch is at time t, and the total number $m^j(t)$ of batches present in the j^{th} node at time t. Indeed, The evolution of the quantities $p_i(t)$ and $m^j(t)$ can be represented by means of the following differential equations, that fully describe the dynamic behavior of the network, providing at each time instant the number of the batches present in each node

$$\begin{aligned} \dot{p}_i(t) &= \sum_{j=0}^{n-1}\delta\left(t-\tau_i^j\right) & \dot{m}^j(t) &= \sum_{i=1}^{m}\delta\left(t-\tau_i^{j-1}\right)-\sum_{h=1}^{m}\delta\left(t-\tau_h^j\right) \\ p_i(0) &= 0 & m^j(0) &= 0. \end{aligned} \tag{5}$$

with $\delta()$ being the Dirac delta function.

3.2 Time-driven dynamics

Denote by $y(t)=[y_1(t)\;\; y_2(t)\;\; \ldots\;\; y_m(t)]^T$ the vector of attributes. As already mentioned, the attribute $y_i(t)$ relative to the i^{th} batch evolves in time according to a (usually nonlinear) differential equation. Consequently, $y(t)$ can be seen as the output of a system of differential equations of the type

$$\begin{cases} \dot{x}(t) &= f\left(x(t),\tau,\theta\right) \\ x(0) &= \varsigma_0 \end{cases} \qquad y(t) = g\left(x(t),\tau,\theta\right) \tag{6}$$

$x(t)$ being a vector collecting the state variables of the different products and the states variables that describe the interaction with the surrounding environment. Notice that equations (5) and (6) define in all aspects a hybrid system, where the time-driven dynamics of (5) depend on the vector of events τ, whose dynamics are expressed by the recursion (4). From a different perspective, (6) may be seen as a switching system, whose switching times are regulated by the recursion (4).

3.3 Optimization strategies

The model described in the previous subsection discriminates the possible behaviors that the system can exhibit acting on the controllable parameters θ_C. The role of the network manager consists of choosing the best operating conditions considering different aspects as operating expenses, product and process conditions and final product quality. In particular, (Dabbene et al. 2007) introduces a performance function J constituted by the sum of three terms

$$J(\theta)=J(\theta_C,\theta_{NC})=\gamma_C\, C(\theta_C,\theta_{NC})+\gamma_P\, P(\theta_C,\theta_{NC})+\gamma_D\, D(\theta_C,\theta_{NC}). \tag{7}$$

The first term takes into account the cost related to the particular operating condition θ_C (e.g. power consumption, transport costs, etc.), while the second term accounts for the achievement of a target performance, measured in terms of product attributes. These could be expressed in different ways depending on the specific product. Requirements as t*rajectory tracking* or *final value objective* can be imposed by appropriately setting $P(\theta_C,\theta_{NC})$ in equation (7). The third term in (7) is related to the logistic aspects of the chain and measures the difference between the actual final time τ_i^n and the desired due-date d_i by means of earliness and tardiness costs.

It is to be remarked that the optimization algorithm should be able to make decisions in an uncertain environment, where the uncontrollable parameters θ_{NC} vary according to (3). A frequently used requirement in this context is to optimize an "average" instance of the problem: in other words, one asks to minimize the expected value of the objective function taken with respect to the random uncertain parameters θ_{NC} (see for instance Kushner & Yin, 1997). That is, one faces the following stochastic optimization problem

$$\min_{\theta_C \in \Theta_C} \mathrm{E}(\theta_C), \qquad \mathrm{E}(\theta_C) \triangleq \mathrm{E}_{\theta_{NC}} \left\{ J(\theta_C, \theta_{NC}) \right\} \tag{8}$$

where $E()$ represents the expectation operator. In (Dabbene et al., 2007), following a similar philosophy to (Tempo et al. 2004), the expectation in (8) is approximated by introducing its empirical version. To this end, N independent identically distributed (iid) random samples $\nu^{(1)}, \nu^{(2)}, \ldots, \nu^{(N)}$ are drawn and the so-called *empirical mean* is constructed

$$\hat{\mathrm{E}}_N(\theta_C) \triangleq \frac{1}{N} \sum_{i=1}^{N} J\left(\theta_C, \overline{\theta}_{NC} + \nu^{(i)}\right). \tag{9}$$

The methodology proposed (Dabbene al. 2007a) for the approximate solution of problem (8) is a modification of a classical gradient descent method, in which the gradient of the cost function is not computed exactly, but is approximated using only few function evaluations. In particular, the approach taken here follows the one proposed by Spall (Spall, 2003) and tackles the problem via a Simultaneous-Perturbations Stochastic Approximation (SPSA) approach. This method approximates the gradient at each iteration using only two evaluations of the cost function. A pseudo-code of the modified SPSA algorithm for the approximate solution of the optimization problem (8) is given next.

Modified SPSA algorithm

1. Select initial point $\theta(0)$ and maximum number of steps K
2. $k = 0$
3. While $k \le K$
   a. $k = k + 1$
   b. Generate a sample $\nu^{(k)}$ and compute $\theta_{NC}(k) = \overline{\theta}_{NC} + \nu^{(k)}$
   c. Generate a vector $\eta(k)$ according to a Bernoulli process
   d. Build $\hat{E}_{\pm}(k) = J\left(\theta_C(k) \pm c(k)\eta(k), \theta_{NC}\right)$
   e. Construct the point $\theta_C(k+1) = \theta_C(k) - w(k)\left[\eta(k)^{-1}\right] \dfrac{\hat{E}_+(k) - \hat{E}_-(k)}{2c(k)}$
4. end while
5. return (approximate) optimal value $\theta_C^K = \theta_C(K)$

To be implemented, the algorithm needs the determination of some parameters, namely the gain sequences $w(k)$ and $c(k)$. To this regard, precise guidelines for their choice are given in (Spall, 2003). In (Dabbene et al., 2007) it is also discussed the case when the controllable parameters cannot be chosen freely, but have to belong to a feasible set $\theta_C \in \Theta_C$. To this end, a projection operator is introduced and the recursion modified as follows

$$\theta_C(k+1) = \Pi_\theta \left[\theta_C(k) - w(k)\left[\eta^{-1}(k)\right] \frac{\hat{E}_+(k) - \hat{E}_-(k)}{2c(k)} \right]. \tag{10}$$

The construction of the projection operator $\prod_{\theta}$ for building a feasible solution is extensively discussed in (Dabbene et al., 2007).

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Perishable Items Allocation in LIFO Storage Systems served by Automated Guided Vehicles

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Abstract

The paper describes a study of designing rack storage systems managed according to a Last-In Fist-Out (LIFO) policy. The system is supposed to house a number of cyclic items (i.e. characterized by batch production and continuous deliveries policies). This kind of behaviour is common for high-consumption products in the food industry, such as pasta and bakery products.

The aim of the study is to define a static design solution by assigning each item to a number of LIFO racks so that the overall system performance results are satisfactory. The dynamic behaviour is kept under control by adopting automated material handling devices such as Automated Guided Vehicles (AGVs).

This paper is an extension of a previous work by Ferrara et al. (2011), here named the single-allocation procedure, by allowing each item to be assigned to two different rack typologies (double-allocation solution).

The convenience of the double-allocation solution in comparison with the single-allocation one is proven by a significant case study from the food industry.

Keywords: *rack storage system, storage efficiency, food industry*

1. Introduction

Racks accessed in a Last-In First-Out (LIFO) manner are one of the most space saving and, as a consequence, economically convenient types of rack storage. In other words, LIFO racks ensure high values for space utilization (see, for example surveys such as Van Den Berg, 1999, and Gua et al. 2010). Let us compare LIFO racks and FIFO (First-In-Fist-Out) racks: while FIFO racks require two access-points for each independent lane, when adopted for storing lanes of similar items (one for put-away and one for retrieval), LIFO racks only require a single access-point for both the operations. On the other hand, FIFO racks ensure that products are rotated properly while LIFO racks are needed for replenishing/emptying cycles in order to allow all the stock-keeping units (SKUs), which are not independently accessible, to be retrieved within a reasonable period of time. This requirement is particularly critical in the case of perishable products, such as food products. A special type of rack storage that avoids the disadvantages of LIFO racks but is considerably more costly, is single-deep selective rack storage, where each pallet location is independently accessible. See Bartholdi and Hackman (2006) for a review of the main advantages and disadvantages of the most widespread types of rack storage.

Ferrara et al. (2011) developed an approach for dimensioning LIFO storage systems that integrates space utilization with a new performance measure named storage efficiency. The authors define storage efficiency as a performance measure related to pallet accessibility and computed by distinguishing between occupied pallet locations, i.e. locations holding SKUs, and constrained locations (i.e. locations that are not occupied but allowed to accept only a single specific type of item). Only pallets containing items partially occupying the lane can be accepted. An example of a drive-in storage system is shown in Figure 1.

Fig. 1. Example of a drive-in storage system.

The storage efficiency is 1 in the case of selective racks (no location is constrained) and decreases as the number of constrained locations in the system arises. Let us consider one of the most commonly used types of LIFO racks, i.e. “drive-in” racks. Since in a drive-in rack all the levels of a certain lane must be devoted to the same item type, the storage efficiency can rarely be 1. On the other hand, the higher the rack capacity, the higher the space utilization results.

The allocation procedure by Ferrara et al. (2011) is such that, given a set of items and a set of LIFO rack typologies (e.g. drive-in racks with different capacities) each item is assigned to a certain rack typology so that the overall system performance is satisfactory in terms of both storage efficiency and space utilization. This design solution is static. The authors addressed the dynamic behaviour of the system by assuming that Automated Guided Vehicles (AGVs) are installed for pallet handling (see Vis 2006 for a review of AGV systems). Specifically, the daily handling missions are divided into two categories, i.e. “operational” missions and “transfer” missions. Missions in the latter category can be executed in order to recover the system from behavioural deviations.

This paper extends the methodology discussed in Ferrara et al. (2011). The allocation procedure by Ferrara et al. (2011) assumes that each item can be assigned to a single rack typology in the static design (it can be transferred to other rack typologies only for adjusting certain system parameters at runtime). We refer to this allocation procedure as the single-allocation procedure. In this paper such a hypothesis is (partially) relaxed by assuming that each item can also be assigned to two different rack typologies in the static design. We refer to the new allocation solution as the double-allocation solution. By applying this approach to a relevant case study from the food industry, we demonstrate that the double-allocation solution performs better that the single-allocation one. Moreover, since the storage efficiency in the static solution is higher, less transfer missions are required.

2. Methodology

2.1 Notation and assumptions

We consider LIFO racks of different typologies $x=1,\dots,X$, where each typology is identified by its own storage capacity $C(x)$. The system houses a number of items $j=1,\dots,J$ and we assume that $C_j(x)$ is the storage capacity constrained by item j on the rack of typology x. The reader may refer to Ferrara et al. (2011) for an item classification technique based on different production/delivery patterns. The focus of this study is on items belonging to the Cyclic Family (i.e. on items characterized by batch production and continuous delivery policies). The justification is that (i) in many industries, such as the food industry, the Cyclic Family is one of the most common item families, and (ii) the computation of the storage efficiency for cyclic items is not trivial. Thus, each item j is characterized by the following parameters: cycle time T_{Cj}, production time T_{Pj}, production rate p_j, delivery rate r_j, safety stock sj and maximum inventory I_j^M during T_{Cj}.

2.1 Space utilization and Storage efficiency

Space utilization is a widely known performance measure related to the specific typology of rack storage and type of forklift trucks (to which different aisle widths are associated) adopted in the system. Nevertheless, it does not take into consideration how efficiently the rack is occupied. Let us denote with $u(x)$ the space utilization of rack typology x (see Barthold and Hackman 2006 for details).
On the contrary, as explained in Ferrara et al. (2011), storage efficiency expresses how efficiently a specific item type occupies the lanes of a certain rack typology. Thus, the storage efficiency of item j in rack typology x is as follows:

$$e_j(x) = \frac{S_j^o(x)}{S_j^o(x)+S_j^c(x)} = \frac{S_j^o(x)}{S_j^t(x)}, \tag{1}$$

where $S_j^o(x)$ and $S_j^c(x)$ represent the number of occupied locations and the number of constrained locations if item j if assigned to rack typology x. $S_j^t(x)$ is the total number of pallet locations of typology x devoted to item j.

2.2 Static Design: Single-Allocation and Double-Allocation

Single-allocation

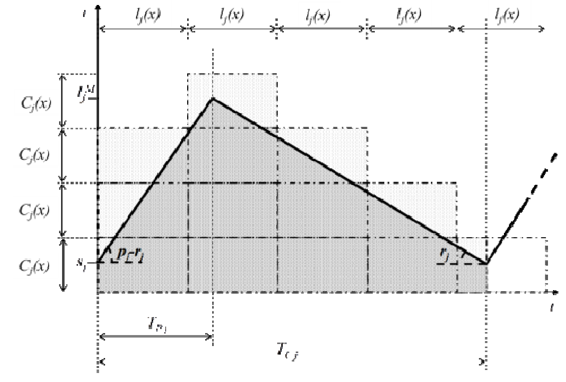

Fig. 2. Item cycle – single-allocation procedure.

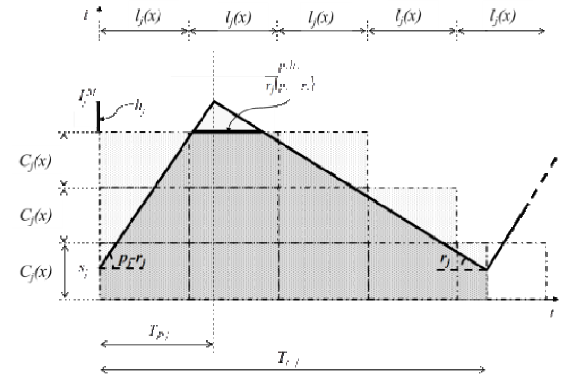

Fig. 3. Item cycle – double-allocation procedure.

The single-allocation procedure by Ferrara et al. (2011) assumes that each item is assigned to a single rack typology. Figure 2 depicts the typical inventory cycle of item j (l_j) assigned to rack typology x, where $l_j(x) = \frac{C_j(x)}{r_j}$ and the remaining parameters are discussed in Section 2.1. $S_j^o(x)$ is the total inventory in T_{Cj} (grey area), and $S_j^t(x) = S_j^o(x) + S_j^c(x)$ is the total number of pallet locations assigned to that item in T_{Cj} (dotted area). Note that $e_j(x)$ cannot be equal to 1 owing to the increasing/decreasing trends characterizing cyclic items.

Given the storage efficiency $e_j(x)$ of each couple (j,x) and the space utilization $u(x)$ of each rack typology x, the single-allocation procedure assigns each item to a suitable rack typology by evaluating the product $e_j(x) \cdot u(x)$. Specifically, the output of the single-allocation procedure is, for each item j=1,…,J, the rack typology x* to which j is assigned, the storage efficiency $e_j(x^*)$ and the number of lanes $\overline{N}_j(x^*)$ necessary for storing item j in that rack typology.

Double-Allocation

By analyzing Figure 2 it can be noted that the storage efficiency of item *j* when assigned to rack typology *x* would increase if all the lanes were fully occupied at the end of the production time T_{Pj}. Thus, in Figure 3 the peak of the inventory curve is cut so that at most $\left\lfloor \frac{I_j^M}{C_j(x)} \right\rfloor C_j(x)$ SKUs are stored in rack typology *x* and the remaining $h_j = I_j^M - \left\lfloor \frac{I_j^M}{C_j(x)} \right\rfloor C_j(x)$ SKUs are stored in rack typology *x'*<*x*.

Let us denote with $e_j^1(x)$ the new storage efficiency of item *j* when assigned to rack typology *x*. The numerator of $e_j^1(x)$, $S_j^1(x)$, differs from the numerator of *e*(*x*), $S_j^o(x)$, by the light-grey triangle in Figure 3. By comparing Figure 2 and Figure 3 we note that the denominator of $e_j^1(x)$, $S_j^{1t}(x)$, is equal to $S_j^t(x)$ minus the area $l_j(x) \cdot C_j(x)$ Thus,

$$e_j^1(x) = \frac{\left(T_{C\,j}\, s_j + \frac{T_{C\,j}\left(I_j^M - s_j\right)}{2} \right) - \frac{p_j h_j^2}{2r_j\left(p_j - r_j\right)}}{e_j(x)\left[T_{C\,j}\, s_j + \frac{T_{C\,j}\left(I_j^M - s_j\right)}{2} \right] - l_j(x)\, C_j(x)} . \tag{2}$$

The average number of lanes of typology *x* allocated to item *j* becomes:

$$\overline{N}_j^1(x) = \frac{S_j^{1t}(x)}{C_j(x) \cdot T_{C\,j}} . \tag{3}$$

The inventory peak of item *j* is stored in a single lane of a different rack typology *x'* for a period $\frac{p_j h_j}{r_j\left(p_j - r_j\right)}$ in $T_{C\,j}$. So:

$$e_j^2(x') = \frac{h_j}{2 \cdot C_j(x')} . \tag{4}$$

$$\overline{N}_j^2(x') = \frac{p_j \cdot h_j}{r_j \cdot \left(p_j - r_j\right) \cdot T_{C\,j}} . \tag{5}$$

Thus, the storage efficiency of item *j* in double-allocation in rack typology *x* and *x'* is:

$$e_j(x,x') = \frac{e_j^1(x) S_j^{1t}(x) r_j\left(p_j - r_j\right) + e_j^2(x')\, p_j\, h_j\, C_j(x')}{S_j^{1t}(x) r_j\left(p_j - r_j\right) + p_j\, h_j\, C_j(x')} . \tag{6}$$

2.3 Dynamic behaviour: AGV transfer missions

A fleet of AGVs ensure 24/7 availability. Thus, during low workload periods some of the AGVs could remain idle and can be employed for re-organizing the system. AGVs missions can be divided into "operational missions" and "transfer missions". Operational missions are executed for transporting SKUs from the production/input area into the storage area and from the storage area to the shipping/output area. Transfer missions are performed within the storage area when some SKUs are transferred from a lane of a certain rack typology to one or more lanes of a different rack typology. The aim of executing transfer missions is to allow the effective performance to remain stable and closed to its static value. Given the static design solution (Section 2.2) and time-series data on actual inventory levels, it is possible to simulate the necessary transfer missions in order to keep the constrained locations to a bare minimum. As a consequence, the AGV system must be correctly dimensioned considering all the required missions of both types.

4. Case study

The present case study is the result of a storage design project developed in collaboration with a food company located in the Emilia Romagna region (Italy). Specifically, the company is a leader in the pasta business worldwide, in the pasta sauces business in continental Europe, in the bakery products business in Italy. Since pasta, sauces and bakery items are produced according to a make-to-stock policy with a fairly constant aggregate demand, these products are characterized as belonging to the Cyclic Family. In this case study we focus on 96 cyclic items. The storage system, which is served by AGVs, can be divided into two zones: an area dedicated to drive-in racks and another to selective racks. Different typologies of drive-in racks are taken into consideration. Since the number of levels of each drive-in lane is assumed to be constant, different typologies are simply characterized by different lane lengths (3-pallet deep lanes, 4-pallet deep lanes and so on).
As regards the static design, Table 1 shows that the double-allocation solution performs better than the single-allocation solution. Specifically, the double-allocation solution requires a lower number of drive-in lanes and pallet locations that, moreover, can be employed with a higher storage efficiency (the comparison is done considering the same set of items and inventory levels). As expected, it is the number of long lanes to be reduced.

	Single-Allocation		Double-Allocation	
Drive-in Typologies	**# of lanes**	**# of pallet locations**	**# of lanes**	**# of pallet locations**
3-pallet deep	11	164	15	222
4-pallet deep	128	2 560	131	2 611
5-pallet deep	133	3 220	132	3 189
6-pallet deep	157	4 699	154	4 617
7-pallet deep	379	12 763	370	12 473
8-pallet deep	253	9 384	249	9 230
9-pallet deep	0	0	1	36
10-pallet deep	2	96	1	50
Total	**1 062**	**32 886**	**1 052**	**32 429**
Storage Efficiency	**87.60%**		**88.64%**	

Table 1. Single-allocation solution vs. Double-allocation solution.

	Single-Allocation		Double-Allocation		
Item	**x**	**e(x)**	**x**	**x'**	**e(x,x')**
Item_1	5	**82%**	5	3	**86%**
Item_2	7	**83%**	7	5	**87%**
Item_3	8	**77%**	8	3	**81%**

Table 2. Comparison results for three item types.

For the sake of example, Table 2 presents the results obtained for three items. Let us consider item_1: in the single-allocation solution item_1 is assigned to 5-pallet deep lanes with a storage efficiency of 82%, in the double-allocation solution item_1 can be stored in a 3-pallet deep lane also and the overall storage efficiency increases to 86%.
Finally, it is necessary to estimate the number of AGV transfer missions by simulation. In this case it is assumed that any SKU relocated in the storage area is transferred from the LIFO rack it was assigned in the static design to a selective rack. Simulation results show that the single-allocation solution requires, on average, 4 daily transfer missions per item, whilst if the double-allocation solution is adopted this number decreases to 2 transfer missions per item on a daily average basis.

5. Conclusions

The study focuses on the design of LIFO storage systems. Specifically, the procedure for allocating items to different rack typologies presented in Ferrara et al (2011), i.e. the single-allocation procedure, is extended. A case study from the food industry shows that the double-allocation solution performs better than the single-allocation one.

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Manufacturing Execution Systems in the Food Industry: Implementation and Performance

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Abstract
Manufacturing Execution Systems (MES) are production and tracking systems used to analyze and report manufacturing processes in a wide range of industrial contexts. In the food industry, this tracking and reporting is especially important due to the industry's focus on product traceability and safety. Currently, MES systems are also implemented to improve manufacturing performances with a positive impact on company financial objectives. Previous academic studies and white papers are generally dedicated to discuss MES benefits or to assist manufacturers and associated support organizations in evaluating and selecting the best MES software. However, MES system implementation brings with it many critical aspects that directly affect in practice its real potential and operational reliability, determining the real length of the investment pay back period. Among others, the difficulty in integrating MES with other software, the large investment initially required, and the need of large programming time. This work intends to develop a conceptual framework that can be applied to analyze and evaluate MES investment alternatives and forecasting future MES performances according to the return of the investment. Four critical decision variables are identified and discussed in the framework by a qualitative approach, which is grounded in the literature and supplemented by practical experiences. Finally, a milk supply chain case study is presented and discussed to illustrate the decision support functionalities of the conceptual framework proposed.

Keywords: *Manufacturing Execution System, Theoretical framework, Decision support system, food supply chain, milk supply chain.*

1. Introduction

Manufacturing Execution Systems (MES) have evolved in the last decades as a tool to support production management in terms of transparency, responsiveness, and cost efficiency (Kletti, 2007), thereby meeting the demands of today's competitive global landscape. MES software solutions integrate the enterprise-wide ERP management area with the detailed (automated) production operations (e.g. supported by CAD, PDM, PLM etc.), by linking the two levels with a real time bidirectional information channel.

In the food industry, significant investments are currently made with regards to MESs, to reverse the increasing disconnection between the plant floor and the enterprise systems (Food Manufacture, 2008). MESs are often limited to single facilities, even if they might be part of a chain or network. In fact, in a supply chain perspective, the application of MES will change from risk management tools to a value added system, thanks to the availability of real-time data and supplementary information necessary to develop efficient and sustainable food supply chains.

The paper discusses the implementation of MES in Food Supply Chains and how MES systems can help the food industry meet the challenges of quality, safety and sustainability. These three challenges were recently stated by Akkerman et al. (2010) as the main challenges in today's food industry. For production and supply chain managers, a MES system implementation brings with it many critical aspects that directly affect in practice its real effectiveness and operational reliability, determining the real length of the investment payback. Therefore, the authors intend to support the decision making by offering a new conceptual framework that can be applied to analyze and evaluate the MES investment feasibility and forecasting future MES performances before implementation.

The paper is organized as follows: section 2 discusses the status of MES usage in the food industry, section 3 presents the new conceptual framework developed through a qualitative approach, and section 4 subsequently shows its application in a milk supply chain. Finally, we conclude our paper and discuss further research opportunities.

2. State of the art: MES in the food industry

Nowadays, the food supply chain is composed by a wide set of interactions and mutual interdependences among the different actors, such as ingredient vendors, different food producers, food processors, distributors, wholesalers and retailers (Grocery Manufacturing Association, 2008).

The food supply chain is different from any other supply chain because products can change continuously their quality and they are subject to limited shelf lives, controlled temperature, interactions with other products or environmental elements and low profit margins (Akkerman et al., 2010). Different product quality challenges have to be faced depending on the different stage level on food industry, such as foreign materials control for ingredients vendors, production parameters control for food manufacturers and processors, or temperature and humidity control for final distributors and retailers. Other issues are related to the entire supply chain like food tracking and tracing, control of non conforming items, successive recalls management and crisis management.

Maintaining the quality of a finished product by monitoring incoming ingredients and regulating the production process are key to the success of a manufacturing company. Consequently, in food supply chains, three important food-industry-specific challenges should be considered: (i) food safety, (ii) food quality, and (iii) sustainability (Akkerman et al., 2010).

Food safety includes a number of procedures to be followed to avoid potentially severe health hazards. International and local legislation has been enforced on this issue to avoid the consumption of contaminated food, with various systems and standards, like HACCP (Hazard analysis Critical Control Point) system and the ISO 22000 standards (European Parliament and Council, 2002; ISO (2005) ISO 22000:2005).

Food quality, which is often defined as the way the product is perceived by the final customer (Grunert, 2005), could be guaranteed at low costs by technological innovations, like time-temperature sensors, which increase efficiency and reduce cost both in the production and distribution process (Trienekens & Zuurbier, 2008).
Not less important, these main aspects should all be achieved in an efficient and sustainable way, with an optimal utilization of available economical, social and environmental resources (Akkerman et al, 2010).
Under these circumstances, the food supply chain is urgently asking for a better understanding of the tools available to reach the challenges described above, and in particular how and when a MES system can represent a successful solution.
Many scientific contributions on food supply chain are currently developed by academics, mainly agriculturalist, logisticians and packaging researchers, while legislations and tools are introduced by Governments and International Standards Associations.
On the other hand, a number of white papers (published mainly by Operation Managers and Software Designers) are available on the MES topic (i.e. MESA 1997a-b-c), discussing MES characteristics, advantages/risks and case studies applications.
The link between food industries literature and MES system implementation is not sufficiently explored and stressed in the academic literature, and only a large set of disaggregated works are available, without coupling the food sector challenges with MES system advantages and specifications. However, MES and Food Supply Chain are intimately related in practice. MES software solutions are the principal tool -coupled with ADC (Automatic Data Capturing) devices- through which the food industries can be able to achieve- simultaneously- the three challenges introduced before.
In other words, we can say that by nature and definition, a well-designed MES should be oriented towards safety, quality and sustainability, in order to completely express its real potentiality (Hwang, 2006; Saenz de Ugarte, 2009; Rockwell Automation, 2009; Hakanson, 2010; Mahalik and Nambiar, 2010). MESs record in real time relevant information automatically, supporting the quality control of work in process (WIP), statistics analysis, production scheduling and the maintenance of equipment and instruments (Hwang, 2006). Consequently recall and risk management systems will become more efficient (Hwang, 2006); since the implementation of a traceability system by itself cannot address the issue of product recall risks effectively (Rong and Grunow, 2010).
Moreover, MESs offer a large chance to solve the lack of models available for the assurance of food safety and quality, since it acts as a catalyst of the whole tracking system (Saenz de Ugarte et al, 2009).
Control systems coupled with MESs increase the amount of information available to manufacturers and distributors, thus data management will become a more important part of ensuring that the sustainability challenge is met and food regulatory compliance are driven (Rockwell Automation, 2009). By using a MES for effective order scheduling, manufacturers can use the total equipment available in the most efficient way, increasing productivity and reducing energy waste and production losses (Sarkis, 2001; Gunther, 2007). Thus, MES systems provide a ready-made fit for achieving a broad array of sustainability goals (Rockwell Automation, 2009, MESA 2000).
Anyway, from the survey of literature, it is clear that researchers on MESs have mainly focused on their successful aspects and there is need for a more critical approach to the

industrial environment analysis while understanding real MES implementation scopes and criticalities.
A recent literature review on MES (Saenz de Ugarte et al, 2009) highlights and summarizes the main limits and opportunities for MES researches and applications.
Among others, the difficulty in integrating MES with other information systems (ERP, WMS, etc.), the large investment initially required, and the need of large programming time are the main difficulties for the implementation (Saenz de Ugarte et al, 2009; Koch, 2001).
Even today, justifying the implementation of MES to improve manufacturing and financial performance is very difficult for many practitioners.
MESs bring, in fact, intangible benefits and relevant costs and risks, and a comprehensive and easy to use systematic assessment is necessary to make this critical investment decision (Saenz de Ugarte et al, 2009).
In the next paragraph we introduce a new qualitative conceptual framework to support both the initial analysis of the practical environment in which MES should operates, both practitioners decision making.

3. Conceptual Framework

Here we introduce a new methodological framework, properly grounded in literature on MES and food supply chain, which is helpful to guide managers in the decision of invest and implement a MES system.
We need to consider, in fact, the timing of the investment and the working environment in which the MES system will work on to completely understand if the MES system implementation is recommended and how it should be planned to minimize the failure risk.
The authors are strongly convinced that a common mistake is present: assuming that a full MES system implementation is always the best approach, without engaging all the necessary stakeholders and not understanding their specific problems and priorities.
Four main specific factors directly influence a MES system implementation in practice (Valckenaers et al, 1998; Blanc et al., 2008 and Saenz de Ugarte et al, 2009):

1) PROCESSES: if the current production/distribution processes consistently apply alternative cycles (task execution alternatives) to face with variability and uncertainty, or incur in frequent unpredictable or disturbing events (appearing in the shop floor), we will encounter problems during the MES system working and we will ask it a great flexibility level. Process reconfigurability and evolvability lead to drastically increase the complexity of the re(design) of MES (Blanc et al, 2008).
Moreover, when MES are required to be connected with more different equipment, the amount of information increases tremendously as the degree of increased complexity on the shop floor. The more a MES want to be connected to the real shop floor environment, more it needs to process data and the less it can be closest to the notion of real-time processing (Saenz de Ugarte et al, 2009).

2) PRODUCTS: when highly customized products are needed and new products are developed to meet customer preferences, many variations and changes in product catalogue are necessary, for instance using new cycles and row materials, unprecedented technology, untested interfaces. Thus, the MES system specifications become unclear, asking MES for a

high flexibility level and the implementation and programming costs become considerable (Simao et al., 2006).

3) ORDERS: If customer demand is highly dynamic (i.e. high uncertainty and variability in order data, unpredicted changes in product specifications, parts of a typical order could be simultaneously made in different plants, etc.), orders are difficult to predict in size and time and changes in order prioritization are ways often used for ensuring the best possible delivery. In such a context, a MES can ensure that the information is available in "real-time" but it cannot ensure that it is accurate and meaningful (Jones et al, 2002). Structurally highly flexible MES systems are thus required and a Multi-Agent System approach need to be implemented (Blanc et al, 2008).

4) RESOURCES: Whenever there is low automation level, the variable nature of human resources and their resistance to changes level increase the risk for MES system failure. Even if automating production processes is one of the major objective of the food industry, many of the processing industries still employ a large number of temporary workers in response of the seasonality of the market and of low profit margins. The presence of un-skilled low-wage workers and high turnover, strongly limits the successful implementation and reliability of a MES solution (Mahalik et al, 2010).

Figure 1 depicts the framework by the use of a radar diagram, in which the four different layers are combined together in order to evaluate specific situations.
An additional factor affecting MES implementation also has to be considered: the PROFIT MARGIN linked to products (Mahalik et al, 2010). It has a direct impact on the size of the grey areas: more high are the product profit margins and more extend is the size of the grey areas.
We can find difference in profit margins both between different actors of the same supply chain and both between different supply chains and different industrial sectors.
If, when we assess our production system factors we see that the implementation environment has characteristics close to the inside of the chart depicted in Fig. 1 then a MES system investment is suitable and strongly recommended.
If we cross (even only with one vertex) the intermediate portion of the radar diagram, a MES system implementation is feasible and recommended, but it requires a step by step approach, applied through a MES modular structure. In this case the pay back period of the investment is normally longer then the previous one.
If however it scores further out, around the plan-driven periphery then perhaps MES system implementation is critical and present limitations.
A particular effort in the MES personalisation and programming activities, also with human resource training and controlling is surely necessary.
Investing in these last key aspects will probably bring the company to a successful final result, but only after a large investment -in time and resources- with a consequent long payback period (Mahalik et al, 2010).
In such circumstances a systematic MES system implementation to the whole manufacturing plant could –sometimes- pay back anymore.

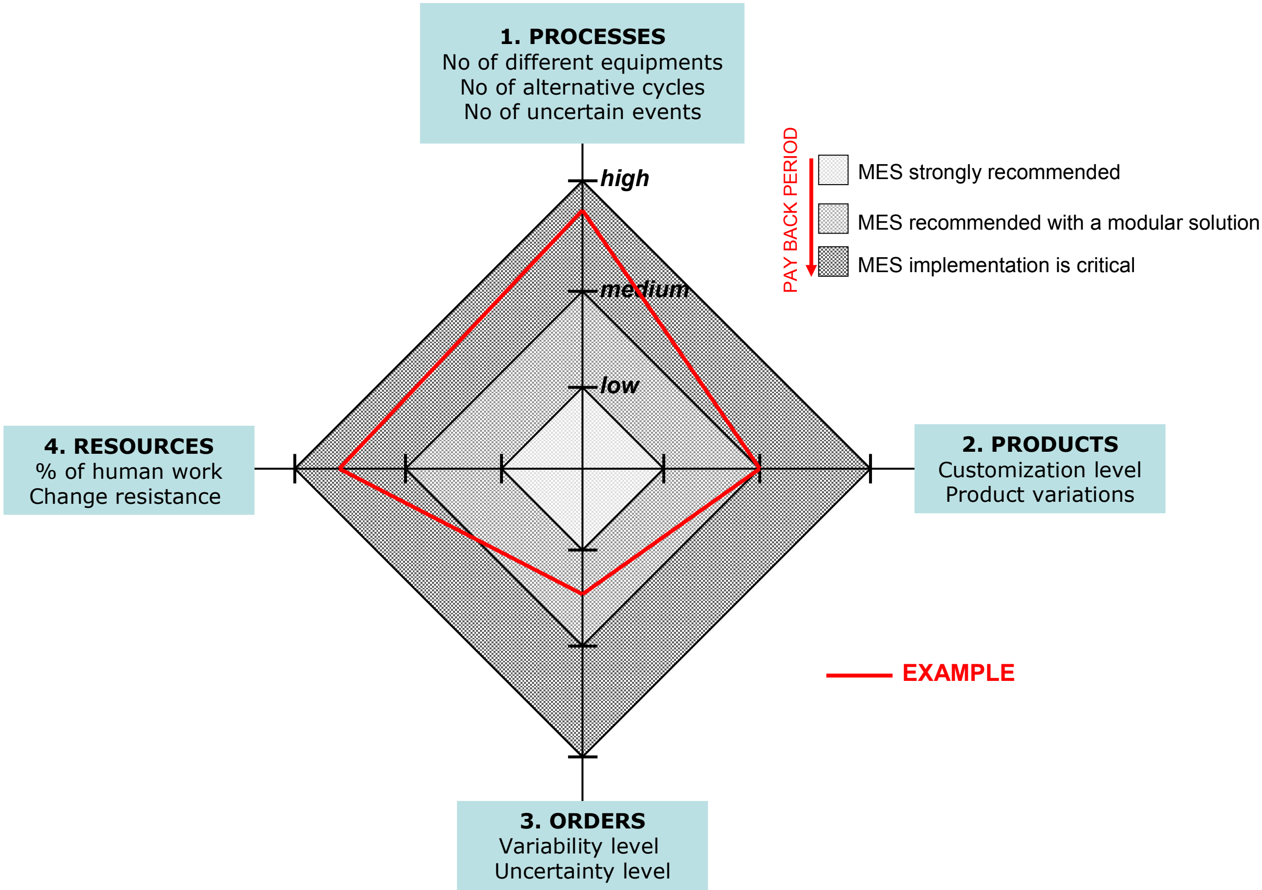

Fig. 2. Conceptual framework for MES implementation

A careful statement of MES requirements is here indispensable before the request proposal and negotiation of a MES solution (Saenz de Ugarte, 2009). Moreover in such industrial environment, deciding on where to first introduce a MES system can be tricky. It's strategic to give the priority to the most critical portion of the production/distribution system, where safety, quality and traceability performances need to be assessed and improved at first. In this way, implementing the MES system only to the critical points of the chain and coupling it with appropriate RFID device solutions could balance the three following aspects (Mahalik et al, 2010): the MES risk of failure, the management need to see results quickly and the need to roll out successful approaches to other part of the plant, so they can get the benefits too.
Thus, it's better to not choose a systematic complete implementation of a MES system when you incur in the critical part of the radar diagram, if you want to obtain successful results and pay back in the medium term.

4. Case study: a milk supply chain

In this paragraph we apply the framework to a local milk supply chain [fig. 2], which is currently controlled by only 3 different private actors, all operating in Veneto region.

These 3 partners together manage the entire process of milk production, distribution and sale from the crop and feed producers, then dairy farm (a), milk tanker collection phase and production-processing stage (b), and finally distribution and retail stage (c).
The authors have been recently engaged in a long-term project regarding the supply chain traceability and the possibility of implementing MES solutions.
Each stage of the supply chain has various characteristics and economic-business volumes so the introduction of MES should be quite different and considerations need to be carefully done according to the 4 layers defined in the framework of Fig.1.
A series of one-to-one discussions and working groups with industrial stakeholders helped us to explore the three sub-systems characteristics and coupling these results with published literature.
In the first stage, regarding the dairy farm, typically a great percentage of human work (Stup et al, 2006) is necessary in order to milk cows and storage the milk in refrigerated silos. These activities are currently extremely variable and subjected to many uncertainties (Valeeva et al., 2005), like cows diseases and low milk productions.
Also the obtained products can be very different between one production and others, due to the feeds, animals and environmental conditions (Athanasios et al, 2010, Valeeva et al. 2005). On the contrary, the uncertainty and variability in customers' orders are quite low.
The second stage regards the milk refrigerated tanker collection and its processing (pasteurizing, production of dairy, packaging).
In this part of supply chain, a high automation level of machines and production/processing systems is implemented (Ilyukhin et al, 2001). There is a quite low variability in the in-bound logistics activities and final products orders. The polygon associated to this stage is the most encouraging one and the first MES system has been successfully implemented by the authors in this portion of the Supply Chain, representing a successful pilot project for the other partners.
The last stage, concerning the distribution and retailer system, is highly affected by random environmental conditions (Agabriel et al, 2007), like temperature and humidity which impact on food quality.
Many activities are made by human operators, like the truck loading and unloading. The process is quite simple while products and orders can change considerably due to seasonality, dynamic costumers demand profile and other reasons.
A specific MES solution (highly personalized) is currently under implementation to this portion of the chain with the purpose of solving problems during the transportation of fresh products to retailers.
Stage 1, due to its criticalities, will be considered only as the final step of the whole project and a MES system will be probably be evaluated and coupled with an RFID technology support), but only for the high-quality milk production.
In this last case, the product unitary profit margins are higher.
A variability in product profit margins, as previously discussed, has a direct impact on the size of the grey areas of the radar diagram. An increment in the product profit margins makes bigger the size of the grey areas, thus shortening the pay back period of the investment in the MES system, mitigating the extensive length of the implementation process.

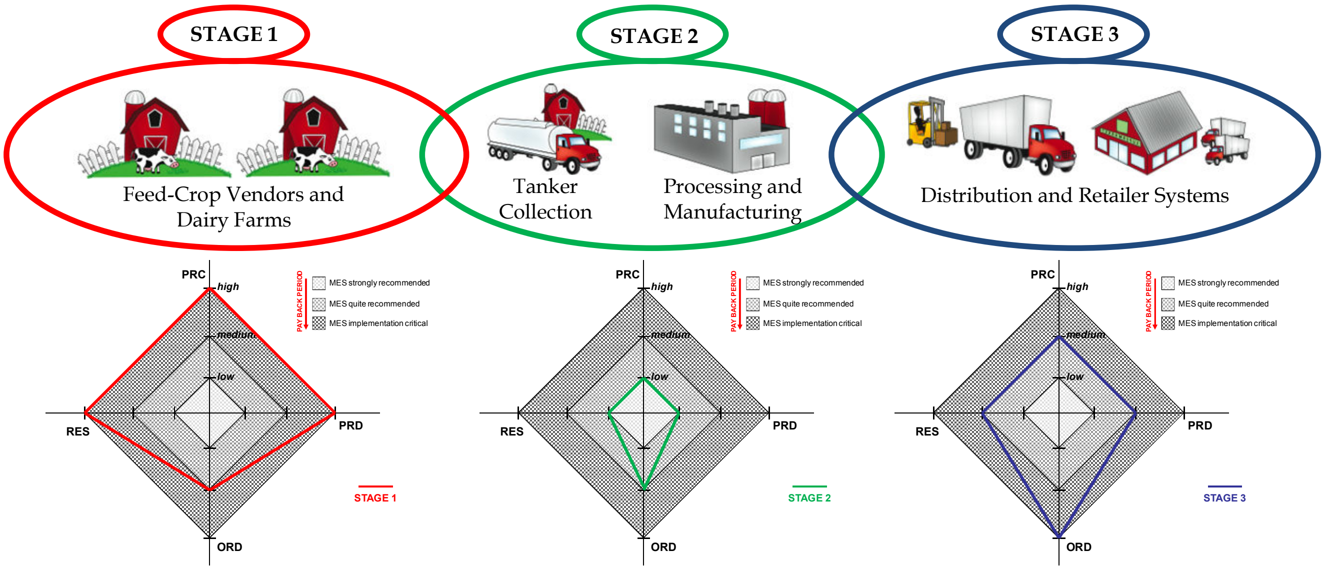

Fig. 2. Qualitative framework application to a three-stage milk supply chain case study.

5. Conclusion

Food companies are learning that MES systems provide a better use of resources, a support to realize products and processes traceability and a way to guarantee high-quality products through the whole chain of partners. Despite all the advances in this area, MES solutions implementation is still a slow and steady process, which often incur in long-term return.

This work has explored and discussed a first theoretical linkage between food industry challenges and MES solutions implementation. Benefits and risk of MES implementation are discussed and surrounded by literature in the field. The conceptual framework developed here only by a qualitative approach and validate by literature and case results, is intended to be a supporting tool for managers and practitioners, when approaching for the first time a MES system investment evaluation. Its value is to easily permit a fast understanding of the opportunities and the criticalities present in the industrial environment in which the MES system should operate.

The new framework presented in section 3 only by a qualitative point of view is intended to be applicable in any kind of industrial sector, not only limited to the food case.

Due to its qualitative nature and strategic purpose, it's use is facilitated when a panel of experts (operation managers and logisticians coupled with other company's stakeholders) is able to trace the right polygon (like the example in Fig. 1) by comparing the industrial environment under study with others, well known in literature or in the industrial practice knowledge.

For example, generally speaking, by comparing the food industry with several manufacturing industries (i.e. the gas tank producer reported in Battini et al., 2009) we can place it in a position closer to the inside of the chart, since MES systems are even more implemented (Wognum et al, 2011) and answer the need of food traceability imposed by authorities (Saenz de Ugarte et al., 2009). On the other hand, the pharmaceutical and petrochemical industries, when directly compared with the food sector, can surely find a

better position in the radar diagram (closer to the centre of the four axes), since MESs are historically well implemented in these kind of process industries (Defang et al, 2008).
It is clear that this work is not finished. Next steps and framework enhancements include the quantification of the four axes for the food industry environment and the collection and analysis of other case studies in order to permit a complete framework validation on the field.

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Tracking the temperatures of international wine shipments: processes, information handling, and temperature simulation

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Abstract

Wine is a temperature sensitive product which is most commonly shipped in non refrigerated containers. In this paper we describe a continuing experiment to document, analyze, and replicate temperature patterns along the wine supply chain. First we describe the temperature recording device chosen. Secondly, we discuss computer software we wrote for the initialization, capture, and analysis of temperature histories. Thirdly, we will describe a device we built to replicate the temperature patterns. Finally we conclude with a discussion of further developments to this suite of tools and their application to other temperature-sensitive supply chains.

Keywords: *Wine, Wine supply chains, wine shipping, temperature tracking, simulation.*

1. Introduction

Wine is a living organism that evolves with time and is directly affected by the surrounding environmental conditions. The wine maker takes special care to maintain controlled conditions to protect the product. At the other end of the supply chain, where the product is sold to the final consumer, the retailer also takes special care to store the product under controlled conditions. But what happens to the product during its travel along the supply chain? A widely known wine advocate and wine writer, Robert M. Parker, offers an alarming opinion (Parker, 2008):

> *"It is a frightening thought, but I have no doubt that sizable percentages (between 10% and 25%) of the wines sold in America have been damaged because of exposure to extremes of heat."*

It is widely known that excessively high temperatures can produce rapid deterioration and color changes in the wine (Recamales et al, 2006; Hasnip et al, 2004; Ough, 1985 and Ough et al, 1960). Changes can be observed in the range of alterations in the color components and phenolic content (Guadalupe & Ayestaran, 2008; Monagas et al, 2006; Recamales et al, 2006)

to sherry-like oxidized characters. Studies have shown that the level of change in the wine characteristics is directly dependent on the temperature level and time to which the wine has been exposed (Sivertsen et al, 2001). Hence it is of direct interest to know and understand under what conditions the product is transported.
The production areas of the so called "new world wines" (Australia, Argentina, Chile and South Africa) are all located in the southern hemisphere, opposite and at a considerable distance from the mayor consumption markets (North America and Europe). Most of the wines coming from these regions have to endure long travel periods over land and sea. During transport the trucks and containers, which are mostly unrefrigerated, can be directly exposed to the sun or can be subjected to changing climatic seasons while crossing the equator, which could lead to exposure to high or low temperatures. A study (Butzke, 2001) has shown that during the summer months, wines shipped to or via hot geographic locations are frequently exposed to temperatures above 24°C (75°F), and often for extended periods of time.
The studies by Robinson et al, 2010 and Wicks et al, 2009 are the first to try to assess the sensory changes in wines under conditions that would potentially be experienced by wines during their transportation. In their study 32 wines were evaluated using sensory descriptive analysis. Trained panellists, 11 for white wine and 13 for red wine, rated the wines on 14 and 23 attributes, respectively. Both sensory and analytical results showed significant differences among the wines stored at the higher temperatures. Differences were noted for a number of compounds which are characteristic of aged wines.
This paper describes a continuing experiment to document, analyze, and replicate temperature patterns along the wine supply chain. First we describe the temperature recording device chosen. Secondly, we discuss computer software we wrote for the initialization, capture, and analysis of temperature histories. Thirdly, we will describe a device we built to replicate the temperature patterns. Finally we conclude with a discussion of further developments to this suite of tools and their application to other temperature-sensitive supply chains.

2. Instrumenting and tracking shipments: process description

The first step in tracking temperature of shipments of wine is to select an appropriate device. The challenges are to find one that is both inexpensive, yet with sufficient capacity to save hourly recordings over a period of several months, so that we can look deeply into the supply chain. Our choice for this task was a temperature recording device called Thermocron DS1921G iButton (Maxim, 2011) manufactured by the company Maxim. This device can record up to 2048 temperature readings, which means it can make recordings every two hours for about 170 days. Also the device has a very small format which means its presence is less likely to interrupt normal business operations. Furthermore, it can be retrieved by regular postal shipping. Finally, the button can be queried by any computer through a USB port. A picture of the iButton and the 1-wire USB interface can be observed in figure 1.

Fig. 1. DS1912G iButton and the RFID reading device.

The process of instrumenting the shipments starts at the winery. At this stage, the person in charge of the instrumenting process initializes the iButton with a special software, that we have previously provided. This software performs two activities, first synchronizes the iButton clock with the computer clock and secondly, sets the iButton to record a temperature reading every 2 hours. Also, at the same time, the person in charge of the instrumenting, fills out information about the shipment on the back of the envelope. This includes the unique identification number of the iButton, origin at which the carton was tagged, date, container number, container type (refrigerated, insulated, dry), position within the container, and destination (see figure 2). After the information has been recorded and the device initialized, then it is placed inside a pre-stamped envelope, which is then inserted in a plastic adhesive bag along with instructions for the receiver. This package is then attached to a pallet of the wine.

Once the container has reached the port, the winery emails us the ID of the iButton, container number, shipping company, vessel, route, destination, and estimated time of arrival. We use this information to track the container through the website of the shipping company, from which we learn the date the container was loaded on the vessel; if transshipped, location and date that the container was unloaded and loaded into the new vessel, and, finally, the date the container was unloaded at the destination port.

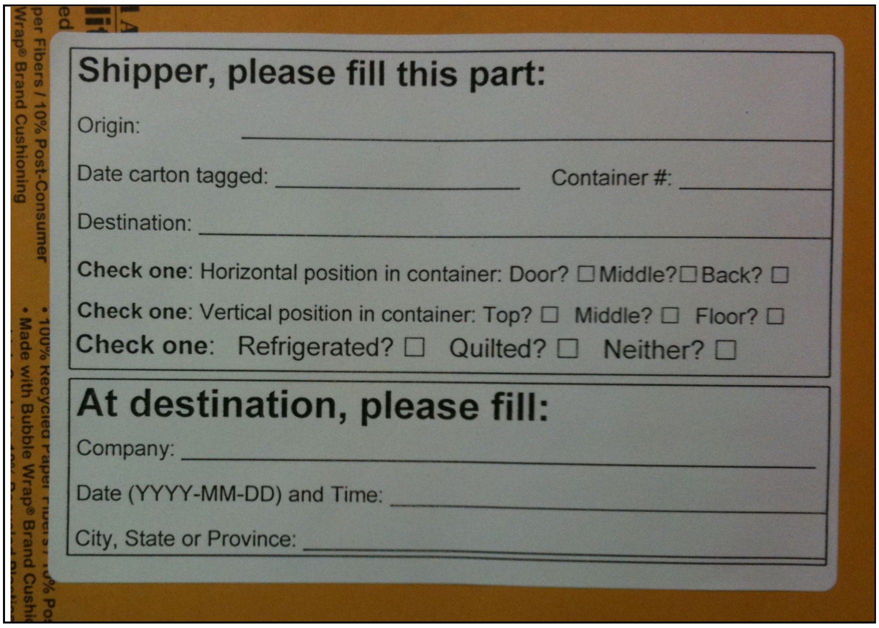

Fig. 2. Information in back of envelope.

Once the container arrives at its destination and is opened by the importer or distributor, he fills out the remaining information: Company, date and time and location (City and state); and mails the pre-stamped envelope (with the device inside) to us.
When we receive the device, we download the complete temperature history (temperature, date, and time) from the device and store that with any additional information regarding: the origin, date/time of activation of the device, position in the container, container number, type of container, whether it was inside or outside the thermal blanket, container tracking information (loading, transshipment and unloading: place and date/time), and the destination and date/time of arrival.

3. Software

We have developed specialized software to manage and analyze the large volume of temperature information that we continue to collect. The software was developed in Java programming language, with a client/server SQL database architecture. It consists of three modules: a device initialization module, the main administration module, and a client visualization module.

3.1 Device initialization module

The module consists on a self installable application that allows the user to: first, configure the port to which the USB reader is connected, second, indicates the status off the device, third, shows the serial number of the iButton and fourth and most important, initializes the iButton for a mission. Figure 3 shows a screenshot of the module.
When the initialization procedure is executed it stops any currently active mission and sends the initialization string to the device, which synchronizes the device clock with the computer clock and sets the device to record one temperature reading every 2 hours. ¶(6pt)

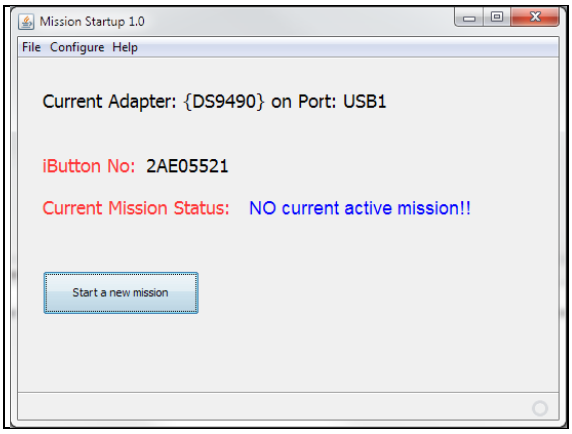

Fig.3. Screenshot of initialization module.

Once this process is done the device is ready to be inserted inside the prestamped envelope and attached to the wine shipment, to track the temperature to its destination.

3.2 Main module: information retrieval, reporting and statistics.

The main module of the software is structured as an SQL database client/server model as shown in figure 4. The client side is composed of three units: the retrieval and input system, a statistics and report interface, and a visualization system. The server side is composed of an SQL server database that stores and handles all the information.

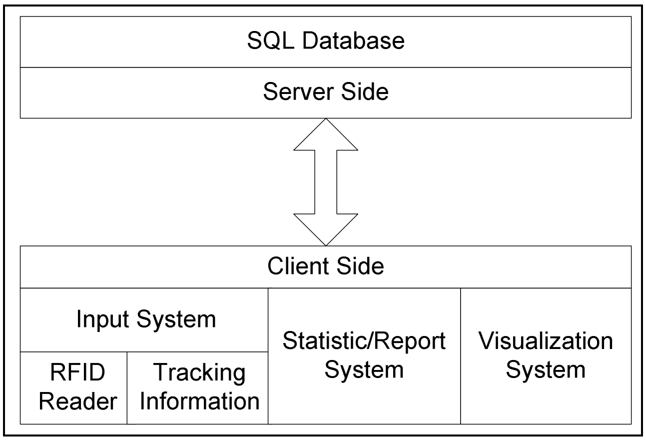

Fig.3. Software client/server model.

Input system

As shown in figure 4 the client side system has an input system that handles the interface between the USB reader with the iButton and the computer, so it can retrieve the unique identification number of the iButton and the temperature/time history from the device. Also this system allows the user to input all of the information regarding the tracking of the iButton. The tracking information that the user can input into the system is:

1. Date/time the iButton was initialized.
2. Date/time, shipper information and location in which the device was attached to the pallet of wine.

3. Position inside the container where the device is located.
4. Container number.
5. Type of container: refrigerated, insulated, or dry. (and, if the container is insulated, whether the device is inside or outside the insulation).
6. Information regarding the route of the container: port of origin, name of vessel, date/time in which the container was loaded in the vessel. If there is a transshipment point: name and location of the transshipment port, date/time the container was unloaded and loaded into the new vessel. Finally the name and location of the arrival port and the date/time in which the container was unloaded. All of this information is available from the shipping line website.
7. Date/time, receiver information and location in which the device was retrieved from the pallet of wine.
8. Al supporting documents and scans of them.
9. Any additional supporting information.

This information is captured along with the temperature readings of the device, processed and stored in the server side SQL database.

Statistics/report system

Once the temperature and tracking information has been input to the system we can generate statistics and reports at many levels of detail.

To get a sense of the temperature risk associated with the transport of wine, the report system generates three types of statistics. One is the percentage of readings that were above a certain temperature threshold. To look for spikes in the temperature (another risk factor), we compute the percentage of devices or shipments that recorded at least one temperature readings above a given threshold. Finally we determine the average, maximum and minimum number of hours that the wine was exposed to temperatures exceeding a given threshold.

Since we are also capturing information regarding the origin and destination and timing and mode of transport, we can correlate this information with the temperature information and obtain the same reports as previously, but organized according to the phase of transportation and/or the origin/destination.

Visualization system

The objective of this system is to retrieve and analyze the temperature and tracking information gathered by each device. When selected, the visualization system opens a pane with a table view that allows the user to look at all of the current information that is available. The table is structured so it presents the following summary information: Id of the iButton, Country of origin, Company of Origin, Date/time initialized, country of destination, company of destination, state, date/time arrived, port loaded and container number. From this table the user can select the specific device/trip he wants to observe its detailed information.

The user then selects a device/trip to observe, and a new window is displayed. (Figure 5 presents a snapshot of the visualization screen.) This window presents to the user 4 levels of information of the device, which allows him to render a detailed portrait of the historical information (Transit and temperature) that the device has captured.

The first level of information is a general statistics level in which the user is presented with temperature information such as: number of observations, average, standard deviation, min and max temperatures. Also as a more visual way to observe the data, a histogram of the temperatures is generated. Since the interest of the system is on analyzing the temperature risk, it also indicates the time and percentage of time that the devices were in, above and below the optimal temperature range of 10 to 20 °C. Finally this level presents the information regarding the transit time (days) giving the total transit time and if available the winery to port, at sea, transhipment and destination port to importer/distributor transit times.

The second level of information the system produces is a comparative statistics of the device against all the information available in the database. First, to compare the temperature risk of this device with the other devices in the system, we present a two line graph of the percentage of readings above a certain threshold, one line is for the current device and the other line is all of the information available. The next comparison done is the average and the standard deviation, to render this comparison the user is presented with a histogram of all the average and standard deviation of the temperatures of the devices that the system has, an arrow in the histogram indicates where the current device stands against the rest.

The third level of information is designed to give the user information regarding the temperature risk at the different phases of transportation. It presents a graph of the percentage of readings above a temperature threshold and descriptive statistics such as: mean, standard deviation, min and max temperatures, for the following phases of transportation: from winery to origin port, transhipment and from destination port to importer/distributor.

Fig. 5. Screenshot of visualization system.

The fourth and final level of information is a time line graph that details the complete date-time and temperature information of the device. If tracking information is available, it is presented by colors and label which indicates the time frame and phase in which the temperature occurred.

Server side: SQL database.

The server side of the system is powered by a relational SQL database powered by MySQL relational database management system (RDBS) (AB, 2010). The database was built in a snowflake structure because of the benefits that this structure posses (Levene & Loizou, 2003) in the flexibility it gives when handling and developing the information and views. In figure 6 we can observe a detailed view of the structure of the database. The structure is composed by a main table and four subgroups of tables which contain the information regarding origin/destination, tracking information, container information and finally, the temperature information.

This database structure has various advantages. First, we can easily correlate the information regarding the origin/destination of the shipment with the tracking information and the temperature information. So we can produce a large and flexible variety of views and analysis. Second, we can increase the amount of information we gather from the process with just small changes to the current structure.

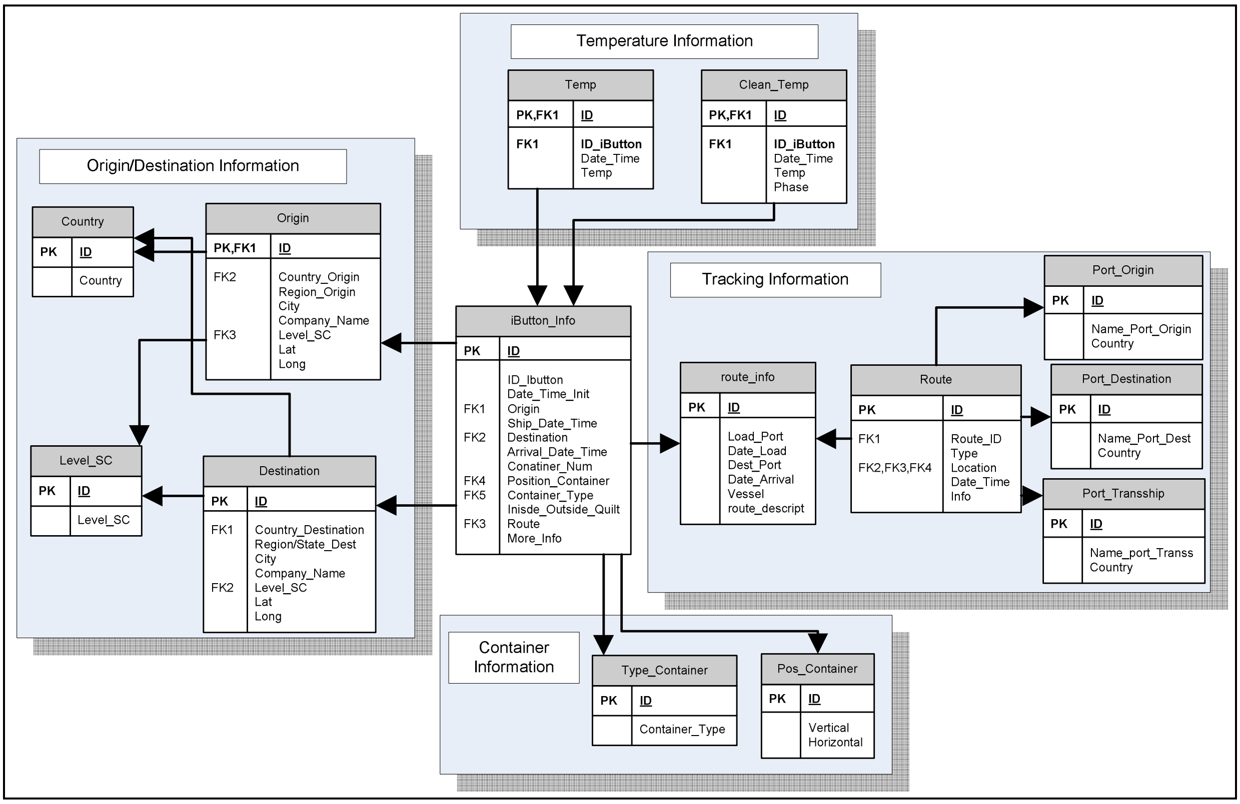

Fig.3. Server side system snowflake database structure.

3.3 Client visualization module

A key component for the success of this project is the participation of both the wineries, which instrument their shipments, and the importers/distributors, who return the iButtons to us. Accordingly we have focused on making these processes as easy as possible and then returning useful information to both participants, while being sensitive to issues of confidentiality. Our software enables each partner to access, visualize and retrieve the temperature and tracking information of their shipments in detail, and otherwise only summary data against which to benchmark their performance.

This is done through a client visualization module in the system, which is currently under development. Since the shipment temperature is sensitive information for the wineries we have devised this module with an authentication layer. Before entering the system, all users must authenticate with a username and password which allows us to filter the information they are able to visualize.

Once the user has logged in, he is presented with a table like one in the visualization system, which allows him to see all of the current information that is available according to his viewing privileges, and to select the one he wants to display.

By selecting a device from the table a new window opens, exactly the same as the one in the main module, which allows him to obtain all the important information of the device: General statistics, comparison and the tracking/temperature profile. There is also the possibility to export the information to an excel spreadsheet and to export the report into a pdf format.

4. Temperature simulation

The final stage in this project is to determine the effects of temperature during transportation on the characteristics of the wine. To do so, we invented a device to replicate the temperature patterns to which the wine was subjected. Figure 7 shows a schematic diagram of the temperature simulation system that we designed and built.

The device consists of four integrated components. The first is the heating and cooling mechanism, which is composed of a 12 volt thermoelectric cooler and warmer (Koolatron, 2011) that can reduce the temperature to approximately to 22°C below the outside temperature and can heat up to 57°C inside. (The switch between cooling and heating is obtained by simply reversing the polarity of a thermoelectric plate.) This range includes all that we have observed in three years of tracking shipments.

The second component is a four-channel temperature monitor and controller kit K190 developed by Ozitronics (Ozitronics, 2011). This consists of four DS1820 digital temperature input sensors (Maxim, 2011), four relays to provide output control and one RS232 interface for reading temperatures or controlling relays from any computer by using simple text strings.

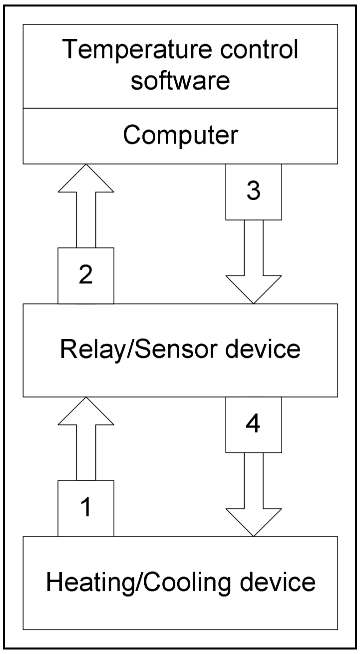

Fig.7. Diagram of the temperature simlation system

The third and fourth components of the simulation system are a computer and a software that we wrote in the Java programming language to control the temperature relay and sensor kit.

The numbers in figure 7 show the steps in the simulation process. The first step, which is not shown in the figure, is to select and input the temperature profile to be simulated into the software. Once this has been done, the system reads the temperature inside the cooling/heating device (1), then the relay/sensor device sends the information of the temperature sensors to the computer (2).The computer performs an average of the temperature of the sensors and compares this temperature with the pattern at the given time. If this average is below 0.5°C of the target temperature, it sends a signal to the relay/sensor device (3) to activate the heating mechanism (4) until the temperature has reached 0.5°C over the target temperature. The converse is done in case the temperature is 0.5°C above the objective. By this mechanism the temperature is always kept within ±0.5°C of the target pattern of temperature that is to be replicated.

The simulation is kept running for the exactly same period of time that the shipment took to get from his origin to its destination, so that the wine is subjected to an identical temperature history, just as if it had been shipped.

5. Challenges and further developments

One of the biggest challenges for the project is the low rate of return of the temperature-recording devices. The return rate of mail surveys is widely found to be around 35% (Cycyota & Harrison, 2006; Baruch & Holtom, 2008; Anseel et al, 2010) which is consistent with our return rate of 34%.

Standard techniques to increase the response level include sending advance notice, following-up, offering incentives, personalizing communication, or improving salience We have concentrated our efforts on sending advanced notices to the importer/distributor and on explaining the value of the information we will return to participants.

Another challenges is the flow of information from wineries. They are naturally focused on fulfilling customer orders and sometimes forget to relay sufficient information for us to track their container.

Among our next steps are to improve the process of data flow from the winery to us. In a new version of the software, when a user activates an iButton, a window will pop up to ask for essential information, which will then be emailed to our central database to initiate tracking of the container. In this way we reduce the number of steps that the winery has to perform during the activation process.

As another improvement to make information readily available to our users in any place and computer, we are assessing the possibility to migrate our client visualization module to a web based arquitecture. In this way the user can be in any part of the world and computer, and access their temperature/tracking information. Also by using a web based approach we do not need to send upgraded versions of the software to our users and also we are independent of the hardware that the client uses.

We are also beginning to gather information about other environmental factors affect the quality of the wine during transportation, including humidity, vibration, and light, all of which affect the organoleptic characteristics of the wine (Lopes et al, 2006; Chung et al, 2008; Maury et al, 2010; Dozon & Noble, 1989).

6. Final Remarks

The processes and equipment we have designed were originally focused on studying temperatures along international supply chains, but we have learned that they enable us to examine many other, related issues as well. For example, besides identifying the temperature risks (locations, times of year, processes), we are evaluating types of protection, such as insulation. And from the container-tracking we can estimate the amount of inventory in the supply chain and gain a better understanding of the dynamics of product flow.

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Development of a Fruit & Vegetable Supply Chain Emissions Model for Victoria

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Abstract

To enable a more sustainable and resilient fruit and vegetable (F&V) distribution system, a freight study to map current value chains for F&V movements in the state of Victoria was undertaken. This presentation describes two complementary approaches used in the development of an emissions model for retail and greengrocer supply chains. The first is a deterministic approach, used to identify and assign suitable values (observed or estimated) for components of the supply chain to enable calculation of summary values and overall measures of efficiency in the system. The deterministic approach was implemented via a Supply Chain Database Tool (SCDT), an Access-based model simulating transport flows of fruits and vegetables and calculating the associated emissions. The tool provides relative (instead of absolute) measures of emissions, which are indicative of the efficiencies that can be obtained from a base scenario with the application of various food transport and distribution policies and strategies. To include the effect of data uncertainty observed in the deterministic approach, a second tool using stochastic analysis and employing Monte Carlo simulation was developed, to extend the sensitivity analysis of greenhouse gas emissions to a wider range of variables. A case study on the impact of transport segments on emissions is used to present and discuss the results of analyses from the two models.

Keywords: *supply chain management, emissions modelling, freight modelling, systems simulation, scenario evaluation*

1. Introduction

The aim of the food industry is to transform agricultural raw materials into safe, convenient, good tasting and nutritious products for consumers, in a profitable and sustainable manner. The horticulture industry in Australia is valued at $3.6 billion (Australian Natural Resource Atlas, www.anra.gov.au) and in Victoria was worth $1.3 billion in 2009-2010. Horticulture in

Victoria supports 8500 enterprises employing 50,000 people full-time and up to 100,000 during harvest periods (DPI, 2011). However, to continue profitably doing so, it is becoming increasingly important for the Victorian horticulture industry to be more environmentally sustainable (particularly in terms of GHG emissions) and resilient to a changing agricultural landscape, oil price fluctuations, markets and weather variability.

To enable a more sustainable and resilient F&V distribution system, the Victorian Eco-Innovation Lab (VEIL) initiated a fruit and vegetable (F&V) freight study to map current value chains for F&V movements in Victoria, not only to better understand the value chain drivers that promote non-sustainable practices or high GHG emission, but to also identify incremental and transformational (including whole-of-chain) intervention options. Such interventions may include changes in transport modes and vehicle types, sharing transport infrastructure, reduced sourcing from interstate at certain times of the year, and better linking production regions with consumers. It will also provide the capacity to explore the circumstances in Victoria where new systems of F&V distribution could achieve significant GHG reductions and reduced vulnerability to oil scarcity / price escalations.

Figure 1 illustrates the principal activities in the Victorian F&V supply chain. As the diagram shows, F&V transport involve complex spatial and dynamic networks in Australia, incorporating many factors, such as: multiple food products and supply chain paths; long supply chains with multiple stages of processing/distribution; specialised transport needs; multiple modes; mixture of domestic and export products; underpinning supply chain relationships; evolving production systems; and climate variability (Higgins et al 2007). Road transport paths between farms, markets, DC's and supermarkets are also a complex network for food freight (Victorian Department of Transport, 2008), which vary substantially with time.

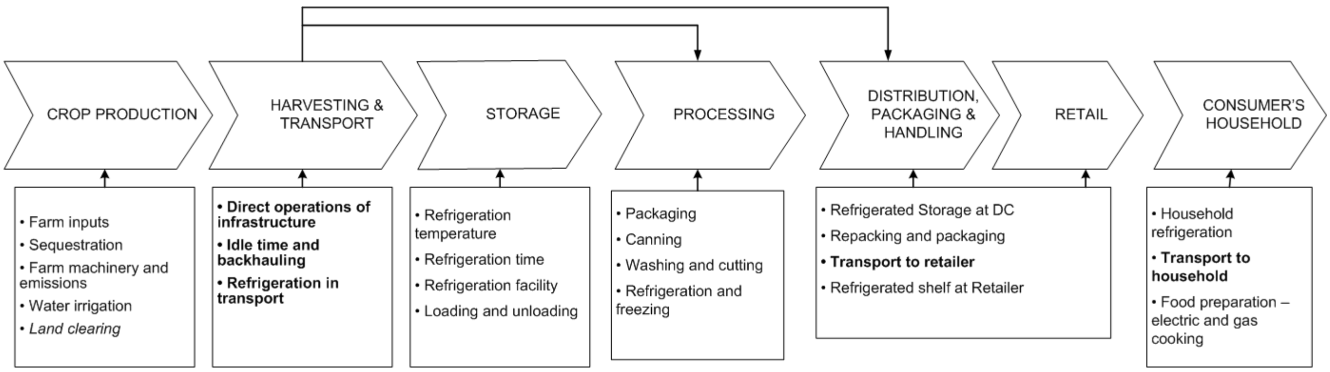


Figure 1. Features of F&V supply chain that contribute to emissions

The boxes below each supply chain stage in Figure 1 capture the processes that lead to the generation of GHG emissions. Processes highlighted in bold were in the scope of the VEIL F&V freight movements project, and encapsulate all of the transport stages from farm to consumer. The VEIL F&V freight study is focused only on the transport components of the supply chain, including refrigeration within transport where required, but it does not include energy use of emissions from production, processing, packaging etc. It should not be understood as a lifecycle analysis, it is intended only to increase understanding regarding the transport components of food (particularly fruit and vegetable) supply chains in Victoria.

The key elements required in the VEIL freight study were identified as:

- Mapping of fruit and vegetable supply chains in Victoria, identifying: sources and destinations; transport types and amounts; key features (*e.g.* bottle-necks)
- Analysing greenhouse gas emissions throughout these supply chains i.e.
  – What are the contributions of different components of the fruit and vegetable supply chains to greenhouse gas emissions;
  – Identifying how these supply chains vary throughout the year, according to seasons and conditions; and
  – Exploring relative contributions to greenhouse gas emissions of changes in these components.

The food movements investigated in the VEIL freight study include:

- Movements of fresh and processed F&V produced and consumed in Victoria.
- Movements of fresh F&V produced external to Victoria and consumed in Victoria (interstate and international);
- Movements of fresh F&V produced in Victoria and consumed externally (not including international transport legs).

This presentation provides an overview of the deterministic and stochastic approaches used to model the impacts of transport segments in the Victorian supply chain on GHG emissions. Full details of the model development and analysis resulting from the VEIL freight study is presented in the VEIL main report and appendices (Marquez et al, 2010).

2. Literature review

There have been limited studies in Australia aimed at analysing food freight logistics in a holistic sense. A State of Logistics study was carried out by CSIRO in 2006/2007 (Higgins et al. 2007) aimed to "Develop and test a methodology that estimates the costs of logistics in Australian food industries, and to apply this methodology to better understand the structure, drivers and challenges of these logistics." Rather than considering all food categories, four different case studies were selected: fresh mango domestic chains, livestock represented by beef and lamb production, field crops including sugar and grain and wine. The project helped to better understand value chains operations such as transport, storage and packaging. The methodology developed can be extended to other food industries in Australia.

A study by Morgan (2008) assessed supply chains of F&V from the perspective of waste and consumption and their impacts on public health in Australia. As with the CSIRO study, case studies were used, primarily due to lack of available large data sets. Morgan considered GHG emissions across the food supply chains through reference to published reports for farming (Rab et al. 2008), distribution and processing and food preparations. The reports cited by Morgan (and Morgan's report itself) provide general statistics rather than a detailed supply chain analysis.

Analysis of F&V GHG emissions at farm scale is far more advanced than post farm gate. A project by HAL, Rab et al (2008) and O'Halloran et al (2008) extensively considered GHG emissions in the Australian vegetable industry by addressing: availability and applicability of emissions factors; limitations on data availability; and features of the production system that have the greatest contribution to GHG emissions. The authors state that their estimation of GHG emissions in the vegetable farming sector (1,047,008 t CO2 / yr) was about one third of other estimates, highlighting the need to gather more relevant carbon footprint data. At the farm scale, the authors considered farm inputs and their land impact, as well as farm operations (*e.g.* irrigation, use of machinery).

There have been various logistics studies conducted at an industry or sector level. For example, grains logistic costs were extensively addressed in the Royal Commission on Grains Handling, Storage and Transport (1988), though the findings are largely outdated. Internationally, there have been State-of-Logistics (SoL) studies aimed at defining R&D and infrastructure investment priorities, with CSIR (2005) providing a general analysis across the major industry sectors of manufacturing, mining and agriculture of South Africa. Scientists from CSIR also conducted a more detailed analysis on South African fruit logistics (van Dyk and Maspero, 2004) with a focus on providing recommendations for priority investments in infrastructure. In light of the high-level analysis and recommendations from the South African studies, several "more-focused" logistics projects between CSIR and South African industries have been established. Our study goes beyond these studies that focus on logistical efficiency, to consider the GHG emissions implications and vulnerability in food supply networks.

3. Transport segments

For the VEIL freight study, a base scenario of fruit and vegetable freight movements has been defined using 2007-2008 as the base year and involving 7 fruit items (apples, grapes, mandarins, oranges, peaches, pears, strawberries) and 28 vegetable items (broccoli, tomatoes, etc) listed by the Victorian Department of Primary Industries (DPI, 2009). The base scenario covers transport legs or segments between the following types of distribution nodes:

- NRM - National Resource Management or farm regions, the sources of F&V production in Victoria ;
- IMP/EXP - import and export points between states and internationally;
- PROC - major packing houses and food processing centres (Simplot, McCain, National Foods, SPC);
- DC/MMA - Melbourne Market Authority (MMA) and distribution centres (DCs) for the four major supermarket chains (Coles, Woolworth, IGA/Foodworks, Aldi);
- MSC/GG - retail outlets for major supermarket chains (MSC), green grocers (GG); and
- CD - census collection districts where the population of consumers are sourced.

The transport segments define the volume and routing of F&V between the above distribution nodes. Five principal groups of transport segments (NRM - PROC/DC/MMA, IMP/EXP - PROC/DC/MMA, PROC - DC/MMA, DC/MMA – MSG/GG, MSG/GG - CD) were identified. GHG emissions were calculated for each transport segment and then aggregated to represent the entire supply chain. Figure 2 illustrates the transport segments and variables needed to model the F&V supply chain for Victoria.

The volumes of F&V moved in each transport segment for the base year were obtained from a variety of sources and models as shown in Table 1. The main sources of data for the F&V volumes were ABS production data for Victoria for 2007-2008 (ABS, 2009), horticultural imports and exports for Victoria for 2007-2008 (DPI, 2009), and 2001 estimates of freight movements (ABS, 2002). These volumes are then distributed to the other nodes using the FruitChain and VegChain model from Food Chain Intelligence (Marquez et al, 2010).

Table 1. Summary of sources of volume, routing and distance data for the transport segments.

Transport segment	Sources for volume data	Routing and distance
NRM - PROC / DC/MMA	2007-2008 Victorian fruit and nut production (ABS, 2009); 2007-2008 Victorian vegetable production (ABS, 2009);	NRM centroids to proc centres/ DC/MMA via Google Maps
IMP/EXP - DC/MMA	Horticulture Exports/Imports by State and Port (DPI, 2009); 2001 Freight Movements (ABS, 2002)	Intl shipping point to Port Melbourne via PortWorld.com; State points to DC/MMA via Google Maps
PROC - DC/MMA	FruitChain model (FCI); VegChain model (FCI)	Proc centres to DC/MMA via Google Maps
DC/MMA - MSC/GG	FruitChain model (FCI); VegChain model (FCI)	DCs/MMA to MSC/GG via Google Maps
MSC/GG - CD	Choice grocery basket (Choice, 2009)	CD centroids to MSC/GG via Google Maps

The routes used and distances travelled in each transport segment were generated using Google Maps for the land routes and PortWorld for the shipping routes. Distances were measured using the shortest routes created by Google Maps or PortWorld between the selected origin and destination points representing the various node types. For example, Google Maps is used to obtain the route distance between the centroid of the Mallee NRM and the Coles DC in Altona. This is done for all possible pairs of origin-destination nodes for this transport segment. A similar process is performed for shipping F&V between international and Australian ports using PortWorld.com. These distances represent a lower bound for the actual distances used. Figure 3 shows a sample route and estimated distance created by Goggle Maps for a given pair of origin and destination points.

Aside from the volumes of produce and estimated supply chain pathways used in a transport segment, a range of factors affecting GHG's were also taken into account. Figure 8.1 identifies at least 16 types of variables or parameters that affect the GHG emissions produced for the different segments. These include:

- Vehicle types, mode and fuel used: articulated, rigid and light commercial (LCV);
- Proportion of trips refrigerated;
- Forward and backhaul trips; and
- Payloads – amount of produce moved within segment.

Each of the variables can take a wide number of values and in some cases such as loading factors, the variables can have an infinite (continuous) number of values between a maximum (capacity) and a minimum (capacity).

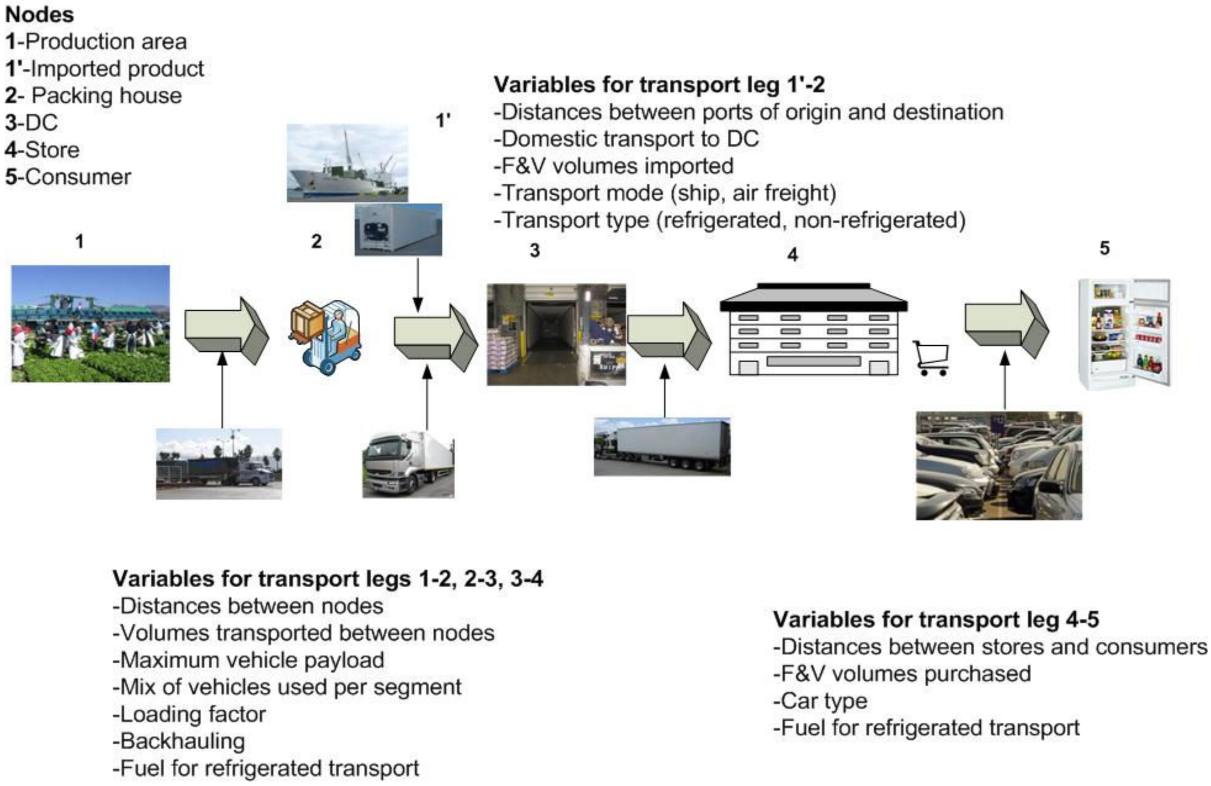


Figure 2. Segments and variables affecting GHG emission in the Victorian F&V supply chain (fresh F&V).

4. Deterministic and stochastic methodologies

Two complementary methodologies were used to perform the analysis required for Figure 2.

The first employed a deterministic approach to the analysis. This approach allowed the study to identify and assign a limited number of representative values (observed or estimated) for each set of variables used in a transport segment of the supply chain. It approximates and makes assumptions as appropriate, to enable calculation of summary values and overall measures of efficiency in the system for this transport leg. Simply put, the deterministic approach is designed to provide the "expected" or "most likely" impacts of F&V transport distribution variables on GHG emissions for a given set of assumptions, where a single best estimate of each variable (*e.g.* fruit and vegetable volumes) is used to determine a single outcome (*e.g.* GHG emissions).

On the other hand, if the objective is to obtain the complete range of impacts on GHG emissions from all possible combinations of the supply chain variables, then the number of permutations of variable estimates required becomes prohibitive for the deterministic approach. A stochastic (probabilistic) approach is then used that allows the simulation of several variables, each one represented by a wide range of possible values, to identify the specific relation between each variable and GHG emissions resulting from each step change. This is achieved by representing each variable as a probability distribution that realistically models the behaviour of each variable. In this way, the model accounts for every possible value that each variable could take and a weighing for each possible value is applied through the use of probabilities. This approach provided insights on general trends that would be difficult to generate through the use of single point (deterministic) modelling, The stochastic modelling has only been undertaken on the fresh F&V chains with the future inclusion of processed F&V chains a research extension.

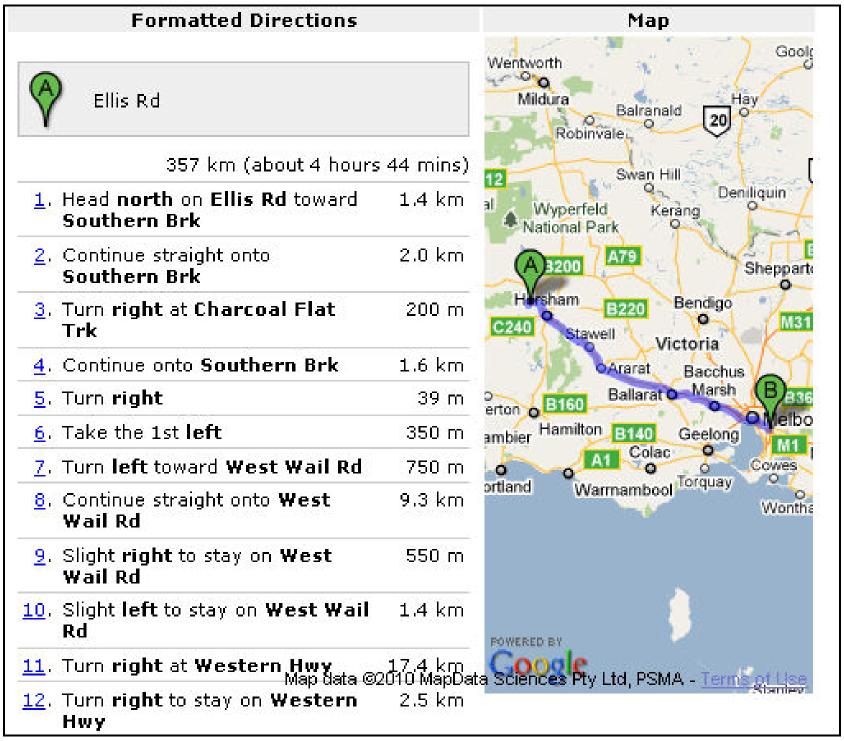


Figure 3. Sample route and distance created by Google Maps for an origin-destination pair.

To illustrate the choice of parameters between the deterministic and stochastic approaches, Table 2, Table 3 and Table 4 present parameters used by the deterministic model to specify representative values for transport modes, types and fuel used in the segments. Table 2 presents the emission factors (in kg/km of CO2 equiv) for the forward portion of the trip, as well as the refrigeration component (based on refrigerated transport at 0°C) and the backhaul (or return trip) component. Emissions from the forward component are calculated for all trips with the emissions from the refrigeration and backhaul components added when necessary. Based on the proportion of F&V where refrigeration is essential for quality and safety maintenance, it was assumed that only 48% of the LCVs, articulated and rigid trucks carrying fruit have diesel-powered refrigeration units while the proportion jumps to 60% for vehicles carrying vegetables[1]. We assumed that the proportion of trips refrigerated were consistent across all NRM regions and specific F&V types. Finally, emissions from backhaul (empty return) trips were added. It was assumed that for fruit deliveries, only 36.6% of the articulated and 37.9% of rigid trucks do the backhaul trip empty, while 36% of LCVs were also assumed to return empty. These proportions represent the ratio of "kms run empty" over "kms run loaded" for rigid and articulated vehicles obtained from the table "Loading of HGVs by vehicle type and weight (2006)" (Department of Transport, 2008). The same proportions apply for vegetable deliveries.

Maximum, minimum and average load capacities for the different vehicle types are presented in Table 3. We assumed that payloads were not differentiated by F&V type, though in practice the space to carry a tonne of mushrooms will be different to that used for a tonne of potatoes. Table 4 presents the fuel, proportion of volume carried and emissions factors for consumer vehicles used during trips to the supermarket.

Table 2. Representative vehicles types and emission factors

Mode	Type	Fuel	Proportion of Volume Carried	Forward Emiss Factor (kg/km)	Refrigeration Emiss Factor (kg/km)	Backhaul Emiss Factor (kg/km)
LCV	Heavy	Diesel	3.50%	0.459	0.138	0.306
Trucks	Rigid	Diesel	32.30%	1.200	0.227	0.800
Trucks	Artics	Diesel	64.20%	2.240	0.520	1.493

Table 3. Vehicle capacities

Mode	Type	Min tonnes	Max tonnes	Average tonnes
LCV	Light	0.10	2.00	0.38
LCV	Medium	0.10	2.50	0.38
LCV	Heavy	0.10	2.50	0.38
Trucks	Rigid	11.00	24.00	6.07
Trucks	Artics	20.00	117.00	22.60

[1] Fruit where refrigerated transport is essential include oranges, mandarins, apples, pears (including Nashi), peaches, strawberries and table grapes. The vegetables list includes: artichokes, Asian vegetables, asparagus, beetroot, broccoli, brussels sprouts, butter beans, French and runner beans, cabbages, capsicums, chillies, cauliflower, celery, cucumbers, eggplant, fennel bulb (Finnochio),herbs, leeks, lettuce (all varieties), melons (all varieties), mushrooms, parsnips, peas (all varieties), silver beet, spinach, spring onions, shallots, bunching onions, sweet corn, tomatoes, zucchini and button squash

Table 4. Types of vehicles for supermarket trips and emissions factors

Mode	Type	Fuel	Proportion of Volume Carried	Emiss Factor (kg/km)
Car	Heavy	Petrol	27.97%	0.329
Car	Medium	Petrol	27.97%	0.240
Car	Light	Petrol	27.97%	0.215
Car	All	Diesel	3.84%	0.175-0.268
Car	All	LPG	2.79%	0.195-0.298
LCV	All	All	10.00%	0.200-0.375

In contrast to the deterministic approach, the stochastic approach generates multiple values of parameters from the defined distributions given in Table 5. The distributions are standard functions provided in the ModelRisk simulation software (Vose Software, 2009). Thus, where the deterministic approach would use an average loading capacity for LCVs of 0.38 tonnes, the stochastic approach would obtain a value from the PERT distribution (a variant of the beta distribution provided by ModelRisk) with parameters (0.0, 0.4, 2.0). And while the deterministic model will make a single run to generate a scenario analysis, the stochastic model will make multiple runs, using different random values generated for each parameter from its corresponding distribution.

Table 5. Distributions of input variables for stochastic model.

TYPE OF VARIABLE	TRANSPORT NODE	STOCHASTIC DISTRIBUTION
Distance (km)	Farm →Packing house	D~Normal(15,5)
	Packing house →DCs	D~D(x_i,p_i) where x= distance from each growing region(i) and P= probability for each growing region (i)
	Country of origin→DCs	D~D(x_i,p_i) where x= distance from each import country (i) and P= probability for each country (i)
	MM→DCs	D~D(x_i) where x= distance from MM to each DC (i), with equal probabilities per DC.
	Interstate→DCs	D~D(x_i,P_i) where x= distance from interstate entry points to each DC (i and P= probability for each state (i)
	DCs→MSC stores	D~D(x_i) where x= distance from DCs to each store (i), with equal probabilities per store.
	MSC stores→consumers CDs	D~D(x_i,p_i) where x= distance from each store (i) and P= probability for each CD as per population(i)
	Packing house →MM	D~D(x_i,p_i) where x= distance from each growing region(i) and P= probability for each growing region (i)

	Country of origin→MM	D~D(x_i,p_i) where x= distance from each import country (i) and P= probability for each country (i)
	Interstate→MM	D~D(x_i,P_i) where x= distance from interstate entry points to MM (i and P= probability for each state (i)
	MM→greengrocer stores	D~D(x_i,) where x= distance from MM to each store (i), with equal probabilities per store.
	GG stores→consumers CDs	D~D(x_i,p_i) where x= distance from each store (i) and P= probability for each CD as per population(i)
Loading capacity (tonnes)	DC/MM→ supermarket/ greengrocer stores	LCV~PERT(0,0.4,2) Rig_2x~PERT(0,6,13) Rig_3x~PERT(0,11.5,23) Art_l~PERT(0,22.5,40) Art_B2~PERT(0,27.5,55)
% backhauling	All	LCV~PERT(25,35,50) Rig_2x~PERT(33,50,66) Rig_3x~PERT(33,50,66) Art_l~PERT(33,50,66) Art_B2~PERT(33,50,66)
Container power consumption for refrigeration (kW)	Country of origin→DCs	PERT(1,4,9)
Fraction of refrigerated cargo	All	PERT(0,0.5,1)
Emissions factor as a function of various car sizes (g CO_2/km)	stores→ consumers	PERT(180.9,213.9,295.8)
Number of consumer trips	stores→ consumers	PERT(44.2,88.4,176.8)
Volumes (tonnes)	Farm →Packing house	V~PERT(Vs*0.5,Vs,Vs*1.5) where Vs= production volume for the fresh supermarket channel in 2008
	Packing house →DCs	Varies as a function of the previous volume
	Country of origin→DCs	V~PERT(Vi*0.5,Vi,Vi*1.5) where Vi= imported volume of fresh F&V for supermarkets in 2008
	Intestate→DCs	V~PERT(Vp*0.5,Vp,Vp*1.5) where Vp= Victorian production volume of fresh F&V in 2008.
	DCs→MSC stores	Varied as a function of the previous volume
	MSC	Varied as a function of the previous volume

	stores→consumers CDs	
	Packing house →MM	V~PERT(Vm*0.5,Vm,Vm*1.5) where Vm= production volume for the fresh Melbourne Market channel in 2008
	Country of origin→MM	V~PERT(Vi*0.5,Vi,Vi*1.5) where Vi= imported volume of fresh F&V for MM in 2008
	Intestate→MM	V~PERT(Vp*0.5,Vp,Vp*1.5) where Vp= Victorian production volume of fresh F&V in 2008.
	MM→greengrocer stores	Varied as a function of the previous volume
	GG stores→consumers CDs	Varied as a function of the previous volume

Table 6 summarises the differences in assumptions used between the deterministic model and the stochastic model. Essentially, all the distances used for the stochastic model were extracted from the deterministic model. The stochastic representation of distances, volumes and other parameter values, and differences in some assumptions indicated are the key points of comparison between the two approaches.

Table 6. Comparison of assumptions used for the deterministic and stochastic models

Assumption	**Deterministic**	**Stochastic**
Vehicle types per segment	Constant mix of vehicles (LCV, rigid trucks, articulated trucks)	Mix of vehicles (LCV, rigid 2 axles, rigid 3-axles, articulated long haul and articulated B-double)
Payload per vehicle type	One load capacity (average payload)	Different loading capacities between a minimum and the maximum capacity per vehicle
Fuel consumption	Constant – independent of load	Variable and dependent on loading capacity used.
Backload per segment	Constant	Variable
Emissions from ship (imported product)	Calculated as per road analysis, with constant emission factors	Multiple assumptions to calculate emissions.
Emissions from refrigeration	Weighting by fuel factor	Factor combining fuel and motion
Volumes of fruit and vegetables	Mass per product type is distinguished	No distinction between product types (lumped volumes of F&V)

Consumer transport (from shops to CD)	100% of trip emissions attributed to F&V for grocery stores, 7.25% for supermarkets (CHOICE basket used)	Healthy Food Basket used. 30% of trip emissions attributed to F&V for both grocery and supermarket trips.
	Fixed number of trips	Variable number of trips
Scale	Individual trips from consumer collection districts	Aggregated over all supermarkets and grocery store trips

5. Estimating emissions

To estimate emissions from the road transport segments, the deterministic approach defined the following indices:

- Let $j \in J$ be an individual supply chain segment such as between a specific NRM centroid and DC or between a supermarket and a consumer CD (collection district) centroid. It can include interstate and international legs as well.
- Let $v \in V$ be a road transport of a given type, mode and fuel category (*e.g.* articulated trucks using diesel fuel).
- Let $i \in I$ be an individual fruit or vegetable item (*e.g.* potatoes, apples, oranges, etc).

If $M_i^{v,j}$ is the total volume (in tonnes) of F&V item $i \in I$ transported over supply chain segment $j \in J$ using vehicle $v \in V$ in a given year, then the amount of corresponding emissions produced $E_i^{v,j}$ (in kilograms) is given by:

$$E_i^{v,j} = (M_i^{v,j} / P^v) \times D^j \times (\lambda^v \times F^v + \alpha^v \times R^v + \beta^v \times B^v) \qquad \textbf{(Eqn. 1)}$$

where

P^v is the average payload (in tonnes) of vehicle type $v \in V$,

D^j is the distance travelled (in km) on supply chain segment $j \in J$,

λ^v is the multiplier used to account for the combined weight of the vehicle and load,

F^v is the emissions factor for the forward component of the trip (in kg/km) for vehicle type $v \in V$,

α^v is the proportion of trips made by vehicle type $v \in V$ that are refrigerated,

R^v is the emissions factor for the refrigeration component of the trip (in kg/km) for vehicle type $v \in V$,

β^v is the proportion of trips made by vehicle type $v \in V$ that have backhaul, and

B^v is the emissions factor for the backhaul component of the trip (in kg/km) for vehicle type $v \in V$. This is usually the same value as F^v.

Note that $(M_i^{v,j} / P^v)$ gives the number of trips required to transport the volume while $(M_i^{v,j} / P^v) * D^j$ gives the vehicle-kilometres covered for the segment. The emissions formula merely multiplies the vehicle-kilometres covered with the emissions factors from the three components of the trip (forward-delivery, refrigeration and backhaul). A similar formulation is used to estimate emissions from shipping, with container capacity and ship emissions parameters replacing those for vehicles.

The stochastic approach applies a similar formulation to Equation 1 but with each parameter for distance, emissions factor, proportion, vehicle type, load and fuel, and number of trips made derived from their corresponding distributions.

Using the above notation, we obtain the following basic aggregations:

1. Total emissions per year = $\sum_{j \in J} \sum_{i \in I} \sum_{v \in V} E_i^{v,j}$
2. Total emissions on supply chain link $j \in J$ for F&V item $i \in I$ = $\sum_{v \in V} E_i^{v,j}$
3. Total emissions on supply chain link $j \in J$ = $\sum_{i \in I} \sum_{v \in V} E_i^{v,j}$
4. Total emissions from vehicle type $v \in V$ = $\sum_{i \in I} \sum_{j \in J} E_i^{v,j}$
5. Total emissions per tonne transported = $(\sum_{j \in J} \sum_{i \in I} \sum_{v \in V} E_i^{v,j}) \ / \ (\sum_{j \in J} \sum_{i \in I} \sum_{v \in V} M_i^{v,j})$

The component nature of the calculations allows for more detailed aggregations for the entire supply chain based on combinations of:

- supply chain segments
- vehicle types
- item types
- specific fruits and vegetables
- processed and fresh produce
- Victorian production, interstate imports and international imports
- supermarkets and grocery stores
- household collection districts
- (export/import) partner countries

The above formulas can also be expanded to incorporate emissions per month in the case of seasonal effects in state production and interstate trade. Unfortunately, the seasonal data available for this report was limited to Victorian production only.

6. Deterministic implementation and results

The deterministic model was implemented in Microsoft Access, with Access queries and VBA code applied on Excel input tables. The result was a scenario assessment tool called the Supply Chain Database Tool (SCDT). The development of this tool was crucial in detaching the modelling work from the uncertainties in the data collection effort, as it enables various combinations of parameters and input tables to define different scenarios. Due to the uncertainties in data collection, the SCDT enables investigation of relative (rather than absolute) measures of emissions, indicating the emissions produced from a base scenario based on one set of average values (*e.g.* average payload, average emissions factors, average distance). The emissions estimates from the supply chain legs for this base scenario were then aggregated into a range of categories to enable comparison i.e. relative contributions of different system attributes.

Table 7 presents the estimated average GHG emissions per tonne of Victorian-grown F&V consumed in Victoria compared to F&V sourced from interstate and imported from overseas. As Table 7 shows, foreign imported fruits and vegetables showed the highest overall transport emission levels (248 and 216 kg CO2-e per tonne, respectively) while interstate supplies were not far behind with overall emissions of 221 kg CO2-e per tonne. Both international and interstate transport presented an emissions profile of almost four times the levels obtained for Victorian grown fruits and vegetables (60 and 49 kg CO2-e per tonne, respectively). These results can be attributed to the significantly longer distances required to connect foreign ports and state capitals to Victorian DCs compared to points within Victoria for Victorian grown fruits and vegetables, particularly the road segments.

Emissions from vegetables were highest for interstate transport while emissions from fruits were highest for international imports. An interesting observation is that the international shipping leg had similar GHG emissions to the interstate road transport leg.

Table 7. SCDT comparison of GHG emissions of between Victorian and non-Victoria produced F&V

Product Type	Destination Type	Kg of Emissions per Tonne transported		
		Vic Produced	Imported	Interstate supplied
Fruit	Victoria DC	59.57	248.02	215.70
Vegetable	Victoria DC	48.73	216.22	222.45
All		51.94	222.89	220.62

Although international imports produced the highest emission levels of 248 kg per tonne of fruit imported, these emission levels only represent transport (including refrigeration) from the port of departure from the partner country to the port of entry in Australia and ultimately to Victorian DCs. Transport GHG emissions between the overseas growing region and the port of departure in the foreign country are not included. Therefore, these results are likely to underestimate the true values. As noted earlier, the land leg portion of international transport is considerably shorter than interstate transport since most foreign imports use the Port of Melbourne as the port of entry into Victoria, and Victoria DC's are already close to the Port of Melbourne.

7. SCDT Sensitivity Analysis

A key objective in the VEIL Freight Study was the identification of the parameters that most influence GHG emissions during the distribution of F&V. To answer this question, a sensitivity analysis is necessary to determine how "sensitive" the model is to changes in the value of the parameters of the model, and to changes in the structure of the model (Breierova and Choudhari, 2001).

A preliminary sensitivity analysis was conducted using the SCDT model to demonstrate the potential for further analysis to be undertaken using this methodology. The first part of the sensitivity analysis was conducted by varying input data in the SCDT to explore the impact of changing truck sizes on emissions.

Parameters related to the mode share and backhaul trips associated with rigid and articulated trucks were modified to examine the impact of transport modes used on the amount of emissions produced. Independent and separate changes were applied on the transport modes to examine four scenarios, namely:

1. Changing the mode share between rigid and articulated trucks, while keeping those made by LCVs constant, for trips made from NRMs to DCs and processing centres.
2. Changing the mode share between rigid and articulated trucks, while keeping those made by LCVs constant, for trips made from DCs to supermarkets and grocery stores.
3. Changing the percentage of backhaul (empty return) trips made by rigid trucks, and
4. Changing the percentage of backhaul (empty return) trips made by articulated trucks.

A summary of the implementation details and results for the four scenarios are presented in Table 8.

The first two scenarios examine the trade off in emissions between the use of rigid trucks versus articulated trucks in transporting F&V, while keeping the mode share of LCVs constant. The first scenario applies the trade off to trips from NRMs to DCs, MMA and processing centres while the second applies the trade off to trips from DCs to supermarkets and grocery stores. The simulation results are the same for both scenarios. The results showed that each 1% switch in mode share from articulated trucks to rigid trucks increased the associated emissions from those trips by 0.556%. Thus, policies encouraging the use of articulated trucks can be expected to contribute to reduced transport emissions. This can attributed to the fact that articulated trucks produce about half the emissions that rigid trucks produce per tonne-kilometre of FFV transported. However, emissions reduction is just one measure for assessment. Other issues relating to safety, congestion, noise pollution and access will have to be considered.

The third and fourth scenarios illustrate the importance of minimising the proportion of empty return trips made by rigid and articulated trucks in relation to forward delivery trips. The simulation results show that each 1% increase in the proportion of backhaul trips made by rigid and articulated trucks will produce a corresponding 0.17% increase in emissions from the associated trips. Consequently, reducing the proportion of empty trucks during the return leg will result in reduced emissions. This can be achieved by policies encouraging more efficient scheduling and routing of trips as well as more flexible packing and consolidation of cargoes.

Table 8. Summary of SCDT results for transport mode scenarios

Scenario No.	Changes implemented on base scenario	Results over emissions from base scenario
1	Increase (decrease) the proportion of rigid trucks with corresponding decrease (increase) for articulated trucks	Emissions increased (decreased) by 5.56% for every 10% increase (decrease) in mode share of rigid trucks
2	Increase (decrease) the proportion of rigid trucks with corresponding decrease (increase) for articulated trucks	Emissions increased (decreased) by 5.56% for every 10% increase (decrease) in mode share of rigid trucks
3	Increase (decrease) the proportion of backhaul trips for rigid trucks for both fruits and vegetables	Emissions increased (decreased) by 1.77% for every 10% increase (decrease) in backhaul pct of rigid trucks
4	Increase (decrease) the proportion of backhaul trips for articulated trucks for both fruits and vegetables	Emissions increased (decreased) by 1.74% for every 10% increase (decrease) in backhaul pct of articulated trucks

Results from the stochastic analysis

As noted earlier, the stochastic model was implemented using ModelRisk simulation software (Vose Software, 2009) with parameter values generated from the distributions given in Table 5. The stochastic simulations focussed on evaluating impacts from two supply chains, one for DCs of MSC and the other for the Melbourne Market (MM). Only these two major chains were developed, given that supermarkets and greengrocers cumulatively account for 97% of the total fresh F&V trade. Further, only fresh products were considered.

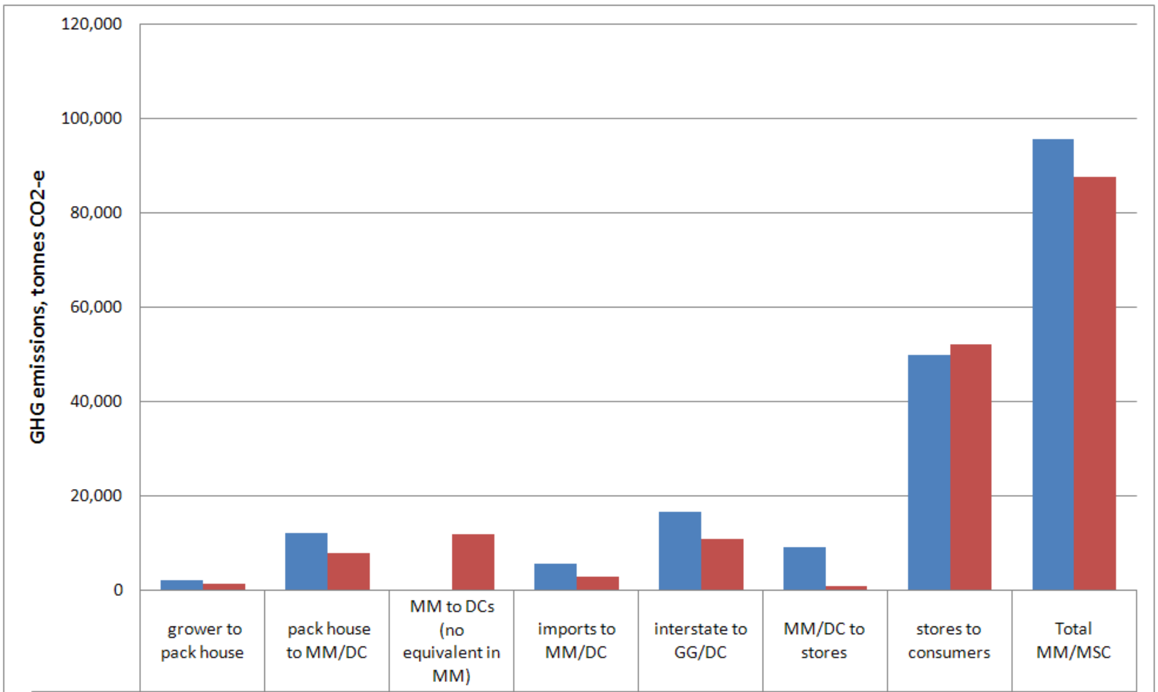
To compare the relative importance of each transport segment in the supply chains analysed, maximum GHG emissions, interpreted as *the maximum contribution potential to GHG emissions derived from the distribution of fresh F&V in Victoria,* were compared for each chain. This maximum contribution is based on the potential values that all variables analysed can take, within realistic supply chain conditions.

The stochastic model enabled two detailed sensitivity analyses to be undertaken:

- A complete farm-to-fork analysis (including consumer travel to shops); and

- A farm-to-store analysis that focused on results relevant to the commercial operations in the F&V supply chain.

Figure 4 shows a comparison of average GHG emissions calculated for MM and MSC chains. MM chains present higher emission averages in all comparable segments, except consumer travel. In the major supermarket chains (MSC), the distribution segments that have the maximum contribution potential to GHG emissions were (in descending order of importance): transport of F&V from stores to consumers' households, transport from DCs to stores and interstate transport to DCs. Figure 5 shows one (in a series of) tornado charts used to evaluate the influence of distribution factors in the MSC supply chain. In the Melbourne Markets (MM) chain, the segments that have the maximum contribution potential to GHG emissions derived from the distribution of fresh F&V in Victoria were (in descending order of importance): transport of F&V from greengrocers to consumers' households, transport from MM to greengrocers and transport from pack houses to MM.



	grower to pack house	pack house to MM/DC	MM to DCs (no equivalent in MM)	imports to MM/DC	interstate to GG/DC	MM/DC to stores	stores to consumers	Total MM/MSC
Mean MM	2091.943479	12051.56868		5717.637379	16779.13551	9145.819482	49902.99641	95689.10094
Mean MSC	1356.178725	7808.68699	11801.3145	2856.894604	10852.55623	920.0996344	52134.12075	87729.85143

Figure 4. Comparison of average GHG emissions expected from each link of the MSC and MM chains

Figure 6 shows the distribution of cumulative GHG emissions produced from the MSC and MM chains**.** The calculated carbon footprint from farm-to-fork distribution of fresh F&V consumed in Victoria and sold through greengrocers and supermarkets is likely to fall within 82,214 and 318,976 tonnes CO2-e. These results reflect the large data uncertainty discussed in the deterministic analyses and the extent to which changes in the variables selected affected the resulting emissions. As the values of variables are refined through more accurate information on commercial distribution of F&V (i.e. the variability is decreased), the resulting GHG emissions would group closer to a mean value.

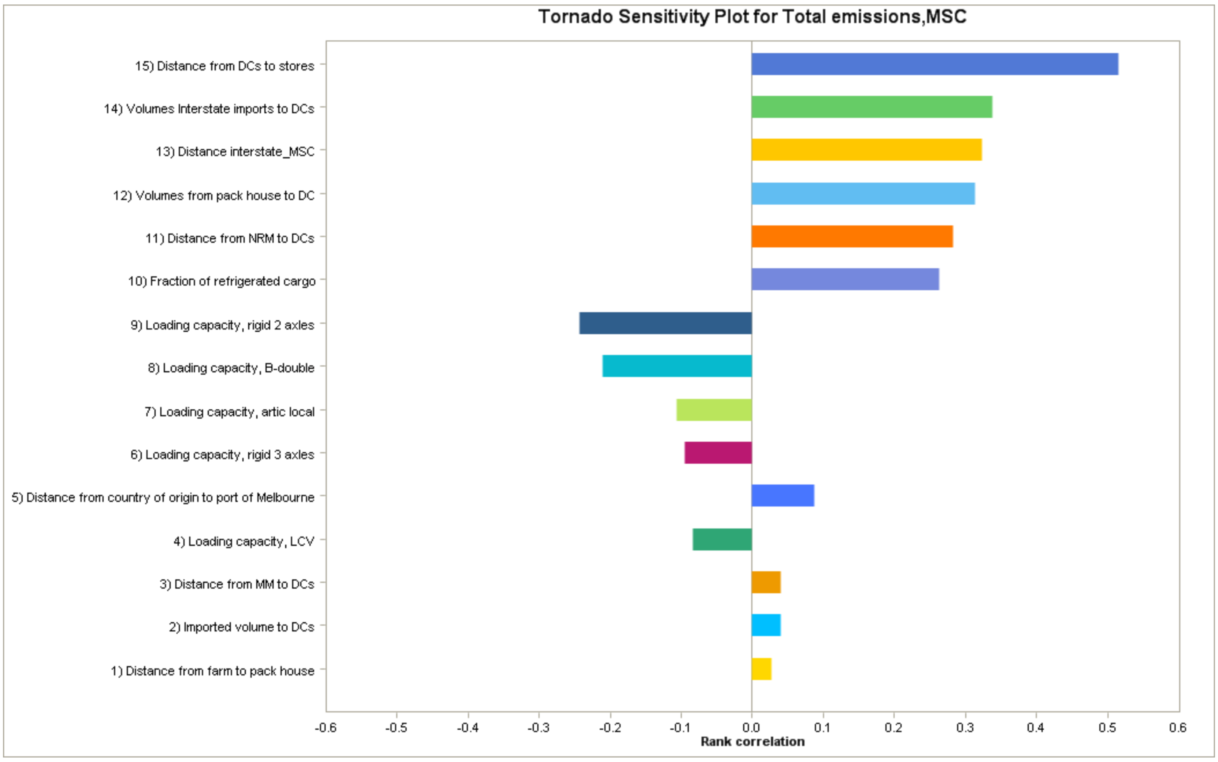


Figure 5. Tornado chart showing factors and sensitivity levels for the MSC chain

In the farm-to-fork analysis, the most significant factor in transport GHG emissions for fruit and vegetables was found to be consumer travel to purchase them. The significance of this factor is found to be greater than in the deterministic analysis, which is likely due to:

- a higher proportion of the consumer trip allocated to fresh fruit and vegetables (30% based on a healthy food basket, rather than 7.25% in the average); and
- refined allocations of truck types used in different supply chain legs. In particular, the assumption of LCVs used only for short trips led to a lower estimation of emissions for intertstate segments.

While the farm-to-fork analysis produced results that may be of interest to policy makers and urban planners, a second analysis was conducted to pinpoint opportunities to decrease GHG emissions during commercial F&V chains. The following results can be highlighted:

- The calculated carbon footprint from farm-to-store distribution of fresh F&V consumed in Victoria and sold through greengrocers and supermarkets is likely to fall within 44,752 and 124,062 tonnes CO2-e. Again, these results reflect data uncertainty and the degree in which changes in the variables selected affected the resulting emissions. As the values of variables are refined (i.e. the variability is decreased), the resulting GHG emissions would group closer to a mean value.
- For MSC, the segments that had the maximum contribution potential to GHG emissions derived from the distribution of fresh F&V in Victoria were (in descending order of

importance): transport from DCs to stores, pack house-to-DCs and interstate transport to DCs. Differences between the GHG emissions of the 2nd and 3rd factors were marginal.

- In the MM chains, the segments that had the maximum contribution potential to GHG emissions derived from the distribution of fresh F&V in Victoria were (in descending order of importance): transport from MM to greengrocers, transport from interstate to MM and transport from pack houses to MM. Again, between the GHG emissions of the 2nd and 3rd factors were marginal.
- Given the importance of the distance between DCs/MM to retail stores, decreasing the uncertainty of variables that affect this variable would lead to more accurate carbon footprints. Such variables include the specific channels used by greengrocers located in remote locations to source their products, the location of all Victorian greengrocers and the split of volumes from the DCs/MM to stores.

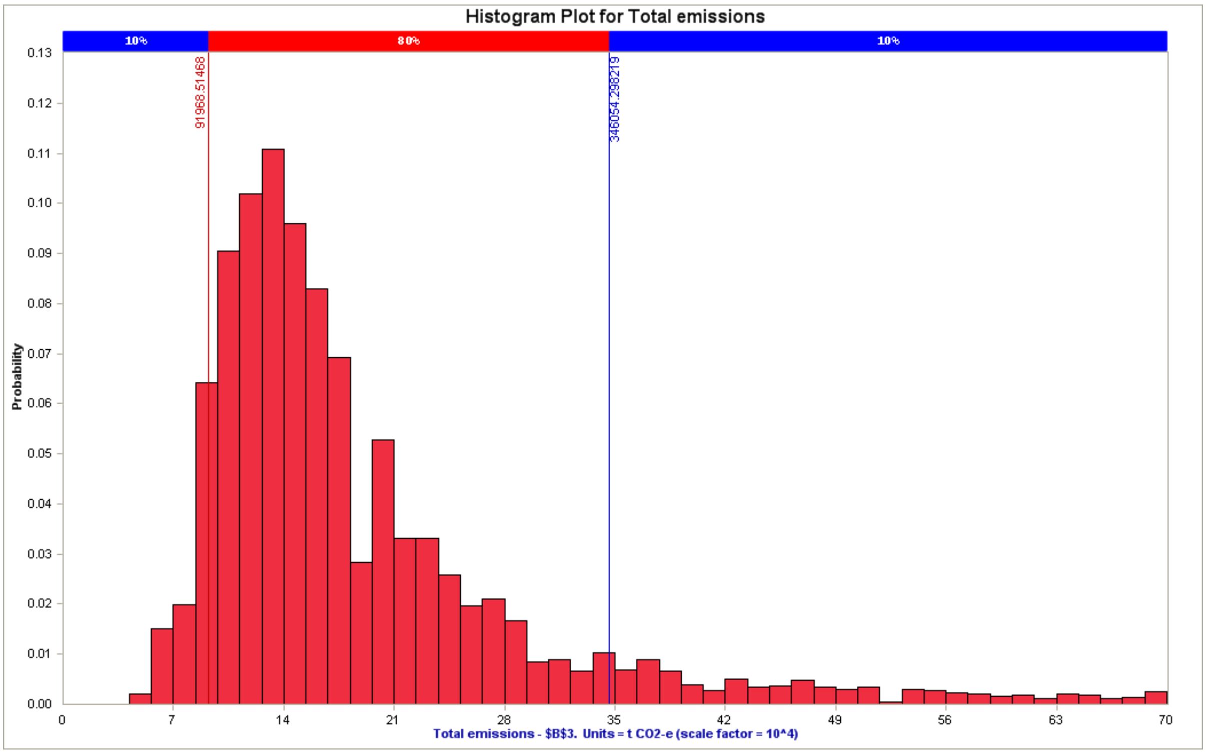


Figure 6. Histogram showing the distribution of potential GHG emissions arising from fresh F&V distribution through both MSC and MM chains in Victoria (from farm to fork).

The greater significance of the distance from DCs / MM to stores is likely to result from the multiple trips to stores in distant locations and the low rate of backhauling assumed, compared to the packhouse-to-DC / MM trip. These findings could have implications for location and/or function of outlets and distribution centres, to decrease distances or increase backhauling opportunities.

A complete discussion of the stochastic modelling formulation and results from the VEIL freight study is presented in Marquez et al (2010).

8. Conclusion and recommendations

In this report two complimentary methodologies were applied to improve understanding on the features of F&V freight chains in Victoria that contribute to GHG emissions and that could lead to supply chain vulnerability. The deterministic method focused on calculating summary statistics by aggregating detailed information across the F&V freight supply chain using a database model. Stochastic modelling was used to provide a better understanding in the context of uncertainty and variability in payloads, volumes, number of trips (etc) and their impact on the distribution of GHG emissions.

The deterministic analysis has shown that distance is the main driver of GHG emissions. This includes the non-even spread of F&V's grown across each Victorian NRM region and the distance from the NRM region to Melbourne. Whilst vehicle types were a key determinant of GHG emissions, nearly two thirds of F&V volumes are assumed to be already transported by GHG efficient articulated diesel trucks. The scope for significant GHG reductions through moving towards more efficient existing vehicles will be limited if it is difficult to shift from LCV's to trucks. For this analysis, it was unknown which vehicle types were used on each supply chain path or for which F&V, which may introduce a bias. For example, LCV's or rigids may be used for roads unsuitable for articulated trucks or when the quantities transported are too small for a larger truck. If this information was available along with reasons why certain vehicle types were used, there may be scope to analyse specific options for optimising the use of each vehicle type as part of reducing GHG emissions. Similarly, varying the proportion of truck types used according to the type of trip (interstate, intrastate, intra-urban etc) would be likely to impact on these results, and would be a priority for further analysis.

The stochastic model was used to provide a wider picture of the key factors affecting GHG emissions for major supermarket chains (MSC) and Melbourne Markets-greengrocer chains (MM), which cumulatively account for 97% of the total F&V trade[2]. For the purposes of identifying the major factors affecting GHG emissions in Victorian F&V chains, MSC and MM chains were considered to be largely representative of current marketing methods. Further, only fresh F&V product entering the Victorian market (through state production, imports and interstate trade) was considered. Exports and F&V volumes leaving Victoria were not included.

Two types of sensitivity analyses were developed: a complete farm-to-fork analysis (including consumer travel to shops) and a farm to store analysis that focused on results relevant to the commercial operations in the F&V supply chain. In the farm-to-fork analysis, the most significant factor in transport GHG emissions for fruit and vegetables was found to be consumer travel to purchase them. Given the importance of the consumer segment, decreasing the uncertainty of variables that affect consumer travel would lead to more accurate carbon footprints. It is also important to note that the significance of the consumer trips is largely driven by the households located at distances over 5.5 km, despite the fact

[2] The remaining trade is attributable to a wide variety of small grower-consumer channels, amply discussed by Estrada-Flores and Larsen (2010).

that these are a minority (less than 20% of the total Victorian households analysed). If the travel distance (or number of trips) of this minority of households were decreased, this would lead to a substantial decrease in the total F&V carbon footprint.

In the farm-to-store analysis, the greater significance of the distance from DCs / MM to stores is likely to result from the multiple trips to stores in distant locations and the low rate of backhauling assumed, compared to the packhouse-to-DC / MM trip. These findings could have implications for location and/or function of outlets and distribution centres, to decrease distances or increase backhauling opportunities.

Results obtained from the VEIL freight study have identified where further priority analyses are needed. Here we note some desired additional analyses and the data acquisitions required to support them.

Seasonal variability of F&V supply was a major determinant of freight volumes and GHG emissions. However, due to the severe lack of suitable data on interstate transport, many questions around the seasonal implications of GHG emissions remain unanswered. This includes better understanding the inefficiencies of interstate (and intrastate) F&V GHG emissions at a more granular scale such as individual trip movements and companies. Such a more detailed analysis would help identify more tangible strategies to reduce GHG emissions. To do this, the key data requirements are: tonnes of individual F&V transported between each state in each week, as well as movements at company scale. If the latter will be impossible to obtain as complete data sets, then we recommend it be collected in part through surveys.

Whilst not considered in this analysis, we expect the seasonal variability in the demand of transport vehicles will also have implications on the level of backloading. We suggest additional investigations be carried out to assess the GHG efficiencies of the road transport from the NRM regions, throughout the year. This would need to be assessed in terms of types of vehicles throughout the year, backloading, and implications of peak demand and excess capacity.

The assumptions made around direct routes, no duplication of trips and provision of produce to the closest DCs (etc) first, are likely to lead to significant underestimates of the actual transport task. Closer investigation of the actual transport movements that happen in specific supply chains would be useful to understand the extent of this underestimation.

The scope of the international analysis needs to be expanded to incorporate freight movements between the growing regions in the country of origin to the port of country of origin. This would provide a fairer comparison with the Victorian and interstate supply chains.

An important extension would be the inclusion of GHG emissions for F&V consumed in food service outlets, and potential freight inefficiencies explored. This is a very complex supply chain and there are several thousand food outlets in Victoria. They vary in terms of small restaurants with local ownership, to large franchises with large complex supply chains. Sourcing of F&V for each restaurant would be hard to determine due to the large number of ownerships and large variety of local versus interstate suppliers. We suggest a GHG analysis of the food service industry be considered as part of further research.

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Improving Agri-food Supply Chain Performance Through E-Business Model

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Abstract

Due to globalization of the world economy, trade liberalization is one of the most important economic powers that affects the agri-food industries specially in the Mediterranean countries and it forced the agri-food firms to improve the agri-food supply-chain performance for increasing products quality and safety to compete in the agri-food global market. Some of the agri-food firms have technological issues and they have an effect on the performance of the agri-food supply-chain, the firm's market position, and the firm's export-ratio. The aim of this paper is to face this problem by proposing an e-business model based on technological and traceability systems as an effective tools for improving the supply-chain performance. This study is a preliminary study of a large study about improving agri-food supply-chain performance. Choosing e-business model based-on three critical supply chain dimensions which are the e-business model affects on, and those dimensions are: information technology, synchronized planning, coordinated workflow. Using a technological system like services applications products (SAP) system and traceability tool like radio freq. identification (RFID) based system to build an e-business model proved its efficiency in solving some of the agri-food supply-chain issues. This paper explains the supply-chain processes by using Supply Chain Operations Reference (SCOR) , and the importance and efficiency of the e-business model on improving supply-chain performance. Furthermore SCOR model will describe the taxonomy of the agri-food supply-chain processes in three levels and it will analyze the relationships between agri-food supply-chain processes and e-business model, and the effects of e-business model on the agri-food performance.

Keywords: *Trade Liberalization, Agri-food Supply Chain Performance, E-Business Model, Information Technology, Traceability , SCOR Model.*

1. Introduction

In today's global market, the competition and the effects of trade liberalization forced the governments to sign international agreements, in order to reduce the trade barriers between countries, and make their trade easier and faster (Boiral, 2003). In 1997, Albisu defined trade liberalization as one of the most important economic powers for the development process in the agri-food industrial firms. Trade liberalization in the agri-food sector started because of the need for the rival in the global market especially for some of the Mediterranean agri-food industrial firms, improving supply chain performance of the agri-food system, and the rapid change in the food sector made the demand shifts from traditional services and products to finished food (Albisu, 1997). In 1995 Euro-Mediterranean Partnership started by designing a structure which contains economics, finance, politics, food industry plans, and it determines the cooperation between the European Union and the Mediterranean countries (Gallina, 2006). After this partnership the agri-food industrial firms started to focus on improving the agri-food systems by focusing on improving agri-food supply chain processes. Eastham (2000) defined agri-food supply chain as a set of activities in which all the materials pass through from the source to the customers. In 2000, Vorst explained the meaning of the agri-food supply chain performance as the percentage to which the supply chain of the agri-food system can offer all the customer's requirements. This percentage measured by using the performance indicators of the agri-food supply chain, and those indicators are: the time to offer products, the cost of the supply chain processes and activities, the utilization of resources, the flexibility to which the agri-food supply chain can respond, and food quality (Vorst et al., 2000). The competition in the global market, increasing products safety and quality, increasing agri-food supply chain performance, and creating a sustainable agri-food environment were the issues that agri-food industrial firms started to find solutions for.

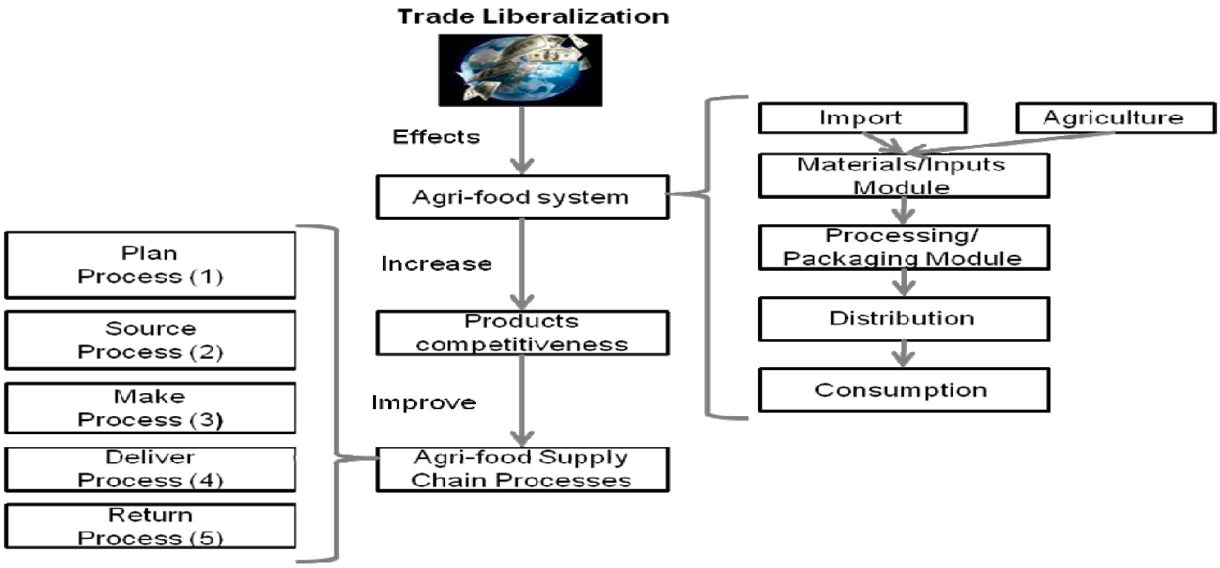

Figure. 1. The effects of trade liberalization on the agri-food system

Figure (1) shows the effects of trade liberalization on the agri-food system processes. Starting from the point of origin (import, agriculture) to the point of delivering products to customers, passing through processing module and products distribution. Furthermore one of trade liberalization aims is to increase products competitiveness which is defined as the performance measure of the country, firm, or sector in selling, supplying, and buying agri-food products in a specific market (Albisu,1997). In 2002, Bijman proved that any improvement process starts by focusing on improving agri-food supply chain processes (plan, source, make, deliver, and return), because the agri-food chain as whole is considered as nothing without the supply chain of the activities and processes. Bijman (2002) analyzed that the importance of the agri-food supply chain lies on (i) tracing the materials starting from the point of origin till the point of delivering products to the end customers, (ii) trace the flow of products and information all together in each activity or department in the agri-food system. In 2000, Lambert analyzed the importance of the agri-food supply chain relying on four main characteristics: the first is the activities and processes which increase the intra and inter organizational, the second is the agri-food firms and the focusing on the importance of the managerial relationships, the third is the supply chain includes bidirectional flow of the data and the information between the agri-food firm's departments and this characteristic is considered as one of the global standards and regulations, and the fourth is the managers and employees that they aim to achieve goals, improve customer value proposition subject to the best use of resources. Recent studies and dissertations proved the efficiency of the agri-food supply chain and information technology approach (IT) approaches in improving the agri-food business performance (Mahalik, et al.2010; Zhou, 2003; Qrunfleh, 2010).

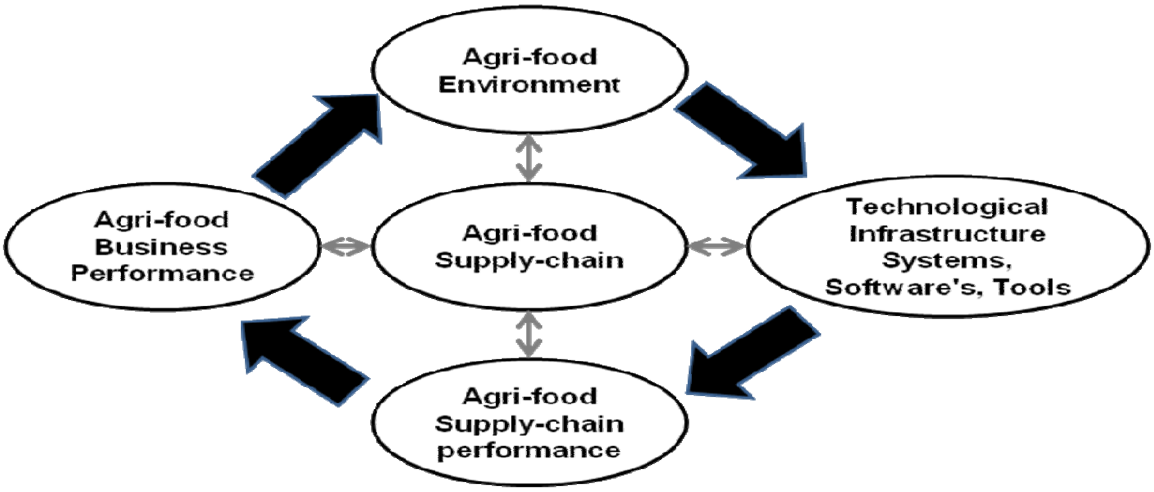

Figure. 2. Agri-food supply chain relationships

Figure (2) shows the importance of the agri-food supply chain for the agri-food infrastructure, supply chain performance, and agri-food business performance. Furthermore this figure shows the role of supply chain in using and applying one of the technological system in the agri-food sector, and its effect on the supply chain performance and on the agri-food business performance as whole. The effects of trade liberalization on the agri-food sector pushed the agri-food industrial firms to start improving the agri-food system processes. Some of the agri-food industrial firms have a technological issues that do not make the final agri-food products conform to the global standards and agreements. This research showed that the main reason is the absence of a high technological system, to monitor and organize the flow of information between the agri-food supply chain processes. This study is a preliminary study of a large study about improving agri-food supply chain performance, and the impact of ICT and e-business on the competitiveness of the agri-food productions. Section 2 reviews the literature about the agri-food supply chain processes and their relationships with the agri-food supply chain performance. Also next section shows the solutions that the researchers proposed to improve a specific process of the agri-food supply chain processes, and what were the differences between them. Furthermore, section

3 analyses the proposed solution of this paper, and its effects and benefits on the agri-food supply chain performance, products competitiveness and the business performance as whole. The summarize and the conclusion of this paper will be in section 4.

2. Literature Review

A lot of studies and researches proposed a solutions to improve the agri-food system supply chain or a specific department of the agri-food system. The differences always were the ability of the technical solution in solving the agri-food problem, and choosing the agri-food department in which the solution to be applied.

In 2005, Schwartz used a demand-driven production management system to improve the agri-food production department in order to reduce the costs, reduce lead-time, and to increase profits. In 2009, Ranalio explained how firms can improve their agri-food industry processes by implementing lean principles. The principles of lean used to identify customers products requirements like: using stream value to identify value-stream, monitor and make sure that the flow is continuous, monitor and check customers values, and try to improve agri-food industry processes to be almost perfection. Cicco (2007) used the discrete event system simulation to improve the manufacturing supply chain processes of cheese industry.

In 2010, Mahalik spoke about the trends' effects on the agri-food manufacturing system, and how by adopting ICT tools on the manufacturing system the effects will improve the efficiencies of manufacturing system operations, and will increase agri-food supply chain performance. In addition, Mahalik analyzed one of the traceability tools, which proved its efficiency in managing the agri-food supply chain. In 2009, Bevilacqua discussed the difficulty to build a traceability system for manufacturing process. He focused on the lack of interoperability between enterprise systems, and the different manufacturing processes from product to another. Bevilacqua built a framework using event-driven process chains (EPCs) as one of the business process reengineering (BPR) tools, this framework was to trace all the materials and information flows for a production supply chain of fourth range vegetable products. This solution used when they tried to develop the business processes for a supply chain of fourth range vegetable products, in order to set up a computerized system for managing product traceability. In 2009, Ahumada explained the importance of managing the supply chain as the only way to solve a food safety problem, and monitor the agri-food production process. He analyzed a lot of models which are used to monitor and control production department, because it is considered as one of the most important activities of the supply chain. The research result found that supply chain activities and processes are still limited and the model should depend on new technology to face a lot of issues like organization management, and improving agri-food production processes. Moreover, Ahmuda proposed for future researches a lot of technological systems like traceability system to monitor and improve production process supply chain.

Depends on previous researches which discussed a specific department or process of the agri-food supply chain, it is shown that the difficulty lies-on propose an effective solution to manage the flow of information between all the supply chain processes, because each product in the food sector has a different specifications from others products. This paper proposed a model depends on the suggestions of previous researches to organize and monitor the flow of information between the agri-food supply chain processes, and to improve the performance of the agri-food supply chain.

3. Modelling and Solution Approach

This section explains and analyzes the indicators that the paper is using, in order to measure the improvement process of the agri-food supply chain. Those indicators are: (i) the efficiency indicator to measure the effects of the proposed solution on the agri-food supply chain performance, (ii) the flexibility indicator to measure how the agri-food supply chain will respond to the new changes of the agri-food infrastructure, (iii) responsiveness indicator to measure the lead-time of receiving and preparing products' orders, (iv) the food quality indicator which measure the changes of the products specifications and the level of applying international specifications during production process.

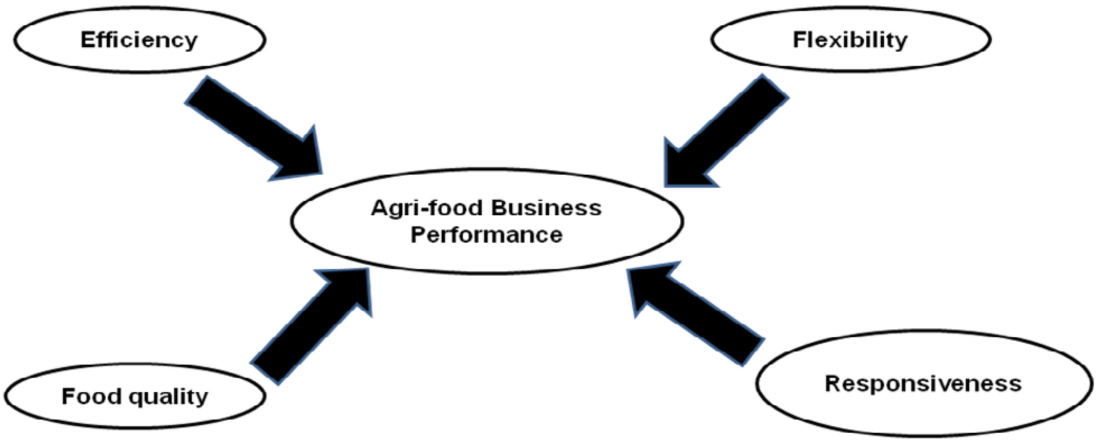

Figure. 3. Indicators of the agri-food supply chain performance

Figure (3) shows the main indicators which used to measure the success rate of the proposed solution in improving the agri-food supply chain performance in particular, and on the agri-food business performance in general. In addition those indicators are considered as the most important which are used to measure the performance in the agir-food firms' industries in general. This paper proposes an e-business model based on technological system and traceability tool, in order to monitor and organize the flow of information between agri-food supply chain processes. E-business model it is about describing the logic of the business system (processes, relations, actors) to produce and create a value (Petrovic et al., 2001). Using e-business model as an effective solution based on three critical agri-food supply chain dimensions the e-business model affects on, and those dimensions are: information technology, synchronized planning, and coordinated workflow. Furthermore adopting e-business can achieve and get a lot of benefits like reducing the costs, increased processes' flexibility, increase processes efficiency and response time. Also adopting e-business approaches for managing the processes of supply chain can realize dramatic returns through improving processes' efficiency, improving the utilization of assets, faster time to market, reduce times of order fulfillment, improving customer service and responsiveness, entering in new markets, increasing assets return, and increasing value of a shareholder (Lee & Whang 2004). The aims of this paper are to improve business performance as whole, organize bidirectional flow of information between processes, decrease cost and waste-time, increase safety and quality, and produce final agri-food products compatible with the global market standards. First of all this paper will use Supply Chain Operation (SCOR) model to define the agri-food supply chain processes and their relationships with the agri-food business performance, by using e-business model solution. This study adapted SCOR model (Zhou, 2003) to explain and show the effects of proposed solution on the agri-food supply chain processes. Figure (4) shows the agri-food supply chain processes by using SCOR model, the agri-food supply chain consists of five main processes: plan, source, make, delivery, and return. And it is difficult to organize the flow of information between those processes and apply products global standards without using a high technological system, that will eliminate the differences between them. This figure below shows how the e-business model based on technological system and traceability tool will be used to organize, manage, and share the information between all agri-food supply chain processes, and this will improve the agri-food supply chain performance in particular by (i) increasing processes' efficiency, responsiveness, flexibility, and customer satisfaction, (ii) decreasing processes' cost and lead-time to prepare product order, (iii) giving the ability to apply world standards which are related to the agri-food products specifications during production process to increase food quality and safety. Improving the supply chain performance of the agri-food business will affect the performance in a direct way. The agri-food system is complex, in which any development process in one of the departments, will change other departments or processes according to the linkage between the departments or the processes. As a result this will improve the global market position of the agri-food firm, and the food products export-ratio.

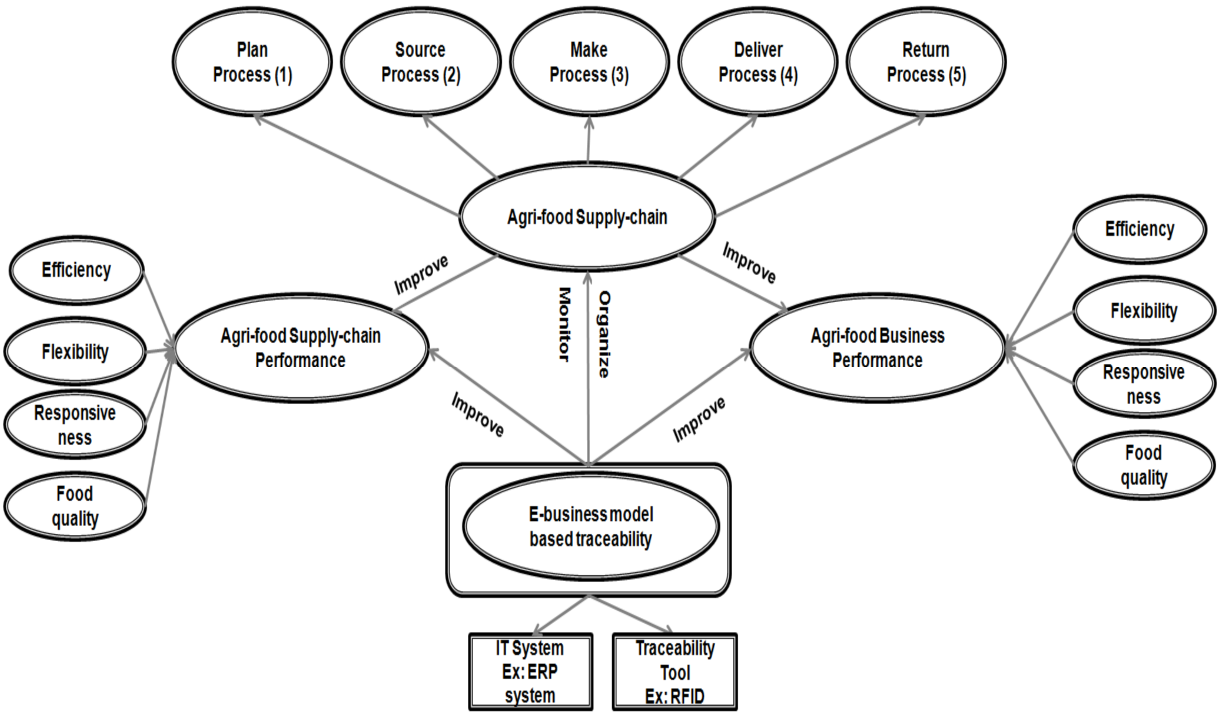

Figure. 3. Agri-food supply chain processes and e-business model through SCOR model (Zhou, 2003)

4. Conclusion

This paper considered as a part of a large study about improving agri-food supply chain performance, and the impact of ICT and e-business on the competitiveness of the agri-food productions. In this paper we proposed an e-business model for improving, monitoring, and sharing the information between agri-food supply chain processes to improve the agri-food supply chain. The e-business model built by using a technological system and traceability tool. This solution organizes the flow of information between the agri-food supply chain processes, improves agri-food supply chain performance, agri-food business performance, and agri-food market position and products export-ratio. This paper used SCOR model to define the agri-food supply chain processes and it is relationships with the agri-food supply chain performance, and agri-food business performance as whole. Four main indicators are used to measure the effects of the proposed solution on the performance as whole, and those indicators are efficiency, flexibility, responsiveness, and food quality.

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Apply lean distribution principles to food logistics

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Abstract

In the current scenario distribution network optimization is one of the most crucial topics about Supply Chain (SC) management (SCM). This element covers even more importance within the food industry where, both at the manufacturer's or wholesaler's side and at the retailer's side, the margins are continuously decreasing and the competition is struggling. Companies require the supply chain's capability to adapt or respond in a speedy manner to a changing marketplace environment. The effect is an extreme research of both efficiency and flexibility in all the logistic processes.

The aim of this paper is integrating the lean principles inside a food SC, introducing an innovative approach for the food distribution network management based on a linear programming model. The output is for each products category how lean is convenient to manage it inside the food distribution network; in other words if it is efficient to pull its demand within the SC with the same frequency/quantity of the customer and if it makes sense pulling its demand with direct deliveries with multi products pallets in terms of demand mix. In order to test the proposed model, a real application in a food SC is presented and a sensitive analysis of the lean-keys factors is developed.

Keywords: *Lean Distribution, Supply Chain, Food, Optimization*

1. Introduction and literature review

Is possible to apply the lean principles to the management of a food SC? Is it always convenient, and if not where? What kind of approach is suitable in this sense?

Generally, the Supply Chain Management (SCM) face with the typical logistics processes of procurement, sourcing, manufacturing, distribution and, especially distribution within a SC is a critical issue since decades.

One key reason for this criticality is the interdependencies among various operations and the autonomous partners across the chain, which makes all traditional myopic models invalid (Georgiadis et al., 2005). The typical objective of the SC distribution management is to achieve to serve customers expectations minimizing the related costs. This result is achievable only with a strong integration among different actors.

For these reasons in the last years some researchers started to think about the possibility to merge the principles of lean production into SC management defining a new paradigm: the Lean SC model. This approach until now has been developed especially in industrial environments. The best known by far is the lean supply model (Lamming, 1993; Womack and Jones, 1996), which has been developed within the automotive industry as a way to manage complex, tiered networks of suppliers with the goal of reducing costs and ensuring high quality.

The lean SCM model prescribes long-term relationships between customers and suppliers, based upon a close integration of both physical and informative flows, adopting practices such as EDI exchange, cost transparency, JIT with Kanban, co-design, etc (Lehtinen & Torkko, 2005). Despite the food sector's relevance, food SC has received only few attention in the literature (Rong et al., 2011). The reason of the little contributions on food SCM may be that the management of food supply chain networks is complicated by specific product and process characteristics (Van Donk et al., 2008). From this point of view the application of the lean principles to the food SCM stemming from product storage to transportation specifications make more relevant the benefits achievable (Hobbs & Young, 2000).

First peculiarity of the food SC is the great variety of products category managed, with completely different impact on logistics activities and different physical characteristics. For example the ratio between volume and value stored, the handling cost, the transportation model, the inventory costs related to the expiration date are completely different from a products category to another. For example product perishability is a typical aspect of the food SC that creates uncertainty for the buyer with respect to product quality, safety and reliability. It is strictly connected to the logistic activities of need for frequent deliveries, dedicated transportation modes and store equipments (e.g. refrigerators). Moreover a lack of efficiency in dealing with these logistics activities creates uncertainty for the seller, leaving unable to store the products awaiting favourable market conditions.

Food products usually exhibit high seasonality in raw materials availability and batch at manufacturers, and therefore they need efficiently designed storage within SC (Battini et al., 2007).

In the last years food safety issues have been profound ramifications on the supply chain design, related also with legal and regulatory aspects. Proper monitoring and response to food safety problems requires the ability to trace back small lots, from retailer to processor or even back to the supplying farm (Georgiadis et al., 2005). These elements have enforced and enlarged the use and application of special traceability equipments like MES (Manufacturing Execution System) at the manufacturer's level, or RFID (Radio Frequency identification) and Bare Code through the whole SC (Regattieri et al., 2007).

The application of the lean principles and the definition of lean SCM able to help managers in achieving efficiency in the food distribution network are today interesting and almost unexplored areas. Only few contributors have been developed in the food sector.

Lehtinen and Torkko (2005) discuss how the lean approach could be applied to a food contract manufacturer examining the structures of demand chains of different customers.

Authors do not propose a SCM model but report as results the experimental data showing how much movement is possible toward the lean supply chain and partnership-based cooperation. Simonsa and Taylor (2007) examined another case study, applying lean tools like the Value Analysis within the UK red meat industry. They introduced a framework to analyze four sub-systems: goals and values, logistics, human resources and management structure evidencing a positive potential logistics benefits along the chain using inter-company alignment chain organizational stability. Zarei et al. (2011), face with food SC proposing other lean tools like the Quality Function Deployment (QFD) to increase the leanness of the food chain.

From the literature review is evident that there is a large contribution on aspects related to the classical SCM problems like facilities allocation, deliveries optimization, reverse logistics activities and other topics (Klose & Drexl, 2005). On the other hand it is clear how, considering the problem of the lean principles application on the food SC, only few contributions are presented, but without introducing effective mathematical models and algorithms, typical of the SCM problems, that keep into account the lean factors.

Moreover whatever is the modelling approach for the food SC, the inclusion of food-specific characteristics is needed in order to achieve a successful results in this area

For this reasons the aim of this paper is to present an innovative SCM model based on linear programming techniques considering the lean principles by its key performance indicators and the specific characteristics of the food sector.

The remainder of this paper is organized as follows. In Section 2 the food SC features, the lean principles and their integration on the proposed SCM model are presented. In section 3 the proposed mathematical model is presented. In Section 4, a case study is presented to illustrate the usefulness and ease of implementation of the model. Finally, Section 5 provides the work's outcomes and the potential future research directions.

2. Lean principles apply to a food SC management

The basic concept of lean philosophy is the *Value Maximization*. The process necessary to implement this concept can be explained by the following five steps:

1. Specify value from end customer's standpoint at the product family level.
2. Identify all the steps in the value stream for each product family, eliminating whenever possible those steps that do not create value.
3. Make the value-creating steps occur in tight sequence so the product will flow smoothly toward the customer.
4. As flow is introduced, let customers pull value from the next upstream activity.
5. As value is specified, value streams are identified, wasted steps are removed, and flow and pull are introduced, begin the process again and continue it until a state of perfection is reached in which perfect value is created with no waste.

From a SCM point of view is possible to identify the value for the customer as to get the products with the expected quantity, mix, quality, availability, safety. From this point of view it occurs that all the SC follows the customers demand in terms of quantity, mix and quality with a pull philosophy, eliminating all the waste causes.

Considering the food SC, some relevant specifications respect other industries' SCs are present. These, as defined before, are principally related to the high difference of products managed in terms of value, physical characteristics, demand pattern, suppliers, safety risk, etc.

From this point of view the proposed model merges the critical aspect of the food SC with the key principles of the lean distribution in a linear programming model for the food SC management. Its output will be:

- How lean can be managed a certain product category?
- Is really always true that lean means efficiency for all the products category for the food SC?
- What happens if the lean concept is stressed for the considered product category to the logistic activities and to its related costs?
- What happens if the lean concept is stressed for the considered product category to the distribution policy within the SC (Distributor Centres and Wholesaler-Manufacturers)?

Table 1 reports the main dimension of a food SC (products, customers, suppliers) and the impacts on the logistic activities of its specifications. The related lean principles and how the proposed model merges them with the SC specification are reported in the relative row.

Distribution network angle	*Food industry supply chain features*	*Lean supply chain principles*	*Model features*
Products	- Great variety of product category managed - High differentiation on physical characteristics	- Pull philosophy focused on the market requirements. - Customers expectation on product quality, availability and safety. - Focalization on the value analyzing the key factors or the value maximization.	- Different products means different distribution strategies, the model focuses on the products category's peculiar features
Customers	- Great variety of customers typology, with different demand pattern. - High sensitivity/elasticity of customers for product attributes as quality, safety, complete availability	- Rapidness in demand response - Flexibility to operate with fluctuations	- Demand response flexible for quantity and mix. - Model considers different delivery policies (direct- indirect), using DCs or directly from manufacturer-wholesaler to customer
Suppliers	- Competition between supply chains. - Focus on the total competitiveness of a value stream versus the limited efficiency of the single part of the SC.	- Supplier is a Partner. Data interchange and interaction. - Production principles (JIT production, high rotation indexes, high physical and information flows)	- The model considers that the demand is pulled by retailers and visible inside to all SC actors. This is the reason why supplier can delivery directly to the retailers
Network operations	- Necessity of high rotation indexes and different management for different products category. - Dedicated way of transportation (e.g. refrigerators). - High variability mix/ quantity/frequency of deliveries. Necessity to small lot delivered in multi product pallet	- All the actors of the SC have to follow the market demand for quantity, frequency and mix - Deliveries pulled by final demand in mix/quantity/ frequency.	The model works for products category minimizing the total costs. Lean KPIs are: - the rotation index balance level through the SC - the feasibility to manage direct deliveries from manufacturers-wholesalers using multiproduct pallets.

Table 1. Food SC specification, lean principles and model integration

In order to link the lean principles to the food SC specification:

- Each product category (PC) is considered once at time in the model, and all its specification are considered as input data.
- It is considered the complete integration with suppliers and the complete data interchange, with the possibility to optimize the deliveries using also direct or indirect shipments from manufacturers-wholesalers.

Moreover for each product category are also considered two main lean KPIs:

- *Rotation Indices Balance.* Pull philosophy from a demand quantity point of view: for a certain product category to analyze if and how is convenient to consider its physical flow directly pulled by the final demand within the SC, in function of the rotation indices balance between the actors its effect on the SC (Retailers - Distribution Centres - Manufacturers/Wholesalers).
- *Upstream multi products pallet feasibility*. Pull philosophy from a demand variety point of view: for a certain products category to analyze (according its real feasibility) what is the impact of deliveries from the Manufacturer/Wholesaler level to Retailer with different level of multi products pallet.

These two lean KPIs jointed together with the product category attributes are the inputs of the model. The KPIs variation, and its impact on the total costs and on the distribution policy gives as output if and how is ideally convenient to manage with a lean approach certain product category.

The real constrains for the application of such approach define the feasible solution. Figure 1 shows the lean SCM model.

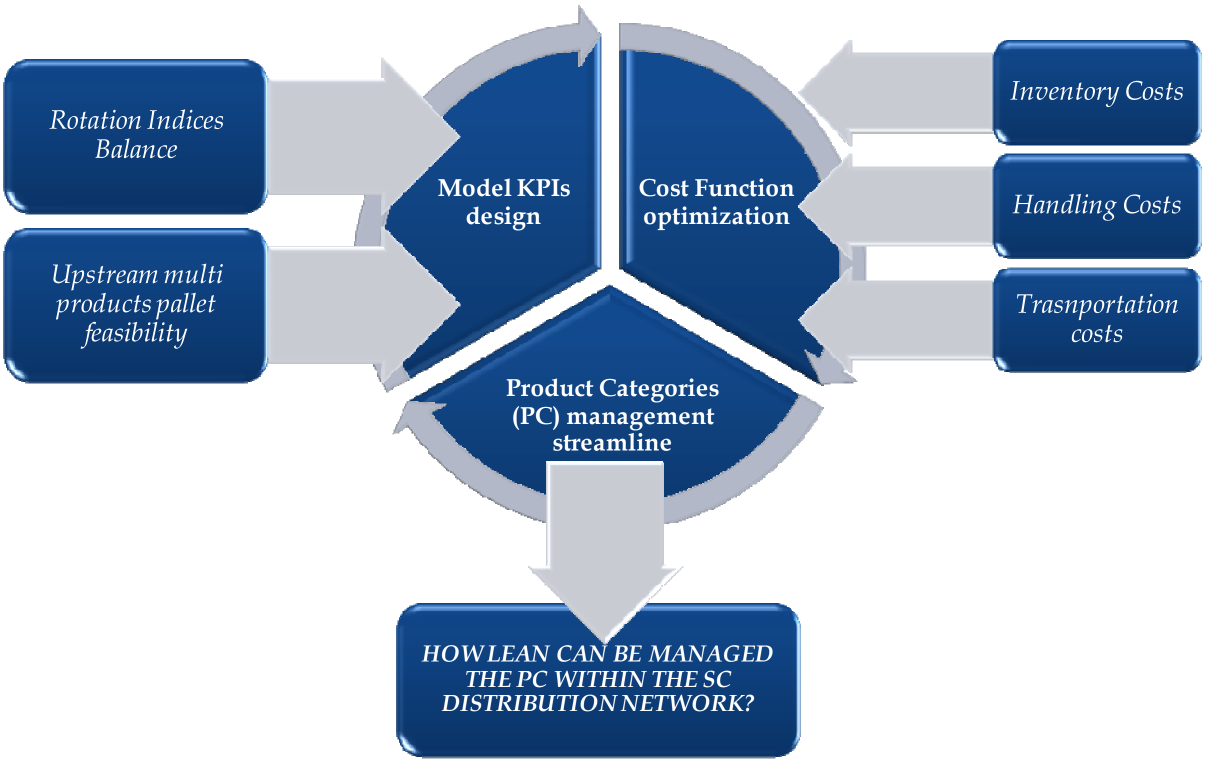

Fig. 1. Lean SCM model flow chart

According the two identified lean KPIs, respecting the value giving by the cost function optimization (especially for the rotation index), and respecting the real constrains (especially for the multi products pallets feasibility at the Manufacturer/Wholesaler level) each product category considered can be placed in one of the 4 different zones defined in Figure 2. The dark blue zone represents the pure lean distribution philosophy where demand pull directly all the levels of SC for quantity and mix.

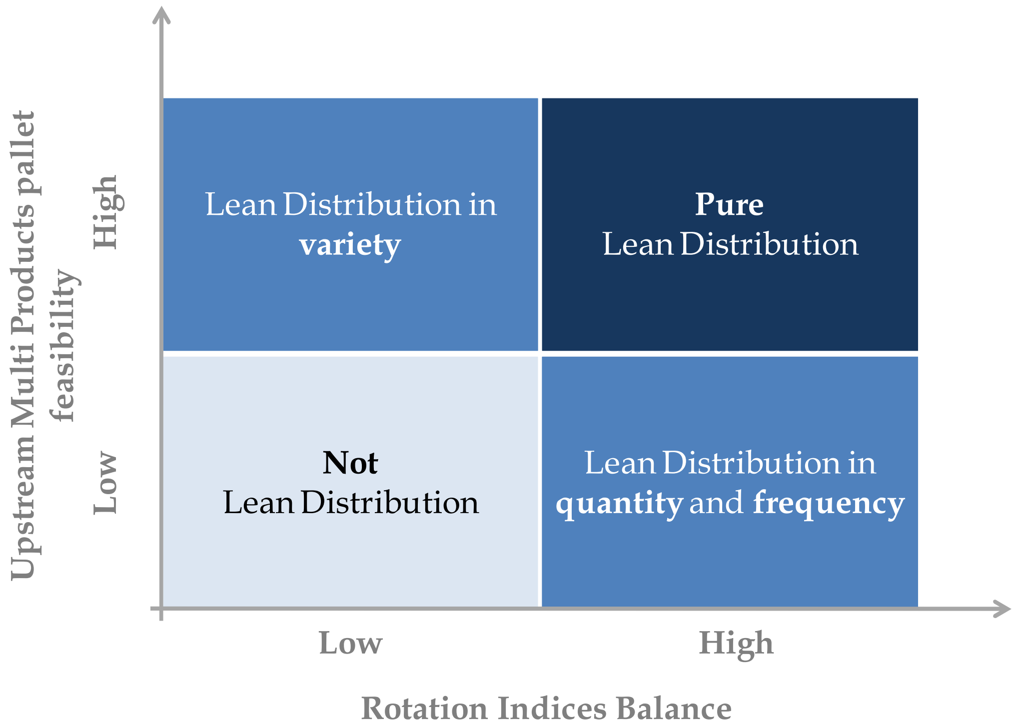

Fig. 2. Lean Matrix: lean model KPIs and lean distribution feasibility

3. The food SC lean model definition

The proposed model considers a three stages distribution network: first level, the Manufacturers-Wholesales (*M*), second level, the Distribution Centers (*DC*) that can be used to deliver goods, and third level, the Retailers (*R*).
All the data are referred to a certain planned period (i.e. year).
Figure 3 shows the considered SC structure.

Indices
i: manufacturer/wholesaler (*M*); $i = 1, \ldots, I$
j: Distributor Center (*DC*); $j = 1, \ldots, J$
k: retailer (*R*); $k = 1, \ldots, K$
l: product category (*PC*); $l = 1, \ldots, L$

Decision Variables
$X1_{i,j,l}$: quantity of product's categories delivered PC_l from M_i to DC_j (m^3).
$X2_{j,k,l}$: quantity of product's categories delivered PC_l from DC_j to R_k (m^3).
$X3_{i,k,l}$: quantity of product's categories delivered PC_l from M_i to R_k (m^3).

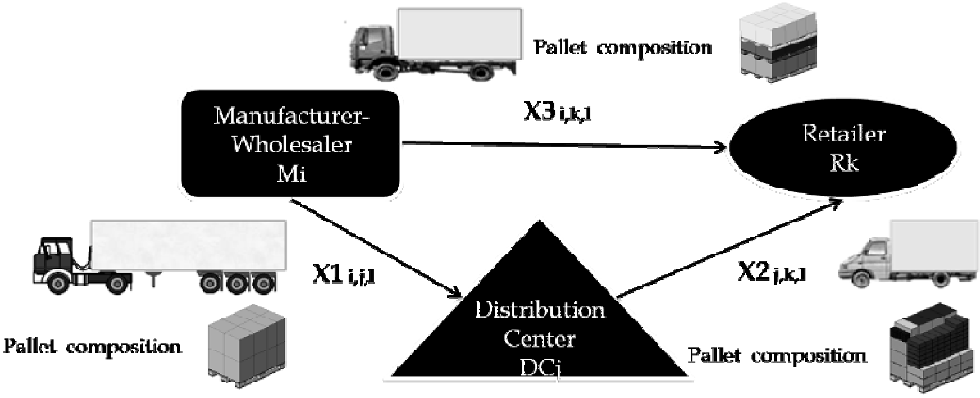

Fig. 3. Considered food SC

Assumptions

- The demand is pulled by Retailers, the SC actors having direct contact with end customers.
- Inventory costs at each SC stage depend on their Safety Stock level and their average level of stocks, by the quantity delivered and by the rotation index of each product category.
- The transports are executed by three different types of trucks, T_1, T_2 and T_3:
  - T_1 truck in use on the routes from M_i to DC_j ; *volume* capacity, 90 m^3, *weight* capacity, 22 tons;
  - T_2 truck in use on the routes from DC_j to R_k ; *volume* capacity, 15 m^3, *weight* capacity, 3.5 tons;
  - T_3 truck in use on the routes from M_i to R_k ; *volume* capacity, 45 m^3, *weight* capacity, 9 tons;

Their capacity limits in weight and volume are considered in order to estimate the specific transportation cost for each products category.

- In the planned period (year) the total quantity of different products category demanded is equal to the quantity produced/sold at the manufacturers/wholesalers.
- DC_j receives goods from M_i and processes them for reshipment to customers with handling costs (depending on product's families) and inventory costs (depending on product's quantity). Other handling costs are not considered because they are always presented.
- The rotation index at the R_k level depends on the product category considered. The relative rotation index at DC_j and Mi is considered minor or equal.
- The service level considered is equal to100%. Safety stock will be dimensioned consequently.

Input Data

H_l: handling cost per cube meter of product's category PC_l (€/m^3).
C_l: cost per cube meter of product's category PC_l (€/m^3).

$s1_i$: inventory cost rate at M_i.
$s2_j$: inventory cost rate at DC_j.
$s3_k$: inventory cost rate at R_k.

The last set of parameters models the unitary inventory cost, function of capital costs, storage space costs, inventory risk costs, including obsolescence, deterioration, pilferage.

$TL1_{i,j}$: transportation limited capacity from M_i to DC_j in a trip (m^3/truck).
$TL2_{j,k}$: transportation limited capacity from DC_j to R_k in a trip (m^3/truck).
$TL3_{i,k}$: transportation limited capacity from M_i to R_k in a trip (m^3/truck).
CT^*: specific transportation cost, depending on the specific truck used (€/m^3)
MLF_l: maximum load factor or volume saturation level, function of the product category and of the truck used (%).
For each couple *i,j; j,k; i,k* is possible to define:

$$CT_l = \frac{CT^*}{MLF_l \times TL} \quad (1)$$

Obtaining:
$CT1_l$: transportation cost of a cube meter of product's category PC_l using the truck type 1 (€/km m^3) from M_i to DC_j.
$CT2_l$: transportation cost of a cube meter of product's category PC_l using the truck type 2 (€/km m^3) from DC_j to R_k.
$CT3_l$: transportation cost of a cube meter of product's category PC_l using the truck type 3 (€/km m^3) from M_i to R_k..

$MC_{k,l}$: total demand matrix of product's category PC_l ordered by retailer R_k (m^3/year).
$MD1_{i,j}$: distance matrix from M_i to DC_j, (km).
$MD2_{j,k}$: distance matrix from DC_j to R_k (km).
$MD3_{i,k}$: distance matrix from M_i to R_k (km).

$R1_{i,l}$: rotation index target for product's category PC_l at M_i (/year).
$R2_{j,l}$: rotation index target for product's category PC_l at DC_j (/year).
$R3_{k,l}$: rotation index target for product's category PC_l at R_k (/year).
This set of parameters models the *rotation indices balance* KPI.

$SS1_{i,l}$: safety stock in M_i of product's category PC_l calculated with the following formula (Persona et al., 2007):

$$SS1_{i,l} = K1_{i,l} \cdot \sigma 1\%_{i,l} \cdot F1_{i,l} \cdot \sqrt{LT1_{i,l}} \quad (2)$$

$SS2_{j,l}$: safety stock in DC_j of product's category PC_l calculated with the following formula (Persona et al., 2007):

$$SS2_{j,l} = K2_{j,l} \cdot \sigma 2\%_{j,l} \cdot F2_{j,l} \cdot \sqrt{LT2_{j,l}} \quad (3)$$

$SS3_{i,l}$: safety stock in R_k for the product's category PC_l calculated with the following formula (Persona et al., 2007):

$$SS3_{k,l} = K3_{k,l} \cdot \sigma 3\%_{k,l} \cdot F3_{k,l} \cdot \sqrt{LT3_{k,l}} \quad (4)$$

Where related to the nodes *i,j,k:*
k: adjusting parameter for customer service level.
SL_l: service level of the product category *l*.
σ : standard percentage demand deviation of the product's family PC_l
LT: supply lead time (weeks).
F: forecasted annual demand of the product's category PC_l directly delivered to the DC_j (m^3). The model assumes that the forecasted annual demand of the product's category PC_l derives from the historical annual demand.

$$F1_{i,l} = \sum_j X1_{i,j,l} + \sum_k X3_{i,k,l} \tag{5}$$

$$F2_{j,l} = \sum_k X2_{i,k,l} \tag{6}$$

$$F3_{k,l} = \sum_j X2_{j,k,l} + \sum_i X3_{i,k,l} \tag{7}$$

$NPC1_{i,j}$: average number of type of products category delivered from M_i to DC_j in a trip.
$NPC2_{j,k}$: average number of type of products category delivered from DC_j to R_k in a trip.
$NPC3_{i,k}$: average number of type of products category delivered from M_i to R_k in a trip.
NPC parameters model mathematically the concept of *upstream multi products pallet feasibility* KPI.

Cost functions
Minimize the total cost for product category PC_l using:

$$TotC_l = IC_l + HC_l + TC_l \tag{8}$$

Where:
IC_l : Inventoryl cost for product category PC_l.
It represents costs incurred by warehousing and storage activities. Usually, direct delivery reduces safety stock inventories, while the presence of intermediate warehouses increases safety stocks. The formula calculated the inventory costs as function of the safety stock installed at the considered point (retailer or distribution center) and by the average level of stock.

$$IC_l = (\sum_i \sum_j \frac{X1_{i,j,l}}{R1_{i,l}} \cdot s1_i + \sum_i \sum_k \frac{X3_{i,k,l}}{R1_{i,l}} \cdot s1_i) \cdot c_l + \sum_j \sum_k \frac{X2_{j,k,l}}{R2_{j,l}} \cdot s2_j \cdot c_l + (\sum_j \sum_k \frac{X2_{j,k,l}}{R3_{k,l}} \cdot s3_k + \sum_i \sum_k \frac{X3_{i,k,l}}{R3_{k,l}} \cdot s3_k) \cdot c_l + \sum_i SS1_{i,l} \cdot c_l \cdot s1_i + \sum_j SS2_{j,l} \cdot c_l \cdot s2_j + \sum_k SS3_{k,l} \cdot c_l \cdot s3_k \tag{9}$$

HC_l : Handling Cost for product category PC_l
When products are moved from plant to trucks, from truck to customers, from truck to

intermediate warehouse and from warehouse to trucks again, handling costs are inevitable. In this model, handling costs in manufacturer plants and in customers' sites are always generated, so they can be omitted in the calculation. The model considers only handling costs due to the transit of products through the distribution centers, which is a direct function of the volume moved and depends on the characteristics of the product category.

$$HC_l = \sum_i \sum_j X1_{i,j,l} \cdot H_l \tag{10}$$

TC_l : Transportation cost for product category PC_l

Transportation costs include all costs involved in the movement or transport of a shipment. The costs vary considerably with volume, weight of shipment, distances, transport mode, etc. Different correlated factors make up the transportation costs considered in this model: distance, goods delivery quantities, physical characteristics of goods delivered, transportation policy and transportation way used, saturation level at the truck level in function of the type of transportation. The specific transportation costs (€/km m^3) have been calculated estimating the cost for kilometer in function of the type of truck, and dividing it for the maximum quantity of m^3 possible to load of the considered product category. The model developed is based on specific transportation cost data, obtained by combining the different factors described above and expressed in Euro per cube meter of goods according the trip.

$$\begin{aligned} TC_l = &\sum_i \sum_j \frac{R2_{j,l} \cdot X1_{i,j,l} \cdot CT1_l \cdot MD1_{i,j}}{NPC1_{i,j}} + \sum_j \sum_k \frac{R3_{k,l} \cdot X2_{j,k,l} \cdot CT2_l \cdot MD2_{j,k}}{NPC2_{j,k}} \\ &+ \sum_i \sum_k \frac{R3_{k,l} \cdot X3_{i,k,l} \cdot CT3_l \cdot MD3_{i,k}}{NPC3_{i,k}} \end{aligned} \tag{11}$$

Subject to:

$$\sum_i X3_{i,k,l} + \sum_j X2_{j,k,l} = MC_{k,l\cdot} \cdot (1 - SL_l) \tag{12}$$

$$\sum_i X1_{i,j,l} = \sum_k X2_{j,l,k} \tag{13}$$

$$\sum_k X3_{i,k,l} + \sum_j X1_{j,k,l} \leq MW_{i,l\cdot} \tag{14}$$

The first constraint ensures that all the goods delivered to the retailer are consumed in the planned period. The second constraint ensures that all the goods received by each DC_j are delivered to the retailers in the planned period. The third constraint ensures that the production capacity at each M_i is greater than the demand for each product category.

4. Applicative case

The following industrial application aims to explain how lean distribution can deal with a food supply chain features and problems.

In particular this application's goal is researching how different food product categories should be managed within a distribution network and how the different distributive policies can be supported by the Lean concepts.

The considered network (as shown in Figure 4) is a three level supply chain, a subset of a bigger distribution network managed by a mid-size Italian supermarket chain.

At the first level there are six manufacturers, or large wholesalers, producing, or selling, different food product categories, indexed from M_1 to M_6.

Then at the second level we considered two different distribution centres, DC_1 and DC_2.

Finally, downstream, twelve different retailers (i.e.: supermarkets) are placed, indexed from R_1 to R_{12}.

The location of each point in the network is reported by Table 2, while Table 3 shows the distances among the different points.

About the analyzed product categories we considered six different ones, indexed from PC_1 to PC_6: three of them belong to the *packed food* cluster, basically the food not perishable in the short term, one belong to the *fresh products* cluster, another one to the *fruits and vegetable* cluster and the last one to the *frozen foods*.

Table 4 shows the average value for each product category, the related rotation index requested at the retailer/supermarket level, the specific handling cost and the inventory cost rate.

Table 5 and table 6, respectively the *demand* matrix and the *delivery* matrix report the quantities related to the flow of materials on yearly basis.

Transportation constraints and the related costs have been modelled considered the following aspects, as shown in table 7:

- For each main route of the network ($x1_{i,j}$ $x2_{j,k}$ $x3_{i,k}$) are made available only one truck category: as shown, both the maximum capacity in *volume* (VTC, Volume Track Capacity) and in *weight* (WTC, Weight Truck Capacity) have been calculated.
- Each type of truck has a different specific transportation cost

Furthermore, considering that a different product category presents different features in terms of volume, weight and perishability a matrix has been designed to model the transportations costs both on the truck dimension and on the product category dimension.

For each product category the inventory cost rate has been estimated.

In terms of service level, in order to respect the lean principles, this parameter has been defined as 100%.

Other data from the applicative case are:

- Planned period equal to one year
- Lead time equal to five working days

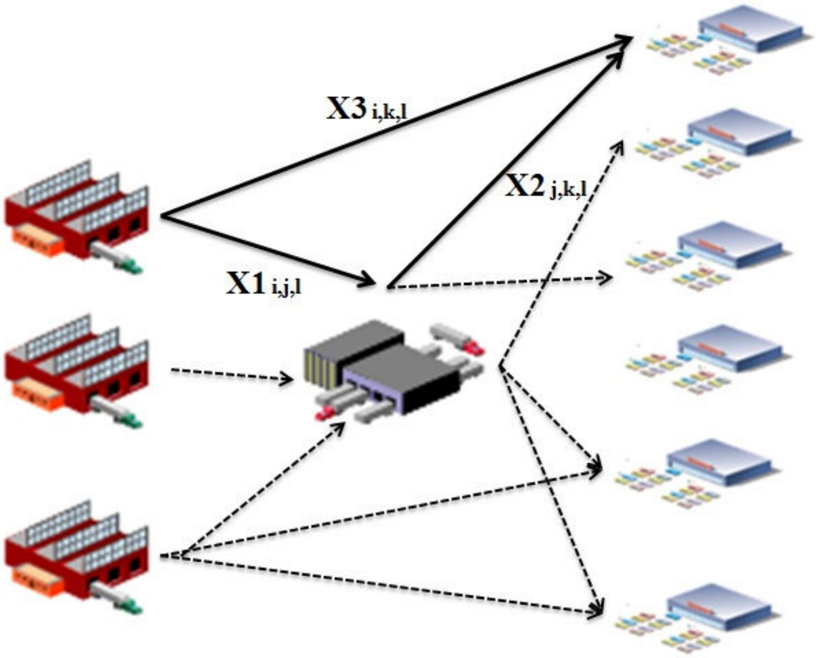

Fig. 4. Applicative case distribution network

	Supply Chain Actor	*Location*	*Region*
W1	Manufacturer/Wholesaler 1	Turin	Piedmont
W2	Manufacturer/Wholesaler 2	Parma	Emilia Romagna
W3	Manufacturer/Wholesaler 3	Milan	Lombardy
W4	Manufacturer/Wholesaler 4	Brescia	Lombardy
W5	Manufacturer/Wholesaler 5	Verona	Veneto
W6	Manufacturer/Wholesaler 6	Treviso	Veneto
DC1	Distribution Center 1	Milan	Lombardy
DC2	Distribution Center 2	Vicenza	Veneto
R1	Retailer 1	Alessandria	Piedmont
R2	Retailer 2	Turin	Piedmont
R3	Retailer 3	Vercelli	Piedmont
R4	Retailer 4	Bergamo	Lombardy
R5	Retailer 5	Brescia	Lombardy
R6	Retailer 6	Milan	Lombardy
R7	Retailer 7	Pavia	Lombardy
R8	Retailer 8	Padua	Veneto
R9	Retailer 9	Venice	Veneto
R10	Retailer 10	Verona	Veneto
R11	Retailer 11	Bolzano	Trentino Alto Adige
R12	Retailer 12	Udine	Friuli Venezia Giulia

Table 2. Food network actors and their location

Distance (Km)	*DC1*	*DC2*	*R1*	*R2*	*R3*	*R4*	*R5*	*R6*	*R7*	*R8*	*R9*	*R10*	*R11*	*R12*
W1	142	339	95	12	82	182	230	155	167	373	413	295	442	520
W2	125	192	164	243	209	162	117	125	113	210	250	144	282	360
W3	15	216	97	141	86	60	107	23	41	247	284	171	307	398
W4	101	120	184	230	174	55	11	100	135	152	188	73	210	299
W5	161	60	242	291	236	116	72	161	194	90	126	8	154	236
W6	297	94	377	426	370	251	205	297	328	71	45	144	291	129
DC1	0	0	99	142	87	60	110	13	41	247	284	170	311	395
DC2	0	0	293	343	287	168	125	211	244	45	83	60	207	192

Table 3. Distance matrix

	Cluster	*Description*	*Average value* (€/m^3)	*Average Retailer Rotation Index* (/year)	*Handling cost* (€/m^3)	*Inventory Cost Rate* (%)
PC1	Packed Food	Mineral Water	50	10	5	20%
PC2	Packed Food	Pasta	1,200	15	5	20%
PC3	Packed Food	Canned Food	2,500	7	5	30%
PC4	Fresh Products	Parmigiano Cheese	20,000	30	10	40%
PC5	Fruits & Vegetables	Carots	2,000	300	10	90%
PC6	Frozen Food	Ice-cream	4,000	50	15	70%

Table 4. Product Categories main features

(m3)	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	TOT.
PC1	1,000	862	936	993	939	972	1,184	1,007	855	811	824	1,152	11,535
PC2	200	228	201	183	200	217	189	202	205	237	211	180	2,453
PC3	40	35	32	36	40	38	32	40	47	34	32	43	449
PC4	20	23	18	18	21	24	19	23	21	22	23	24	256
PC5	7	8	6	6	7	8	7	8	7	10	6	5	85
PC6	15	13	14	16	12	15	16	18	18	14	14	13	178
TOT.	1,282	1,169	1,207	1,252	1,219	1,274	1,447	1,298	1,153	1,128	1,110	1,417	

Table 5. Demand matrix

(m3)	W1	W2	W3	W4	W5	W6	TOT.
PC1			8,000			6,000	14,000
PC2		3,000					
PC3			1,000				
PC4		1,000					
PC5	50				60		
PC6	100				150		
TOT.	150	4,000	9,000	-	210	6,000	

Table 6. Delivery matrix

Truck	*From*	*To*	*VTC* (m^3/truck,trip)	*WTC* (kg x 1000/truck,trip)	*Average Specific Trasportation Cost* (€/Km)
Type 1	Wi	DCj	90	22	1.5
Type 2	DCj	Rk	15	3.5	0.7
Type 3	Wi	Rk	45	9	1.1

Table 7. Transportation features

	Cluster	*Description*	*Specific Trasportation Cost, Type 1 Truck* (€/Km x m^3)	*Specific Trasportation Cost, Type 2 Truck* (€/Km x m^3)	*Specific Trasportation Cost, Type 3 Truck(€/Km x m3)*
PC1	Packed Food	Mineral Water	0.076	0.272	0.118
PC2	Packed Food	Pasta	0.056	0.196	0.086
PC3	Packed Food	Canned Food	0.208	0.817	0.324
PC4	Fresh Products	Parmigiano Cheese	0.125	0.490	0.194
PC5	Fruits & Vegetables	Carots	0.067	0.245	0.104
PC6	Frozen Food	Ice-cream	0.097	0.327	0.151

Table 8. Transportation costs

The following tables group the key input data for each product category and their relative rating.

Variable	*Description*	*Unit of Measure*	*Rating*
C	Product's category average value	(€/m3)	•
H	Handling cost	(€/m3)	• •
CT	Average Specific Trasportation Cost	(€/Km x m3)	• • •
R3	Retailer Rotation index	(/year)	• • •
s	Inventory Cost Rate	(%)	•
NPC3	Multiproducts Pallet Feasibility at Mi	(avg # of PCs/pallet)	•

Table 9. Mineral water input data table

Variable	*Description*	*Unit of Measure*	*Rating*
C	Product's category average value	(€/m3)	• •
H	Handling cost	(€/m3)	• •
CT	Average Specific Trasportation Cost	(€/Km x m3)	• •
R	Retailer Rotation index	(/year)	• • •
s	Inventory Cost Rate	(%)	•
NPC3	Multiproducts Pallet Feasibility at Mi	(avg # of PCs/pallet)	• •

Table 10. Pasta input data table

Variable	*Description*	*Unit of Measure*	*Rating*
C	Product's category average value	(€/m3)	• • •
H	Handling cost	(€/m3)	• •
CT	Average Specific Trasportation Cost	(€/Km x m3)	• • • • •
R	Retailer Rotation index	(/year)	• •
s	Inventory Cost Rate	(%)	• •
NPC3	Multiproducts Pallet Feasibility at Mi	(avg # of PCs/pallet)	• •

Table 11. Canned food input data table

Variable	*Description*	*Unit of Measure*	*Rating*
C	Product's category average value	(€/m3)	● ● ● ● ●
H	Handling cost	(€/m3)	● ● ●
CT	Average Specific Trasportation Cost	(€/Km x m3)	● ● ●
R	Retailer Rotation index	(/year)	● ● ● ●
s	Inventory Cost Rate	(%)	● ● ●
NPC3	Multiproducts Pallet Feasibility at Mi	(avg # of PCs/pallet)	● ● ●

Table 12. Parmigiano Cheese input data table

Variable	*Description*	*Unit of Measure*	*Rating*
C	Product's category average value	(€/m3)	● ● ●
H	Handling cost	(€/m3)	● ● ● ●
CT	Average Specific Trasportation Cost	(€/Km x m3)	● ●
R	Retailer Rotation index	(/year)	● ● ● ● ●
s	Inventory Cost Rate	(%)	● ● ● ● ●
NPC3	Multiproducts Pallet Feasibility at Mi	(avg # of PCs/pallet)	● ● ● ● ●

Table 13. Carrots input data table

Variable	*Description*	*Unit of Measure*	*Rating*
C	Product's category average value	(€/m3)	● ● ● ●
H	Handling cost	(€/m3)	● ● ● ● ●
CT	Average Specific Trasportation Cost	(€/Km x m3)	● ● ●
R	Retailer Rotation index	(/year)	● ● ●
s	Inventory Cost Rate	(%)	● ● ● ●
NPC3	Multiproducts Pallet Feasibility at Mi	(avg # of PCs/pallet)	● ● ● ●

Table 14. Ice-cream input data table

For each product category the total distribution network cost has been calculated as a sum of the different contributions: transportation costs, inventory costs and handling cost. Every product category management costs simulation has been replicated in order to perform a sensitivity analysis on the focal *lean* KPIs of the model:

- Rotation Indices Balance
- Upstream Multi Products pallet feasibility

The optimal solution for each product category is that solution minimizing the overall costs and at the same time respects the constraints of the peculiar supply chain.
In the following table the spectrum of the potential optimal solutions has been highlighted in light grey, the optimal solution in dark grey.

	Input Data						Output Data								
Run	*r1*	*r2*	*r3*	*NPC1*	*NPC2*	*NPC3*	*TotC*	*TC*	*HC*	*IC*	*X2*	*X3*	*X TOT*	*X2 %*	*X3 %*
1	2	7	22	1	20	3	157,000	90,084	-	66,911	-	11,535	11,535	0%	100%
2	8	13	22	1	20	3	276,940	202,630	42,620	31,697	8,524	3,011	11,535	74%	26%
3	22	22	22	1	20	3	403,600	324,210	57,675	21,718	11,535	-	11,535	100%	0%
4	2	7	22	1	20	8	100,690	33,781	-	66,911	-	11,535	11,535	0%	100%
5	8	13	22	1	20	8	158,420	129,950	4,055	24,419	811	10,724	11,535	7%	93%
6	22	22	22	1	20	8	341,190	311,840	13,210	16,137	2,642	8,893	11,535	23%	77%
7	2	7	22	1	20	20	80,423	13,512	-	66,911	-	11,535	11,535	0%	100%
8	8	13	22	1	20	20	77,705	54,050	-	23,654	-	11,535	11,535	0%	100%
9	22	22	22	1	20	20	163,120	148,640	-	14,479	-	11,535	11,535	0%	100%

Table 15. Mineral water output data table

Upstream multi products pallet feasibility

Due to the upstream manufacturers/wholesaler features within this product category, only NPC_3 very low are considered feasible: beverage makers or sellers never will compose a pallet dedicated to the specific retailer's requirements.

Rotation Indices Balance

In terms of rotation indices balance it is observed that the most cost effective solution is setting different values at the different stages of the food SC.

Positioning on Lean Matrix

For the above considerations this approach does not suggest at all to adopt the lean distribution to optimize the distribution network for mineral water product category.

Distribution strategy

The distribution strategy finally to be adopted, according to the simulation outcomes, provides direct delivery from the manufacturers/wholesalers M_i to the retailers R_k.

	Input Data						Output Data								
Run	*r1*	*r2*	*r3*	*NPC1*	*NPC2*	*NPC3*	*TotC*	*TC*	*HC*	*IC*	*X2*	*X3*	*X TOT*	*X2 %*	*X3 %*
1	2	5	18	1	20	3	375,190	27,740	-	347,450	-	2,453	2,453	0%	100%
2	7	11	18	1	20	3	234,280	97,091	-	137,190	-	2,453	2,453	0%	100%
3	18	18	18	1	20	3	328,530	229,040	3,045	96,441	609	1,844	2,453	25%	75%
4	2	5	18	1	20	8	357,850	10,402	-	347,450	-	2,453	2,453	0%	100%
5	7	11	18	1	20	8	173,600	36,409	-	137,190	-	2,453	2,453	0%	100%
6	18	18	18	1	20	8	179,420	93,623	-	85,792	-	2,453	2,453	0%	100%
7	2	5	18	1	20	20	351,610	4,161	-	347,450	-	2,453	2,453	0%	100%
8	7	11	18	1	20	20	151,750	14,563	-	137,190	-	2,453	2,453	0%	100%
9	18	18	18	1	20	20	123,240	37,450	-	85,792	-	2,453	2,453	0%	100%

Table 16. Pasta output data table

Upstream multi products pallet feasibility

Due to the upstream manufacturers/wholesaler features within this product category, only NPC_3 very low are considered feasible: beverage makers or sellers never will compose a pallet dedicated to the specific retailer's requirements.

Rotation Indices Balance

In terms of rotation indices balance it is observed that the most cost effective solution should be setting rotation indices along the SC partially pulled from downstream.

Positioning on Lean Matrix

For the above considerations this approach suggests to move toward the lean distribution archetype only, and partially, in terms of *Rotation Indices Balance*.

Distribution strategy

The distribution strategy finally to be adopted, according to the simulation outcomes, provides direct delivery from the manufacturers/wholesalers M_i to the retailers R_k.

	Input Data						Output Data								
Run	r1	r2	r3	NPC1	NPC2	NPC3	TotC	TC	HC	IC	X2	X3	X TOT	X2 %	X3 %
1	1	4	12	1	20	3	384,700	8,226	-	376,470	-	449	449	0%	100%
2	4	7	12	1	20	3	156,810	32,906	-	123,910	-	449	449	0%	100%
3	12	12	12	1	20	3	119,500	29,909	1,355	88,237	271	178	449	60%	40%
4	1	4	12	1	20	8	379,550	3,085	-	376,470	-	449	449	0%	100%
5	4	7	12	1	20	8	136,250	12,340	-	123,910	-	449	449	0%	100%
6	12	12	12	1	20	8	102,500	24,255	650	77,594	130	319	449	29%	71%
7	1	4	12	1	20	20	377,700	1,234	-	376,470	-	449	449	0%	100%
8	4	7	12	1	20	20	128,840	4,936	-	123,910	-	449	449	0%	100%
9	12	12	12	1	20	20	82,589	14,808	-	67,782	-	449	449	0%	100%

Table 17. Canned Food output data table

Upstream multi products pallet feasibility

Due to the upstream manufacturers/wholesaler features within this product category, higher NPC_3 values are allowed in comparison to *mass* products' categories such as beverage and pasta.

Rotation Indices Balance

In terms of rotation indices balance it is observed that the most cost effective solution is, potentially, setting the same (or similar) rotation indices along the supply chain in order the upstream flow of material is perfectly pulled by the end customer' demand.

Positioning on Lean Matrix

For the above considerations this approach suggests to follow the lean distribution fully in terms of rotation indices balance and partially in terms of upstream multi products pallet feasibility: in other words a lean distribution in quantity and frequency.

Distribution strategy

The distribution strategy finally to be adopted, according to the simulation outcomes, provides both direct deliveries, mainly, from the manufacturers/wholesalers M_i to the retailers R_k (~70% in volumes) but also deliveries by distribution centers (DC_j).

	Input Data						Output Data								
Run	r1	r2	r3	NPC1	NPC2	NPC3	TotC	TC	HC	IC	X2	X3	X TOT	X2 %	X3 %
1	3	9	30	1	20	3	831,820	9,996	-	821,830	-	256	256	0%	100%
2	11	18	30	1	20	3	361,990	36,651	-	325,340	-	256	256	0%	100%
3	30	30	30	1	20	3	307,380	99,958	-	207,430	-	256	256	0%	100%
4	3	9	30	1	20	8	825,570	3,748	-	821,830	-	256	256	0%	100%
5	11	18	30	1	20	8	339,090	13,744	-	325,340	-	256	256	0%	100%
6	30	30	30	1	20	8	244,910	37,484	-	207,430	-	256	256	0%	100%
7	3	9	30	1	20	20	823,330	1,499	-	821,830	-	256	256	0%	100%
8	11	18	30	1	20	20	330,840	5,497	-	325,340	-	256	256	0%	100%
9	30	30	30	1	20	20	222,420	14,994	-	207,430	-	256	256	0%	100%

Table 18. Parmigiano Cheese output data table

Upstream multi products pallet feasibility

Due to the upstream manufacturers/wholesaler features within this product category, higher NPC_3 values are allowed in comparison to *mass* products' categories.

Rotation Indices Balance

In terms of rotation indices balance it is observed that the most cost effective solution is, potentially, setting the same (or similar) rotation indices along the supply chain in order the upstream flow of material is perfectly pulled by the end customer' demand.

Positioning on Lean Matrix

For the above considerations this approach suggests to follow the lean distribution fully in terms of rotation indices balance and partially in terms of upstream multi products pallet feasibility: in other words a lean distribution in quantity and frequency.

Distribution strategy

The distribution strategy finally to be adopted, according to the simulation outcomes, provides direct delivery from the manufacturers/wholesalers M_i to the retailers R_k.

	Input Data						Output Data								
Run	*r1*	*r2*	*r3*	*NPC1*	*NPC2*	*NPC3*	*TotC*	*TC*	*HC*	*IC*	*X2*	*X3*	*X TOT*	*X2 %*	*X3 %*
1	29	96	320	1	20	3	18,819	7,210	110	11,599	11	74	85	13%	87%
2	115	192	320	1	20	3	28,037	18,759	430	8,847	43	42	85	51%	49%
3	320	320	320	1	20	3	48,335	39,744	500	8,091	50	35	85	59%	41%
4	29	96	320	1	20	8	14,310	3,261	-	11,050	-	85	85	0%	100%
5	115	192	320	1	20	8	18,504	10,642	150	7,713	15	70	85	18%	82%
6	320	320	320	1	20	8	31,952	23,969	370	7,613	37	48	85	44%	56%
7	29	96	320	1	20	20	12,354	1,304	-	11,050	-	85	85	0%	100%
8	115	192	320	1	20	20	12,184	4,675	80	7,429	8	77	85	9%	91%
9	320	320	320	1	20	20	19,150	12,383	110	6,657	11	74	85	13%	87%

Table 19. Carrots output data table

Upstream multi products pallet feasibility

Due to the upstream manufacturers/wholesaler features within this product category, the top NPC_3 values are allowed in this fresh food supply chain.

Rotation Indices Balance

In terms of rotation indices balance it is observed that the most cost effective solution should be setting rotation indices along the SC partially pulled from downstream.

Positioning on Lean Matrix

For the above considerations this approach suggests to follow the lean distribution fully in terms of upstream multi products pallet feasibility and partially in terms of rotation indices balance: in other words a lean distribution in variety.

Distribution strategy

The distribution strategy finally to be adopted, according to the simulation outcomes, provides mostly direct delivery (~90% in volumes) from the manufacturers/wholesalers M_i to the retailers R_k.

	Input Data						Output Data								
Run	*r1*	*r2*	*r3*	*NPC1*	*NPC2*	*NPC3*	*TotC*	*TC*	*HC*	*IC*	*X2*	*X3*	*X TOT*	*X2 %*	*X3 %*
1	1	4	12	1	20	3	558,180	990	-	557,190	-	178	178	0%	100%
2	4	7	12	1	20	3	187,350	3,960	-	183,390	-	178	178	0%	100%
3	12	12	12	1	20	3	112,200	11,881	-	100,320	-	178	178	0%	100%
4	1	4	12	1	20	8	557,560	371	-	557,190	-	178	178	0%	100%
5	4	7	12	1	20	8	184,870	1,485	-	183,390	-	178	178	0%	100%
6	12	12	12	1	20	8	104,770	4,455	-	100,320	-	178	178	0%	100%
7	1	4	12	1	20	20	557,330	149	-	557,190	-	178	178	0%	100%
8	4	7	12	1	20	20	183,980	594	-	183,390	-	178	178	0%	100%
9	12	12	12	1	20	20	102,100	1,782	-	100,320	-	178	178	0%	100%

Table 20. Ice-cream output data table

Upstream multi products pallet feasibility

Due to the upstream manufacturers/wholesaler features within this product category, the top NPC_3 values are allowed within frozen food supply chain.

Rotation Indices Balance

In terms of rotation indices balance it is observed that the most cost effective solution is, potentially, setting the same (or similar) rotation indices along the supply chain in order the upstream flow of material is perfectly pulled by the end customer' demand.
Positioning on Lean Matrix
For the above considerations this approach suggests to follow the pure lean distribution.
Distribution strategy
The distribution strategy finally to be adopted, according to the simulation outcomes, provides direct delivery from the manufacturers/wholesalers M_i to the retailers R_k.

In figure 5 there is the summary of the different lean distribution approaches to be followed for the different product categories.

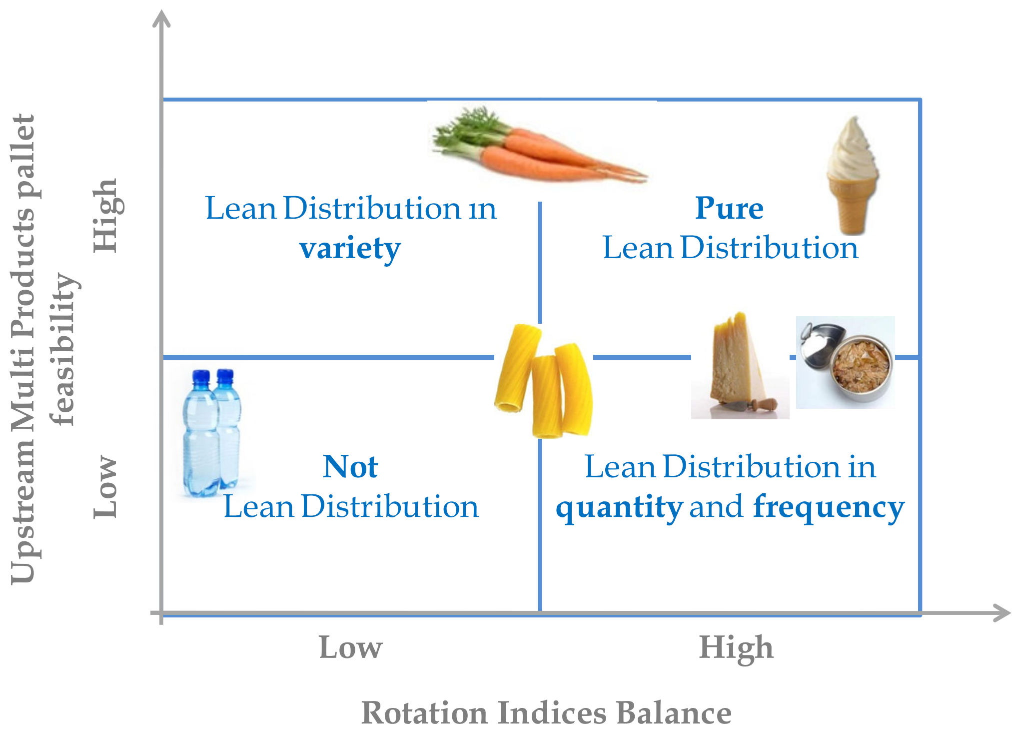

Figure 5. The different product categories mapped into the Lean Matrix

5. Conclusions

The study on hand introduces an innovative lean distribution model for the food industry. Firstly the paper focuses on the lean distribution literature review observing how there is a lack of mathematical models that use as driving input lean KPIs. For this reason authors evidence how the food SC has typically specifications that make it different and more critical respect other SC and evidence how the lean principles can help manager in achieving benefits. The proposed model integrates the lean principles in a mathematical model defining how lean can the distribution strategy be for a specific category product. Authors evidence as well in their applicative cases how different products category need different level of lean distribution in order to minimize the total distribution costs and respect the real Manufacturers/Wholesalers constrains.

Future research will integrate the presented lean distribution model with another critical aspect of the food SC: the product deterioration and its relative level of safety.

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Design, development and test of a vibration monitoring embedded system

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Abstract

This paper presents the design, development and test of a μController-based embedded system designed to monitor vibration profiles during the shipment of products along the supply chain. A digital accelerometer detects the mechanical shocks while sensors, embedded as auxiliary devices, trace, wherever is necessary, other variables like the temperature, pressure, moisture, etc. The developed system is managed by a Cortex M3 μController characterized by high performances and low consumption. All data, acquired during the transport, are periodically stored on a large capacity SD card and can be diplayed thanks to a user-friendly interface. In addition, the developed system can, also, interface with a shaker to perform, in laboratory, simulations and tests reproducing the stress profiles measured on the field. Evaluations of the quality degradation of products are thus possible. In the last section of this paper, a case study, presenting an analysis of mechanical stresses in the fresh fruit supply chain, is presented and discussed.

Keywords: vibration, data logging, fresh produce supply chain, mechanical stresses, sensor.

1. Introduction

For many companies providing high quality addressing safety standards represents, not only a constraint imposed by legislation but either a strategic asset to compete (Wang et al., 2006). Consequently, the interest in monitoring and controlling the key variables that affect quality of produced goods increased progressively through years in an even more wide set of industrial sectors. The literature frequently discusses the importance of collecting and analyzing data of manufacturing, storage and shipment conditions especially for those products that are more sensible to environmental stresses. Different strategies and solutions are presented, many of them, adopting innovative tracing technologies like the radio frequency identification (RFID). See, as example, Ma, Panos & Freed and Amador et al. for

applications in the fresh produce supply chain (Ma, 2009; Panos & Freed, 2007; Amador et al., 2009). Weiskircher (Weiskircher, 2008) analyzes the transportation conditions of foodstuffs describing, in particular, six shipments of containers. A reduction of quality of the carried produces has been detected due to the high temperature and mechanical shocks.
Aim of this paper is to describe an independent, user-friendly, electronic device that allows to monitor vibrations along the supply chain of fresh foodstuffs. The physical structure of the prototype is described, giving full details about the main components and functions. The memory management strategy is, then, discussed. In order to validate the accuracy of the developed device a set of check tests, made considering different and controlled frequencies of vibration, have been performed. Finally, a case study, monitoring the mechanical stresses experienced along the fresh fruit supply chain, is presented.
The reminder of this paper is organized as follows: Section 2 introduces the designed prototype with reference to the specification, the physical structure and data logging. In Section 3 the prototype validation is presented. Section 4 discusses a case study considering the fresh fruit supply chain. Finally, Section 5 presents conclusions and suggestions for further research.

2. Technical features of the prototype

The developed embedded prototype is designed to reach a sampling frequency of 400 Hz and 2 billion samples of storage capacity corresponding to 33 days of continuous monitoring. This specification is assured thanks to the integrated large capacity SD memory card. However, if the data logging is optimized, through the setting of a threshold that triggers the sampling activity only when necessary, more than 60 days of monitoring can be recorded.
The main parts of the prototype are the following:

- ✓ accelerometer;
- ✓ microcontroller;
- ✓ external extractable memory (Secure Digital card);
- ✓ batteries;
- ✓ custom case.

The accelerometer is an ultra compact low-power three axes linear sensor. It includes a sensing element and an IC interface able to provide the measured acceleration to the microcontroller through I2C serial interface. It has two dynamically user selectable full scales of ± 2g and ± 6g and it is capable of measuring accelerations with an output data rate of 640 Hz. The device resolution at that frequency is 3.9 mg.
The prototype is also configurable including other types of sensors to control moisture, temperature and pressure. These variables give an interesting indication of the environmental shipment conditions.
Data are collected through a 32-bit microcontroller based on ARM – Cortex technology, with the following features:

- ✓ 32BIT MCU, CORTEX M3, 128K FLASH
- ✓ Core Size: 32bit
- ✓ Program Memory Size: 128KB
- ✓ Clock Frequency: 72MHz
- ✓ Data Memory Size: 20KB

- ✓ Interface: CAN, I2C, SPI, USART, USB
- ✓ Peripherals: ADC, DMA, PWM, RTC, Timer

A dedicated firmware was developed in order to manage the data saving. Three buffers are used to compensate the gap between the period of data saving on SD card and the period of filling the buffer.

Following Figure 1 presents a *flow chart* of the process, considering, for the sake of simplicity, only two buffers. After reading data from the accelerometer, the state of the first buffer is checked; whether it is full, the prototype starts writing data on the second buffer and begins saving data stored in the first buffer on the SD card. Similarly, the process runs for the second buffer.

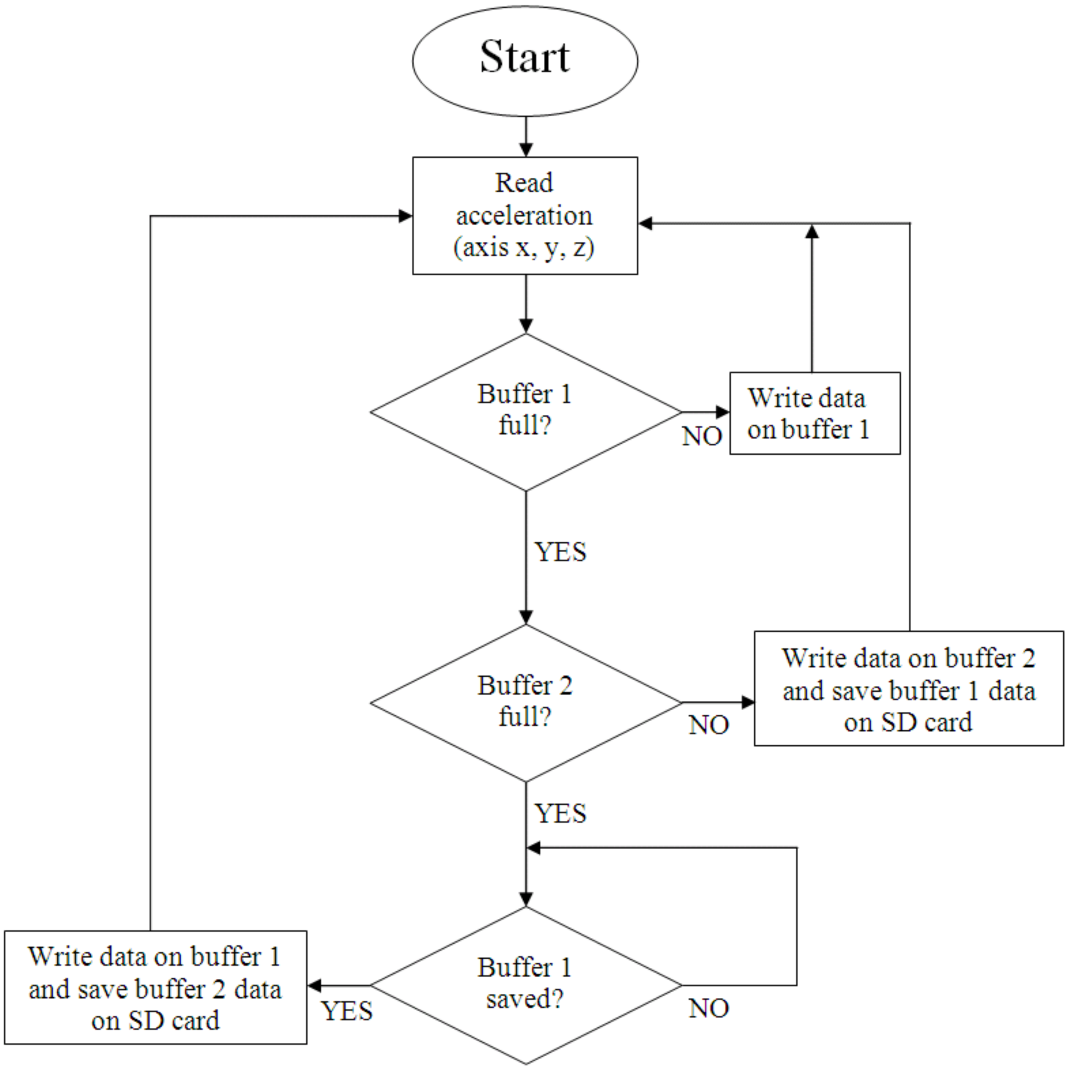

Fig. 1. *Flow chart* of the memory management.

To assure a long time power supply six large capacity batteries of 2400 mAh are used (Figure 2). Moreover, the consumption of the prototype is optimized thanks to the use of a low-consumption microcontroller, the absence of LEDs and the use of a stand-by technology

between two successive samples. Thanks to all these features, it is possible to monitor long shipments also with intermediate temporary storages.
The described components are included in a small and compact custom case (80x120x85mm, 350g) that allows to protect the system from possible damages.

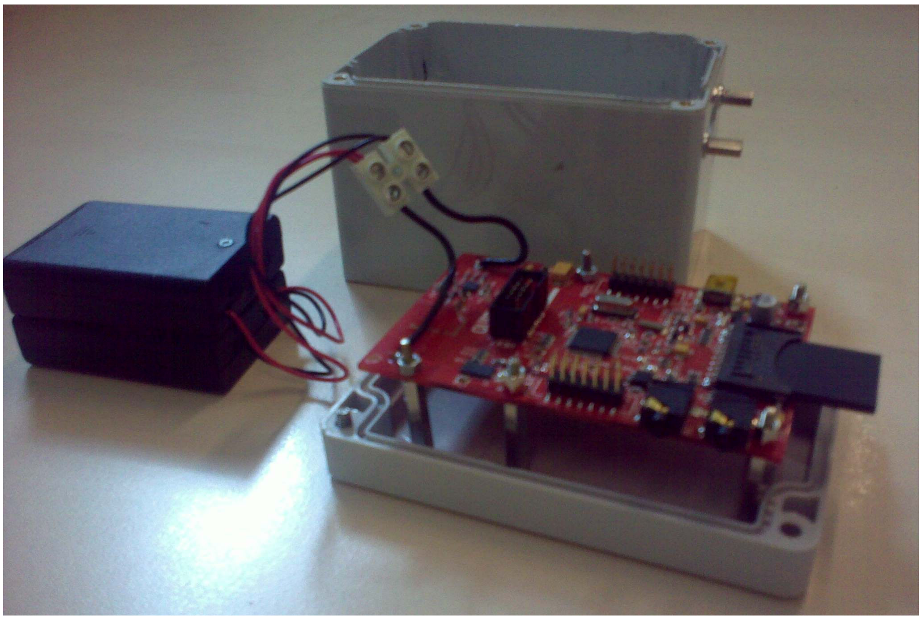

Fig. 2. Main elements of the designed prototype: case, board and battery pack.

3. Validation of the prototype accuracy

A set of tests is conducted in laboratory in order to validate the developed system. A professional shaker is used to produce precise vibration profiles and comparisons between the acquired and the shaker signals are made.
Two different types of tests have been performed considering different mechanical stresses. Figure 3 compares prototype and shaker waveforms considering three constant levels of frequency in the range from 5 to 60 Hz. In Figure 4 a similar comparison is represented considering, as stress, a bust of impulses instead of a regular acceleration profile.

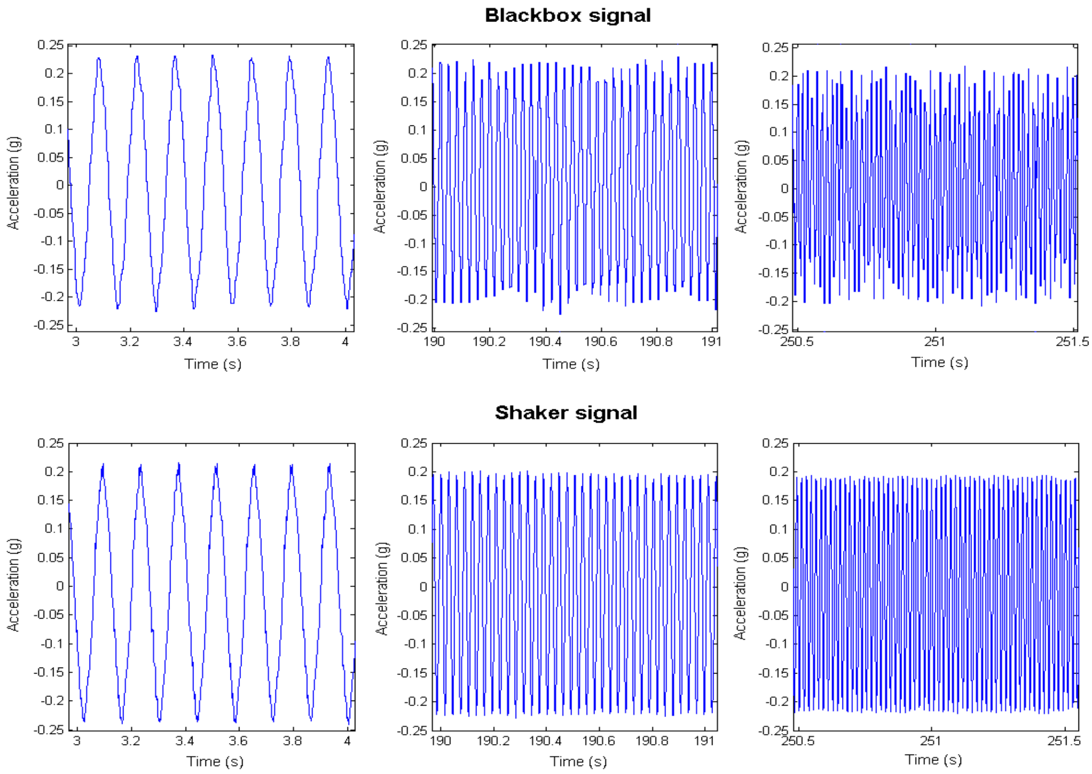

Fig. 3. Comparison of the acceleration profiles between prototype and shaker signals considering three levels of frequency 7–34–60 Hz.

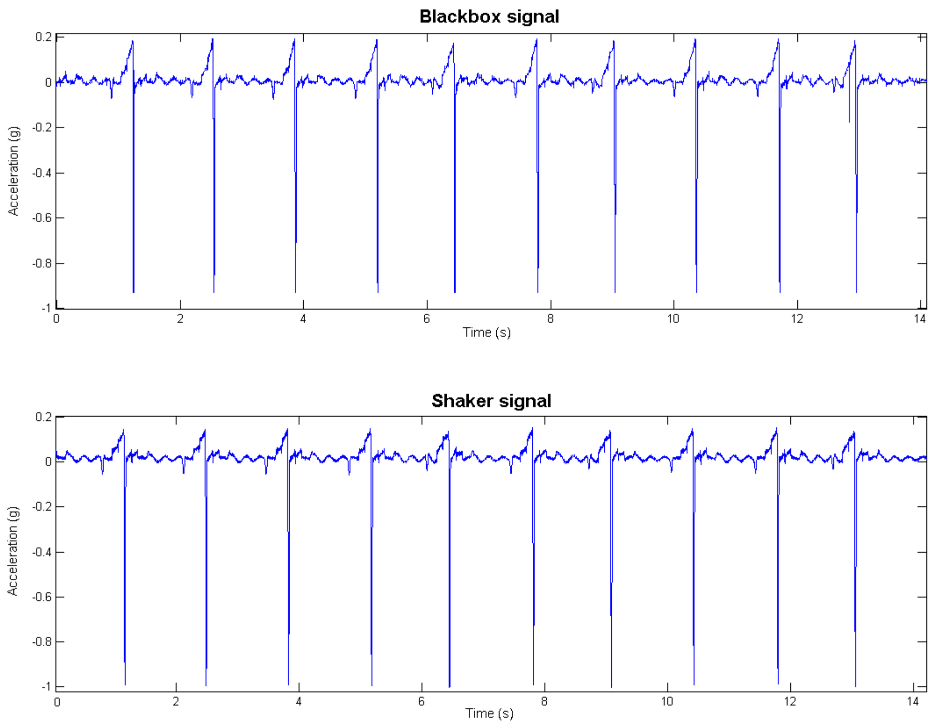

Fig. 4. Comparison between prototype and shaker signals on an impulse sequence.

As it is possible to see from the figures above, the prototype adequately follows the shaker measuring signals of similar amplitude and frequency. Possible differences between the amplitudes of the two waveforms are probably caused by the case structure that partially attenuate the shocks. Improvements of this component are considered a necessary future development.

4. Case study: vibration monitoring in the fresh fruit supply chain

The fresh fruit is considered a very critical produce due to the high possibility of damage during both harvesting and shipment, *from farm to fork*. For this produce, the most critical variable that can bruise it decreasing or compromising the quality, is represented by mechanical shocks. Consequently, the interest in studying the vibration profiles for this kind of product increased in the last years together with the development of techniques and best practices to preserve the integrity and quality. A crucial step of the analysis is the monitoring of the vibration profiles experienced by the produces in order to identify where major shocks happen. This activity is preliminary and essential to the definition of possible corrective actions. This Section describes a case study, considering a particular and too delicate fruit produce, the strawberries, presenting the main results of a vibration monitoring campaign made at the first level and stage of the supply chain. In particular, the harvesting and shipment processes are considered monitoring mechanical shocks from the field to the producer/farmer temporary storage area and, then, from this storage area to a local distribution center (DC). The measurement campaign has been assessed thanks to the collaboration of a small farm placed in Gambettola, within Cesena surrounding, in the north of Italy.

4.1. Mechanical stresses during the harvesting process

First of all the harvesting process has been studied identifying the sequence of its activities. The whole process is made manually directly by the farmers. Their movements along the crops field are not done only on foot but also thanks to a proper non motorized three-wheeler vehicle (Figure 5) that allows the pickers to remain sit next to the strawberry plants so that the picking activities are facilitated.
The process consists on five main steps:

1. one or more empty crates are placed on the three-wheeler at the beginning of the crops field;
2. the picker begins his activity, moving through the field, harvesting the fruits and filling in the container;
3. when all the boxes are full of strawberries another picker takes each container and carries it, on foot, to a small depot placed next to the field.
4. once arrived, each box is weighted and temporarily stored in stacks;
5. finally, the containers are placed on pallets and load up to a small van for transportation to a local DC.

Fig. 5. Harvesting process of the strawberries: pickers work using a proper three-wheeler.

The next Figure 6 summarizes the described harvesting process.

Fig. 6. Main steps of the harvesting process of strawberries.

The measurement of vibrations has been done by fixing the developed sensor on the plastic box (Figure 7) and sampling, at the frequency rate of 400 Hz, the accelerations on the vertical axes, i.e. the direction orthogonal to the ground and generally called *z* axes.
The process has been traced more than once. Particularly, when the crate completes the process, i.e. it was placed on the van, the sensor has been removed and fixed to a new empty

crate. The registration of the instants of time when the process begins and ends allows to identify and outdraw the vibration profile of each test.

Fig. 7. Sensor of vibration fixed to a crate.

An example of the measured accelerations is presented in Figure 8.

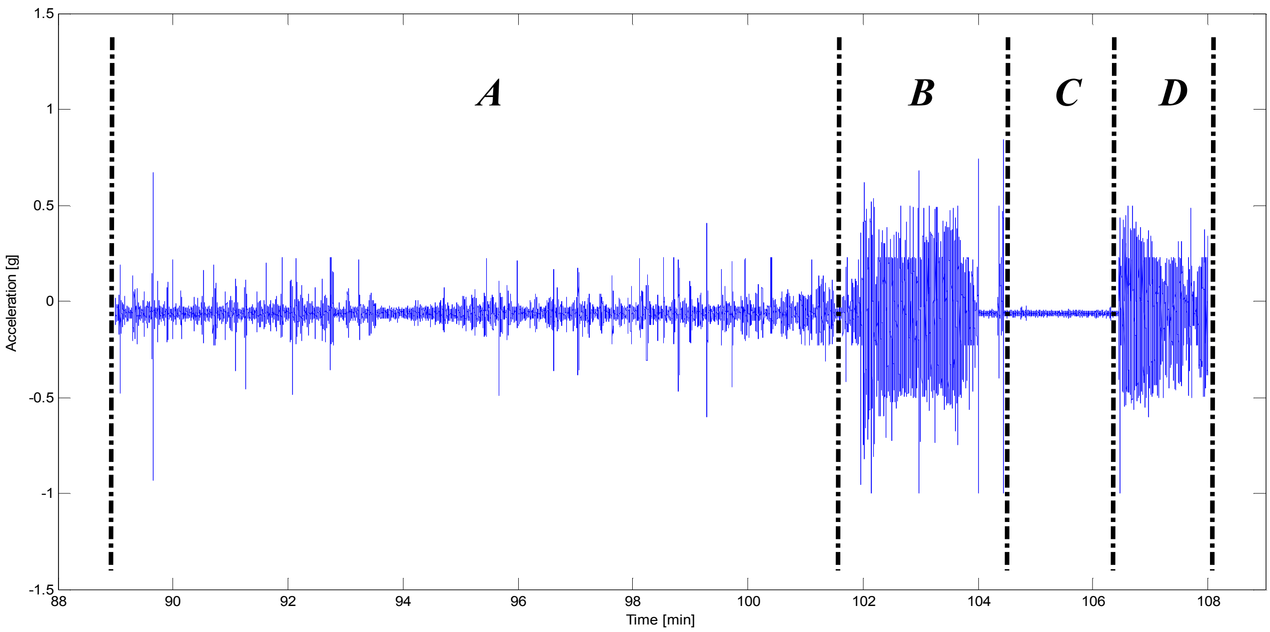

Fig. 8. Measured acceleration profile during harvesting process of strawberries.

The dash-dot black lines identify the five steps described before. During the picking activity and, obviously, during the temporary storage in the depot, i.e. regions A and C, the produces do not experience frequent relevant shocks. The regions B and D are different, i.e. the manual shipment from field to depot, the consolidation of pallets and the load of the van. These steps stress more the produces, with accelerations inside the range of ±0.8g. The

possible causes are the quick steps of the operator carrying the container and the fast movements from the stacks to the van.
Next Figure 9 shows the acceleration profile of five subsequent harvesting cycles, made in sequence. Each cycle is numbered and distinguished using dash-dot lines.

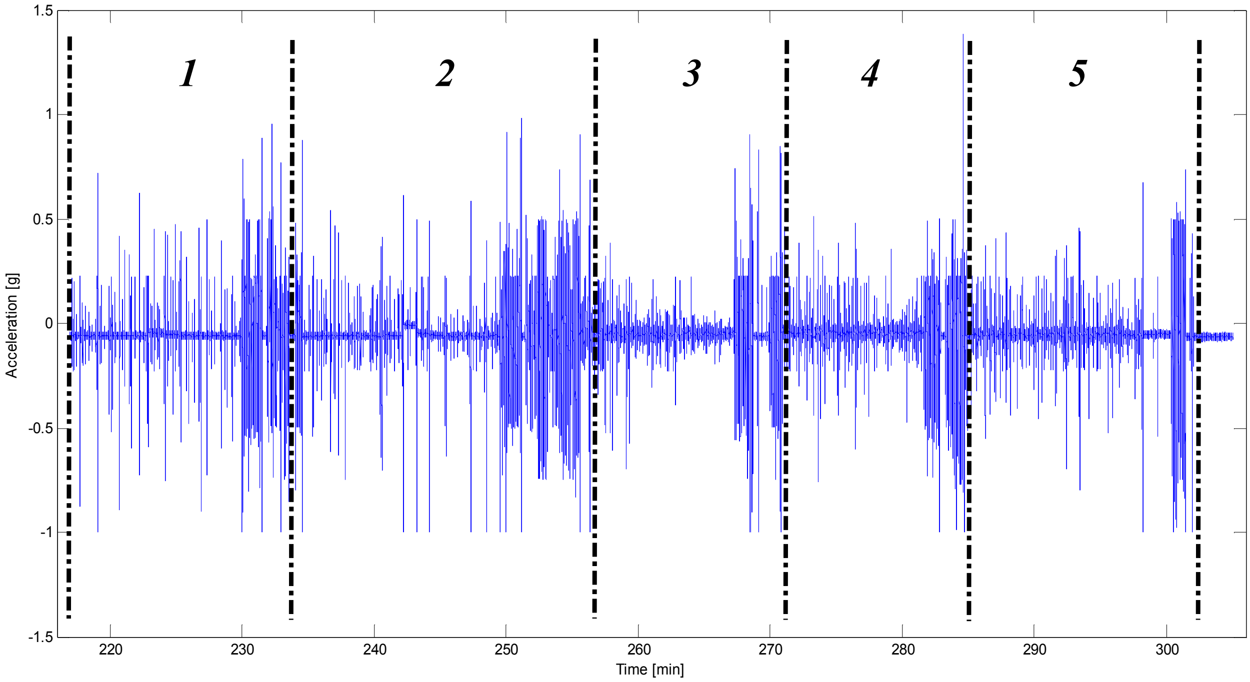

Fig. 9. Acceleration profile of a sequence of five harvesting cycles.

In this profile, an higher number of significant shocks has been registered. However, for each cycle, the mentioned four regions, previously called with letters from A to D and corresponding to the main steps of the harvesting process, can be clearly identified.
In conclusion, the implemented monitoring campaign allows to draw two different considerations about mechanical stresses experienced by fresh strawberries at the first level of the supply chain. First of all, the harvesting process does not heavily stress the produce. Approximately all monitored stresses falls in the range ±1g that are considered critical bounds to preserve produces from damages. Considering each harvesting cycle, the most critical activities are the shipment from the field to the depot and the load of the van. An interesting consideration is that the picking activity on field, using the three-wheeler represented in Figure 5, does not significantly stress the produces.

4.2. Stresses during shipment from the farm to a local distribution center

The first stage of the strawberries supply chain is now considered. The mentioned small van carries the pallets from the farm, placed in Gambettola, to a local DC placed in Godo, close to Ravenna. The next Figure 10 represents the route done by the van. The numbers 1 and 2 represent the departing and arriving sites. The total distance is approximately of 42 km.

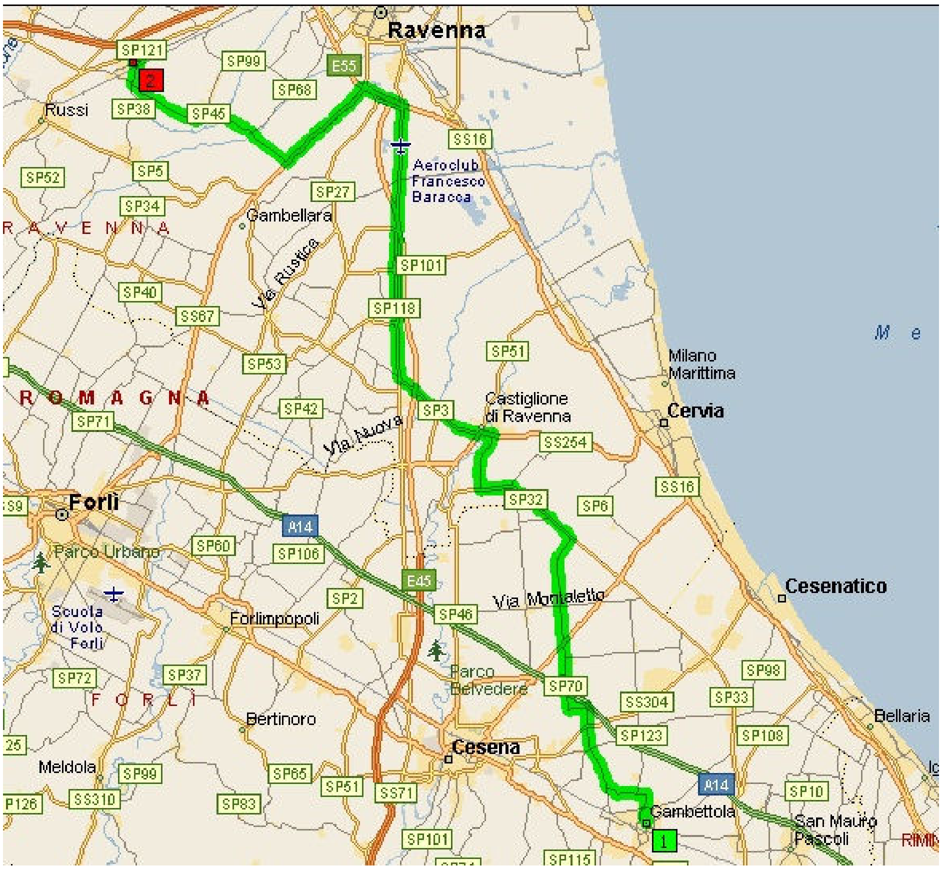

Fig. 10. Route from the farm (1) to the local distribution center (2).

Vibrations during this shipment have been monitored installing the developed sensor directly on the floor of the van. Figure 11 shows the acquired profile.

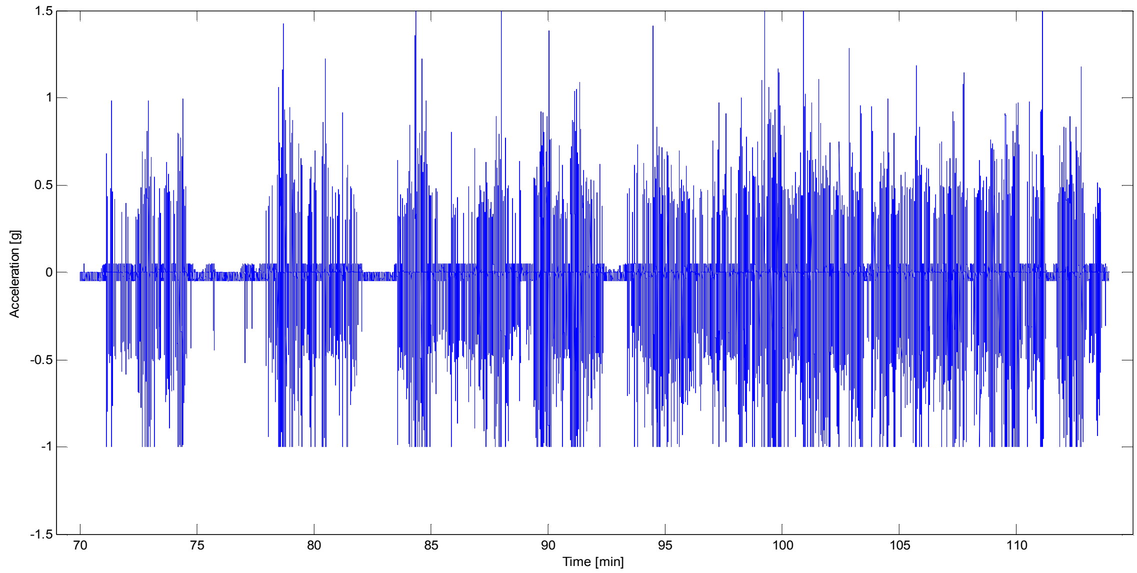

Fig. 11. Profile of vibrations during shipment from the farm to the distribution center.

Unfortunately, shocks with an amplitude higher than -1g are not traced due to the lower sensing limit of the instrument. However, the graph shows clearly that most of the shocks falls into the range of ±0.7g even if sometimes an higher acceleration is registered, i.e. values greater that +1g. Consequently, comparing profiles of the harvesting and shipment processes it is possible to highlight that the last activity has an higher impact on produces quality due to the significant level of mechanical stresses experienced by produces.
An interesting future research deals with the laboratory simulation of the monitored profiles to study if these levels of stresses impact on the quality of the produces causing a damage or a degradation of the physical, chemical or nutritional properties.

5. Conclusions and suggestions for further research

This paper presents a vibration monitoring embedded system developed to monitor mechanical stresses of products during the shipment. The structure of the device, the main components and physical connections are described. In particular, two elements play a crucial role for the whole system: the accelerometer, that is the sensor that measures mechanical shocks and the SD card that allows to save the collected data and, successively, download them. The designed system reaches high sampling frequencies and can collect more than 2 billion samples. These specification contribute to increase the flexibility and applicability of the prototype in the real contexts. The accuracy of the developed system has been already tested in laboratory, performing different check tests. A description of them together with the results obtained is given in the paper. As a consequence, the prototype is ready to be used in operative contexts. The described case study, considering the process of harvesting and shipment of fresh strawberries, shows the potentiality of the sensor in the monitoring of mechanical stresses. Despite the device is still operative a set of further possible developments are possible. Firstly, an optimization of the external case is necessary to optimize the vibration transmission features so that the accuracy of measured data increases and no attenuations of signal amplitude happens. Also an expansion of the capacity of the SD memory card is possible whether necessary to monitor long shipments without interruptions and data losses. Finally, a reduction of the power consumption is required to reduce the number of the batteries making the sensor less heavy and large. Once these features will be improved, making the developed vibration monitoring system more flexible and accurate, other experimental studies become possible, considering other kinds of fruit, foodstuffs and produces in general whose quality, integrity and safety are heavily affected by mechanical stresses.

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Accelerating life testing for food packaging. A case study of Italian oil-for-food distribution

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Abstract
Accelerating life testing analyses deal with products subject to failure and stressed over nominal operating conditions in order to quickly capture reliability parameters under stress and indirectly estimate them during nominal conditions. A few studies have been conducted on accelerating life testing applied to packaging design. Literature does not present results on the measurement of the effects of temperature, the typical stress parameter, on different bottles of oil for food. The food packages can differ for the content of the bottle, e.g. extra virgin olive oil, rice oil and vinacciolo oil, for the type of bottle (e.g. glass or plastic), for the closure adopted (plastic or aluminium caps) or the presence/absence of the cap cover. For different combinations of these factors an expected value of life duration given a specific stress value, also including the use/nominal operating stress, can be estimated. A case study is illustrated and the obtained results for different packages are discussed.

Keywords: package design, Weibull distribution, reliability, time to failure, oil-for-food, life-stress analysis

1. Introduction

This paper illustrates a case study conducted for an Italian company specialized in the distribution of oils for food (virgin olive oil, extra virgin olive oil, vinacciolo oil, rice oil) from Italy to many countries intra- and extra-Europe, e.g. Germany, UK, Taiwan, China, Japan, USA, Brazil, Canada, etc. The products are usually shipped as pallets in containers and adopting different transportation modes, e.g. truck, rail, and sea. During the transport the products is subject to significant variation of temperature, light exposure, shocks and vibrations, humidity, etc. In particular, temperature affects the quality of product, especially at high levels of temperature and low levels. At low levels (about 6-7 °C) the olive oil can crystalized accelerating the process of deterioration; at high levels of temperature the oil can

fill out of the package at direct contact with air compromising the expected shelf-life and the quality of the product at the consumer location.
In particular, the transportation issues can significantly stress a food product like (extra) virgin olive oil. As a consequence, logistics issues and food products' journey assume a very important role for quality and safety assessment of foodstuff at the consumer location. The level of quality is significantly affected by the integrity of the adopted packages, and package design reveals one of the most important and critical activities in food industry.
This study presents the results of the application of reliability-based models and tools to estimate the life duration of a package subject to failures, by the analysis in stressed operating conditions. Stressed operating conditions can significantly accelerate the failure process generating significant samples of time to failure data useful for the reliability evaluation process.

The remainder of the paper is organized as follows: Section 2 illustrates the theory of accelerated life testing (ALT), Section 3 illustrates the case study, Section 4 presents the obtained results. Finally, Section 5 presents conclusions and further research for reliability engineering applied to food packaging.

2. Accelerated life testing

In reliability engineering, accelerated life testing (ALT) analyses deal with entities, usually called components, subject to failures, e.g. manufacturing parts and components. They are stressed over the normal operating conditions, named *nominal conditions*, in order to capture reliability data (e.g. failure rates, expected mean time to failure - MTTF, etc.), more rapidly than in nominal operating conditions. A lot of different approaches to evaluate failure rates and reliability parameters by an ALT analysis are available, but all of them belong to two fundamental categories: qualitative and quantitative approaches. Qualitative accelerated tests are primarily used to investigate failure modes for the product. These are "on/off" tests: if the product survives, the test is passed; otherwise the test is failed. This kind of test is usually employed to limit the cost of analysis in comparison with the so-called quantitative test, more expensive.
For the equipment that works intermittently, the accelerated test lies in its extended use: the product subject to test operates at a rate greater than normal to simulate longer periods of work under normal conditions. Anyhow, devices are very often expected to operate continuously under normal conditions. In this case a different type of accelerated life test, founded on overstress, must be used in order to get data more rapidly. By an over stress acceleration, one or more environmental factors, such as temperature, voltage, humidity, vibrations, etc., are supposed to cause the product to fail under normal conditions and can increased in order to stimulate the product to fail more quickly during the test. The stress types and levels used in an overstress acceleration test must be carefully chosen, in order to speed the failure modes of the product without introducing others failure modes that would never occur under normal use conditions.
Examples of stressed conditions are mechanical strains, force cycling, cold to hot, and vibrations. The approach is usually very cheap because the sample is limited to few components; however, in general, it does not provide information useful to exactly quantify the failure rate or the reliability parameter of the product under normal use conditions. The

quantitative accelerated life testing applies punctual levels of stress and requires a numerical evaluation of the resulting life data. The test output is useful for an estimation of the probability density function for the product under normal use conditions. Others important metrics for the generic product subject to over stress conditions are: reliability, probability of failure, mean (expected) life, failure rate, etc. The application of the stress can be constant, i.e. time-independent, or time-dependent as well. Each stress combination, based on single or multiple levels, is usually called "stress cell". When a stress cell is operating for a fixed period censored failure data can be generated (Manzini et al. 2010).

Accelerated life data sets from stress cells require special data analysis techniques, including the adoption of complex mathematical models to "translate" the probability density function from *stressed* conditions to *normal/nominal use* conditions. These models, called life-stress relationships, work the probability distribution at each accelerated stress level out in order to estimate the probability density function, at the normal stress level.

A typical problem affecting the accelerated life tests is the determination of the best stress cells: often the link between strains and product performance is not clear (e.g. an electronic device facing temperature, humidity, vibrations, etc.), the definition of a representative group of stress cells and the consequent robust analysis of data are quite complex tasks.

Available life-stress relationships include these principal models (Bryan et al. 2006, Manzini et al. 2010):

- Arrhenius;
- The inverse power rule;
- The exponential voltage model;
- Two temperature/voltage models;
- The electromigration model;
- Three stress models (temperature, voltage and humidity);
- Eyring;
- The Coffin-Manson mechanical crack growth model.

The Arrhenius model is very general and widely applied to chemical and electronic failure mechanisms. The Coffin-Manson model works well for many mechanical fatigue-related mechanisms. The Eyring approach is used when more than three kinds of stress are considered, or in alternative to the above mentioned models. The final goal is to detect the connection among the reliability behaviours under stress conditions and the behaviour under normal (nominal/use) conditions.

ALT analyses can be conducted in presence of censored data (right censored, interval censored and/or left censored).

The adopted estimation statistical modelling is the maximum likelihood estimation (MLE). Given a set of failure data and a selected life-stress model (e.g. Arrhenius model), the best life statistical and parametric distribution (density function) can be determined for each stress level including the use/nominal stress: the parameters of a selected density function best fitting data sets can be identified. For example, Arrhenius model can be selected for an over stressed analysis assuming a Weibull distribution function as a parametric density function for the random variable time to failure.

Literature presents a lot of studies on accelerating life tests, but a few discussing on packages for food products (Lu and Xu 2009).

2.1 Weibull distribution and life stress models

The Weibull distribution (Manzini et al. 2010) is one of the most commonly used distributions in reliability engineering because of the many shapes it attains for various values of *b*, named also as *β* (slope). It can therefore model a great variety of data and life characteristics. The *Weibull* density function *f(x)* is defined as follows:

$$\begin{cases} f(x) = \dfrac{b}{a}\left(\dfrac{x}{a}\right)^{b-1} \cdot \exp\left[-\left(\dfrac{x}{a}\right)^{b}\right] \\ x > 0 \end{cases} \tag{1}$$

where

a scale parameter;

b shape parameter.

b is called *shape parameter* because:

- *b<1* implies *infant mortality* i.e. high mortality of infants typical of both electronic and mechanical systems. This is why, before the products are delivered, several of the components are subject to acceptance tests known as "burn-in" and stress screening so that infant mortality is by-passed. Hazard rate declines with age.
- *b=1* implies *random failures* i.e. failure modes are "ageless" and the probability density function is an exponential.
- *1<b<4* implies *early wear out.* The cost of unplanned failure for this component is generally higher than the cost of planned failure. Consequently, there is an optimal replacement time that minimizes the global cost.
- *b≥4* implies *old age and rapid wear out*. The probability density function is somewhat symmetrical and similar to a normal distribution. Typical failure modes are stress corrosion, material properties, erosions, etc. These components require inspection and corrective action.

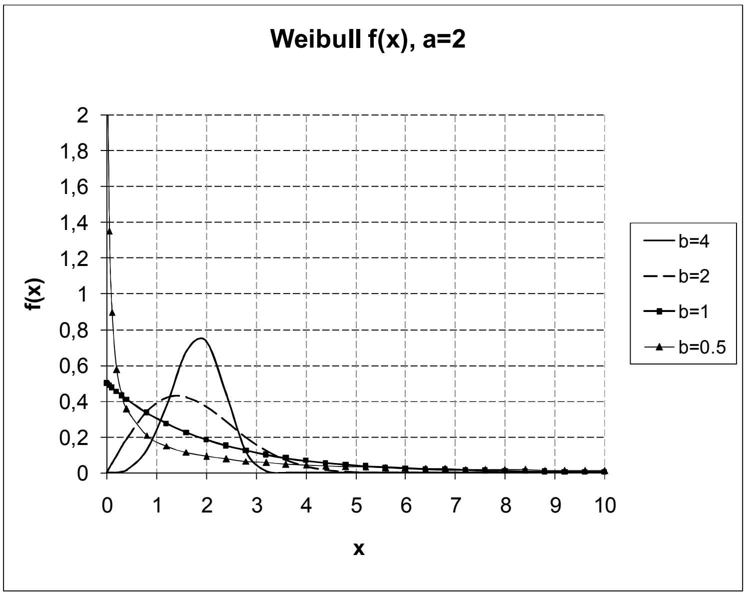


Fig. 1. Weibull distribution for different b. Density function *f(x)*

The authors of this paper choose to adopt the Weibull distribution as the density function to model the failure behaviour of a package system, because it is a very versatile statistical function.
The adopted life-stress model is the Arrhenius, which is the most common life-stress relationship utilized in accelerated life testing (Manzini et al. 2010). In particular, the Arrhenius reaction rate equation is given by:

$$R(T) = Ae^{-\frac{E_A}{kT}} \tag{2}$$

where

- R speed of reaction;
- A non thermal constant;
- E_A activation energy (eV). This is the energy that a molecule has to have to participate to a reaction. This is a measure of the effect that temperature has on the reaction;
- K the Boltzman's constant;
- T the absolute temperature (Kelvin - K).

The life is proportional to the inverse reaction rate of the process. The mean life is:

$$L(V) = Ce^{\frac{E}{V}} \tag{3}$$

where

- V stress level, e.g. temperature;
- C, B model parameters.

Since the Arrhenius is a physics-based model derived for temperature dependence, it is strongly recommended that the model be used for temperature-accelerated tests. Temperature values must be in absolute units (Kelvin).

3. Oil-for-food packages. A case study

This case study deals with the conduction of accelerated life tests for the design of new bottles of food oil in presence of different oils (e.g. virgin olive oil, vinacciolo oil, and rice oil), different kinds of bottles, different closures and presence/absence of sleevers as special covers of the caps. The company of interest is an Italian leader in the production/distribution of food oil shipped all over the world (China, Taiwan, USA, north of Europe, Australia, etc.). They usually ship products in containers without special equipment, e.g. thermal covers, refrigeration (i.e. temperature and humidity control). Figure 2 illustrates an example of a critical and typical problem identified at the arrival of the bottles of oil at a few destination points when containers are shipped in special periods of the year (e.g. when the weather is quite hot). During a shipment high levels of temperature, e.g. 60 °C, can be monitored.
In particular, Figure 2 shows a problem of oil coming out the bottle as a result of high level of temperature and thermal dilatation of the oil. Such a problem can force the logistic

distributor to ship a new order of bottles, even in presence of 2-3 containers, to the customer who does not accept the product lots not respecting standards of quality and safety.

Fig. 2. Oil coming out the bottle

Fig. 3 shows the trend of temperature monitored inside a container of oil bottles from Italy to Taiwan. The container was shipped in November 2010 at the port of La Spezia (Italy) and arrived in December 2010 at Keelung (Taiwan): the duration of the shipment was about 2 months. The maximum level of temperature monitored was 33°C.

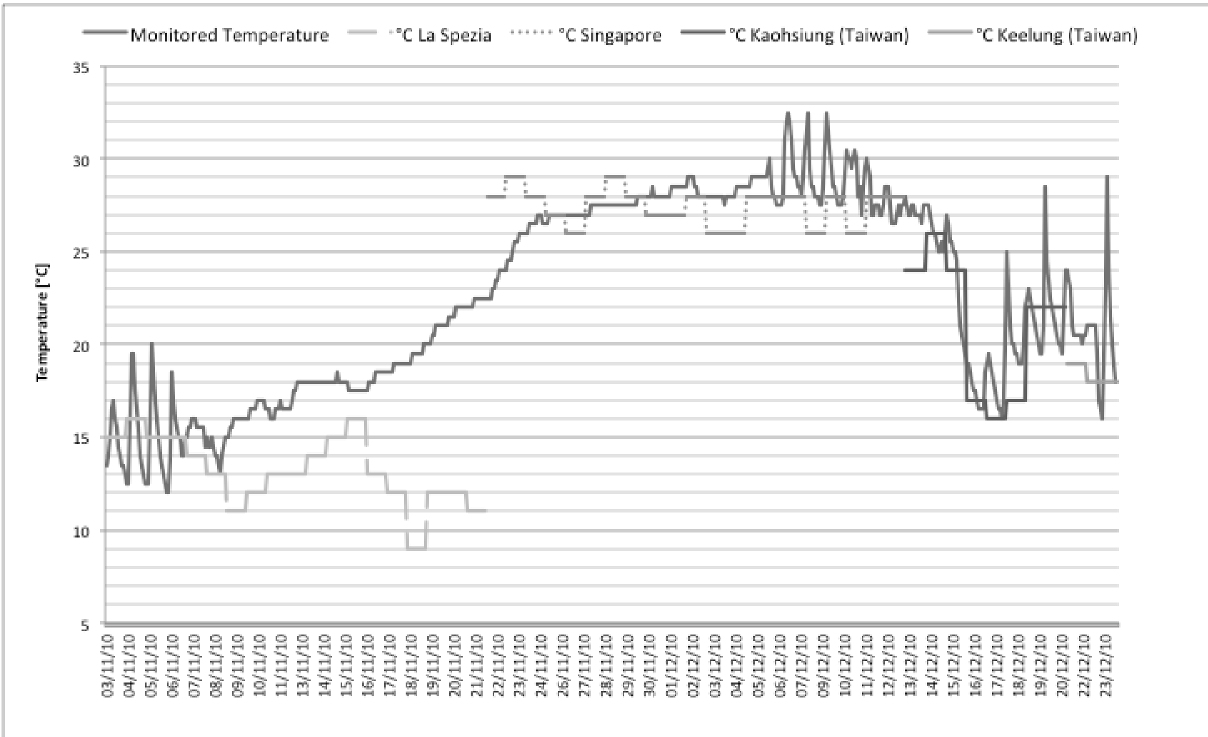


Fig. 3. Temperature profile. Shipment from Italy to Taiwan.

In order to prevent the occurrence of *oil moving out* in future shipments towards critical destination points, we decide to design new packages systems with the support of the execution of accelerated life tests in order to have packages with a controlled level of reliability when subject to high stress temperature.

3.1 Test planning

A set of tests has been planned for the execution of the accelerated life analysis under over stress operating conditions. The stressed variable is the *temperature* inside the container. The monitored options (factors of the analysis) and the related levels are:

- Oil (extra virgin olive oil, rice oil, vinacciolo oil)
- Cap of the bottle (new vs old, plastic and aluminium, etc.);
- Presence/absence of a sleever (sleeve enclosure) to protect the cap.

Bottles of oil have been stressed under different levels of fixed temperature monitoring the *time to failures* (ttf) that correspond to the coming out of oil and/or the self-extraction of the closure (cap) from the stressed bottle.

4 Obtained results

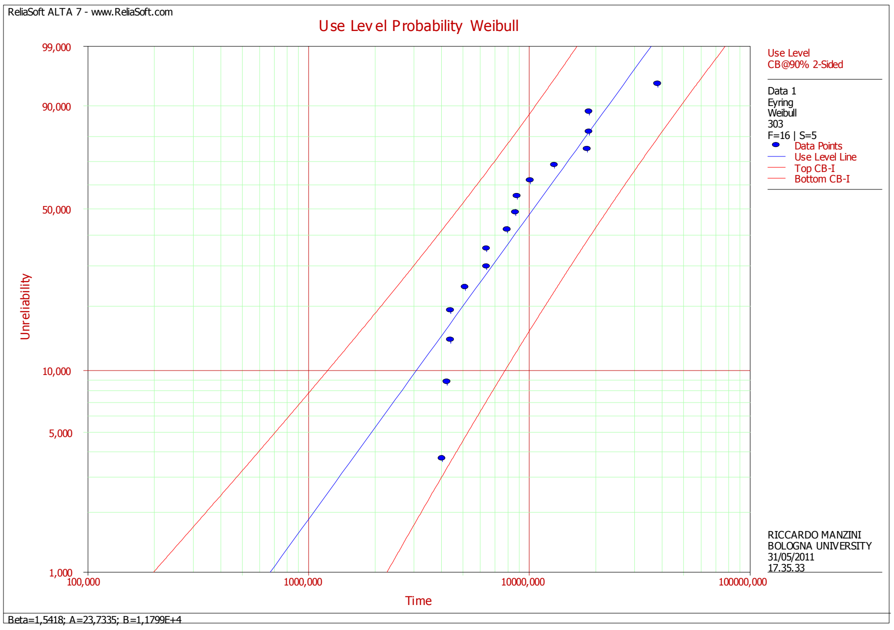
The following graphs represent the results obtained on different package prototypes under stress-temperature conditions.

The following subsections present different sets of results in order to compare the performance of alternative packages solutions.

Figure 4 exemplifies the most important results generated by the execution of stressed tests (1), the collection of failure times (2) and the application of Arrhenius modelling (3) for the estimation of the expected failure behaviour, i.e. the probability density function, at the nominal stress. The best fitting analysis has been conducted adopting the Weibull statistical distribution. The components, bottles of oil, subject to different over stressed temperature levels are grouped accordingly with each simulated temperature. Also confidence bounds levels at 90% on the expected mean value of time (life) are reported. The tests are executed at the following temperature levels: 333 K, 343 K, 353 K and 363 K. The use level is 303 K. The so-called "eta line" is the expected "line of life" for different stress-temperature levels.

Figure 5 compares the results of conducting the life-stress analysis adopting the Arrhenius model and the Eyring model. The use level probability is plotted and also the confidence curves are reported. Both Arrhenius and Eyring models are suggested in presence of temperature dependency of the time to failure. The results are very similar: shape parameter is about 1.5424 and 1.5418 adopting Arrhenius and Eyring models respectively. As a result the Arrhenius model is the right choice for the analysis of the package system object of this case study.

Fig. 4. Arrhenius model. Weibull density function. Life-stress analysis



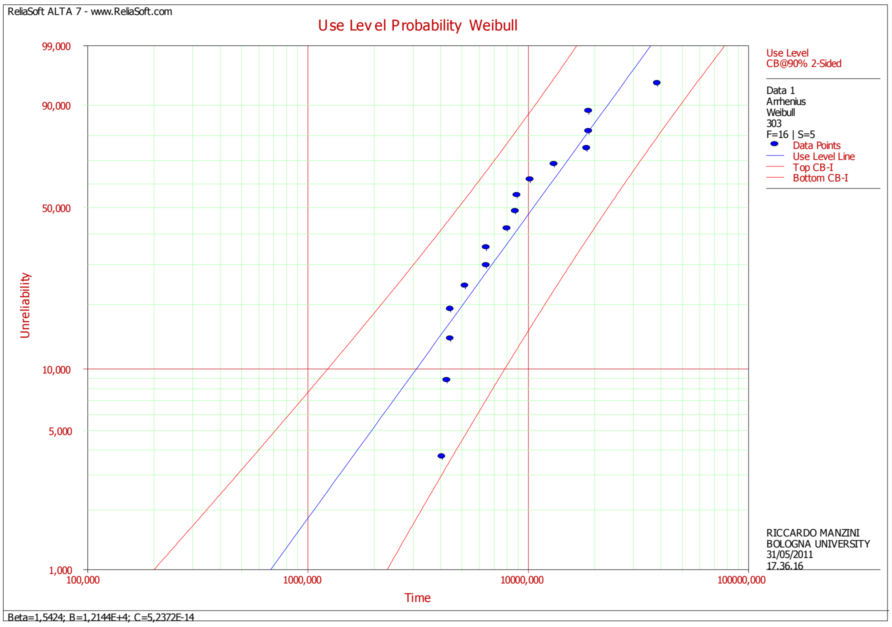


Fig. 5. Eyring (a) vs Arrhenius (b) life-stress models. Censored data 5/21

4.1 New package plastic enclosures

These results refer to glass bottles of vinacciolo oil and have been obtained by the stressed simulation of different levels of temperature. Two new packages, named "new" and "new2", have been tested in order to solve the problem illustrated in Figure 2 (typical for bottles using the so called "old", the first illustrated in Figure 6). The new packages differ for the absence (pack "new") and presence (pack "new2") of a sleever on the plastic cap of the bottle respectively (see Figure 6).

Fig. 6. Plastic enclosures: old, new and new2 packages

Figure 7 compares the probability plots generated for the new packages at the nominal/use operating conditions. The failure behaviour is significantly different: the shape factor *b*,

usually called *beta* (β), for the package "new" is about 7 as typical of rapid wear out components subject to failures, while for pack "new2" *b* is about 1.3 (early wear out components). In particular, given an operating temperature of 30°C the unreliability as the percentage of failures occurred is greater for "pack new" than " pack new2". Figure 8 supports a similar conclusion showing the *reliability function* at the operating/use temperature.
As a consequence "pack new2" performs better than "package new".

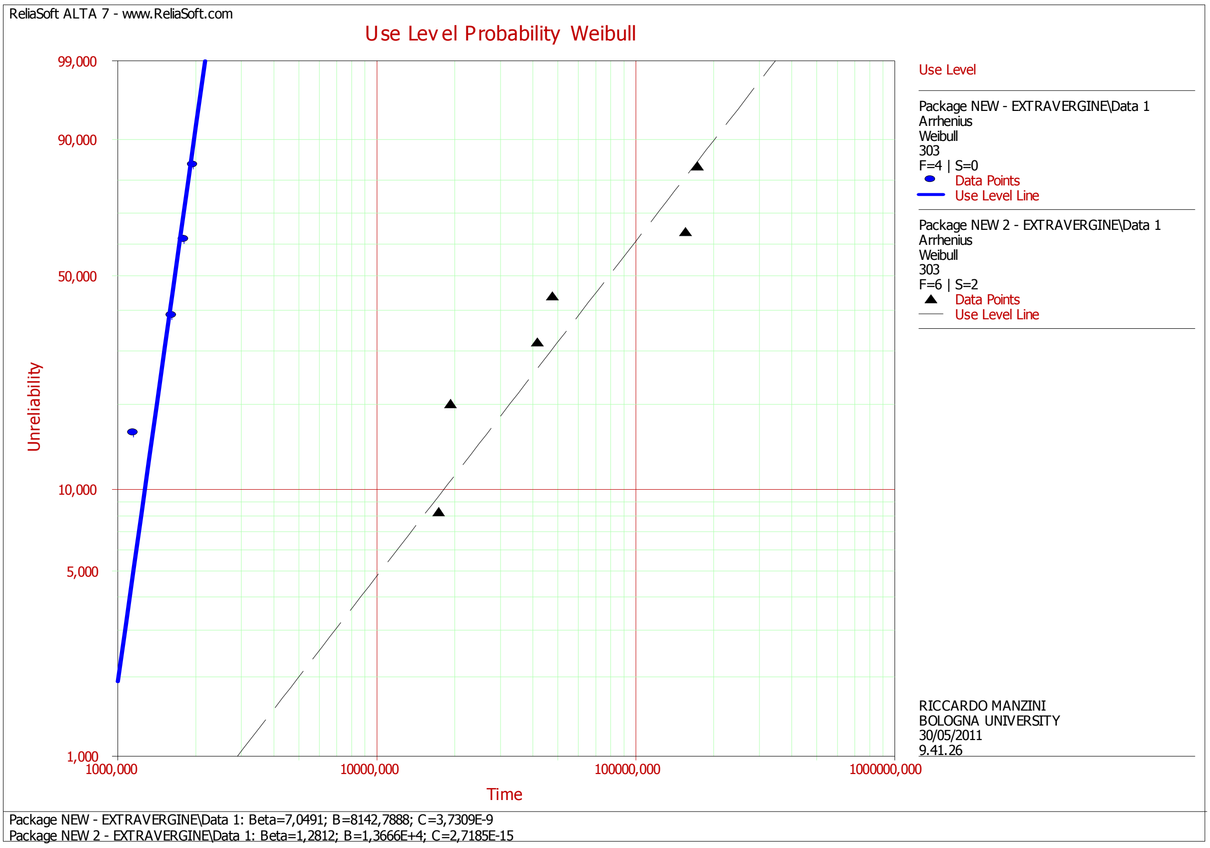


Fig.7. Probability plot. Bottle 500 ml, extra virgin oil, pack "new" vs pack "new2"

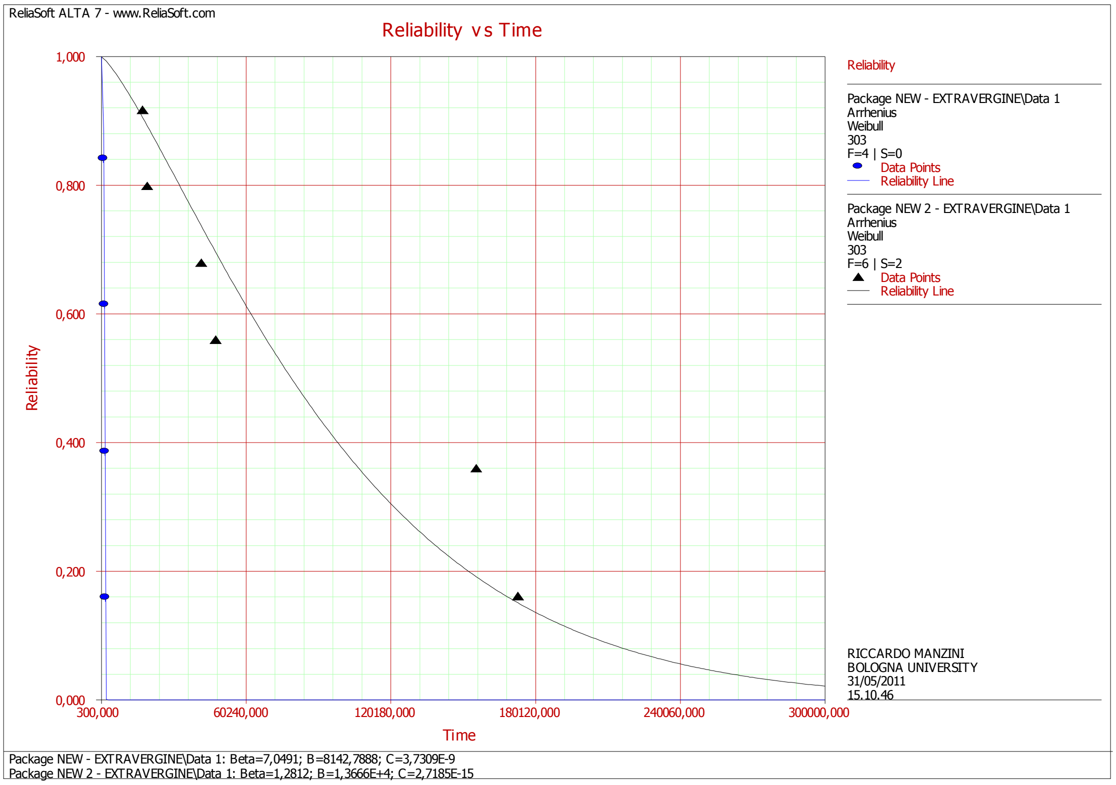


Fig.8. Reliability function. Bottle 500 ml, extra virgin oil, pack “new” vs pack “new2”.

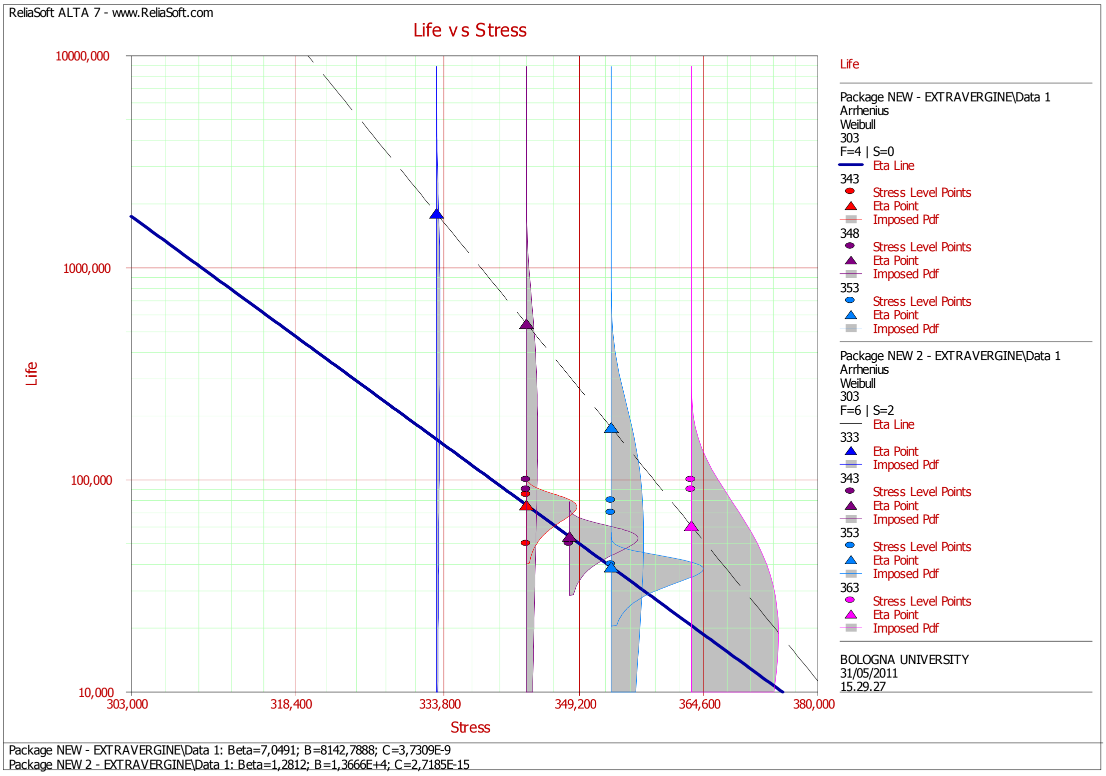


Fig.9. Extra virgin olive oil. "Pack new" vs "pack new2" for different stress temperatures

Figure 9 presents the life vs stress graphs illustrating the failure behaviour of the two kinds of bottles for different levels of stress-temperature (e.g. 333 K, 343 K, 353 K). In particular, the two different lines of expected life for the two packages are reported: the largest line refers to pack "new" and the slightest line to pack "new2". Given a generic stress of temperature the expected life of pack "new2" is greater than the expected one for pack "new": this is true especially for not significantly stressed levels of temperature, where the two line converge. Finally the variance of the Weibull density functions associated with the pack "new2" is quite lower than the variance measured for the pack "new",

4.2 New package aluminium enclosures

A similar analysis has been conducted for glass bottles of packages whose enclosures are in aluminium and differ for the type of lock of the cap: the so-called "internal" and the so-called "external" (see Figure 10). These different kinds of aluminium enclosures define two packages, named "pack 3" and "pack 4" respectively.

Fig.10. Cap-locked internal (pack 3) vs cap-locked external (pack 4)

Figure 11 reports the life vs stress analysis conducted for different levels of temperature: package "pack 4" performs better than "pack 3" for temperature stress level not greater than 360 K; given higher levels of stress "pack 4" performs better than "pack 3".

4.3 Different oils comparison

This analysis compares the failure behaviours of a same glass bottle with plastic enclosure (previously called pack "new") filled with three kinds of different food oils: *vinacciolo*, *rice* and *virgin olive* oils. The use level probability plots have been generated adopting the Arrhenius stress-life model, the Weibull density function and a use stress level of 303 K.

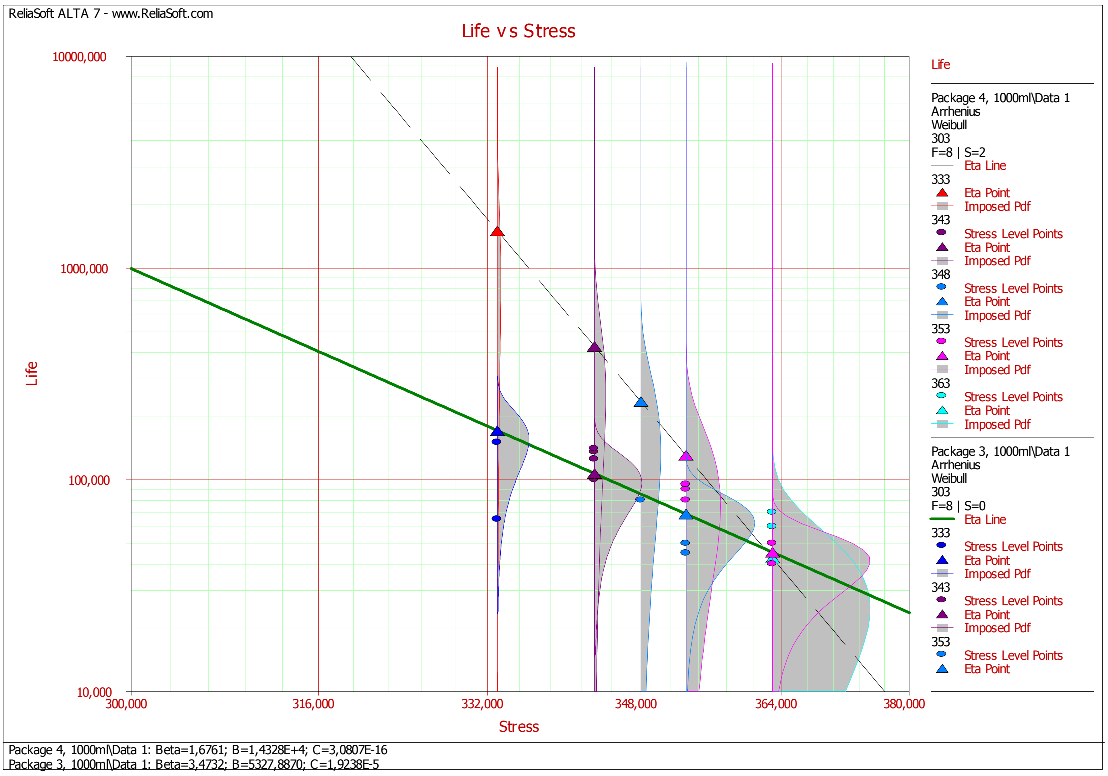


Fig. 11. Life stress analysis: Pack 3 vs pack 4. Glass bottles 1000 ml.

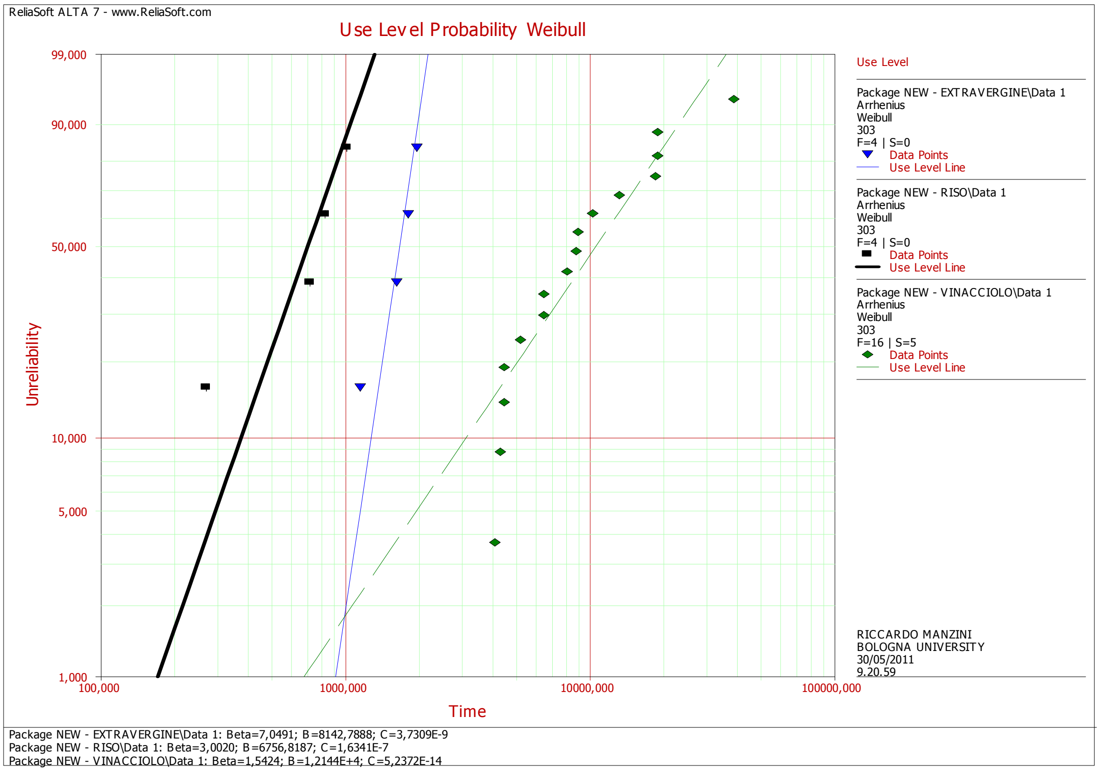


Fig.12 Pack "new", oils comparison. Nominal use stress 30°C.

Given the use/nominal temperature level, the best performing oil is the vinacciolo and most critical is the rice oil.

5. Conclusions and further research

This paper presents a set of accelerated life tests conducted on different packages prototypes demonstrating that stress-life models, as Arrhenius model, are effectiveness and can significantly support the design of new packages. The level of reliability of a package is significantly correlated to the level of safety of food products, e.g. food oils. In particular, bottles of oils are sensible to temperature variations, which can be controlled in order to avoid the coming out phenomena.
The previously discussed analysis demonstrates that it is possible to accelerate the failure behaviour of a package in order to quickly collect data of failure, even if in over stress operating conditions.

Which are the combined effects of temperature and vibrations on food packages? And on foodstuffs' quality? Further research is expected on the development of a two stress-controlled simulation system where the stresses are the *temperature* and *vibrations*. The department of industrial mechanical plants of Bologna University is working on the design of a controlled temperature system to be combined with a controlled-shaker as generator of vibrations. The idea is to stress both temperature and vibrations (frequency and/or amplitude of accelerations levels), in order to quantify the effects due to nominal couples of values.
New studies and accelerated tests adopting time-dependent stress models, known as "cycle stresses", are expected.

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Impact in wine supply chain as a consequence of the climate change

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Abstract
The last Conference on climate change, there have been enough evidence to think with will be the most probable change next scene on many macro regions. Local weather offices have works with this macro model and can say us which kind of change and with amplitude the change will affect every micro regions. Base in this information is possible determine where new areas will appear to cultivate vineyards and where traditional vineyards will be closed by decrease of it inherit competitiveness. At the same time many other traditional zones will need to change the amount or the variety of grape that can adapt to the new environmental conditions. This work explore the impact in the wine supply chain as a consequence of this change, that many enterprises are strategically planning, and how to develop a tactical conception of a lean chain that can adapt himself to the needs of the markets.

Keywords: *Climate Change, Carbon Footprint, Wine Supply Chain, Innovation Applied to Process, Green Logistics, Sustainability.*

1. Introduction

In the last five year, a lot of works and research effort had been made in the field of climate change. The International Panel on Climate Change [IPCC] (UNEP FAO) has developed a climate model forecast that is more or less accepted by the scientific community and the economic sector, and all them are thinking to take actions.
The wine industry is not an exception in this line of work, but the same organization (IPCC) is recommending now that a more fine research must be made in the local climate change and then every one bust to take the correct action to mitigate the global worming effect. In this work a detailed analysis of the small a local climate change expected, in the inner space of the local grid, is commented. Additionally a prospective work is made to explore the possible impact in the logistic and supply chain for the wine industry as a consequence of the climate change.

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2. Tools and methods used

For this work a GIS (Geographic Information Systems) analysis tool had been used. The tool called *Mapresso* is a java software application that is able to import information from many different GIS servers, likes *ArcInfo*, *MapServer*, *GeoServer* or *PostGis*, and show dynamic transformation in the map like a grey scale according to the gradient change in one variable or make a transformation of the aspect of the map using de first or second derivative of the variation of the changing variable used.
Additionally a part of the data has been processed with *R-Cran* software to establish a confidence interval and work with the information used.

3. Aim of this work, the climate change problem locally focused

As we have showed, the problem of the global climate change is a self surviving matter. In the wine industry, there are not mandatory action that force to reduce the CO2 emissions or any else. But despite of this every winery in the planet is trying to make an effort as great as possible, because they can see the consequence of the climate change over his principal row material (the grapes). This way to solve the problem may be discussed, some one can argue that it may be necessary a central authority that lead the organized effort, but this way is, by now, the only way that all the producers have. The way to combat climate change that has been adopted is something like Edgar Murin's slogan "*think globally, act locally*".

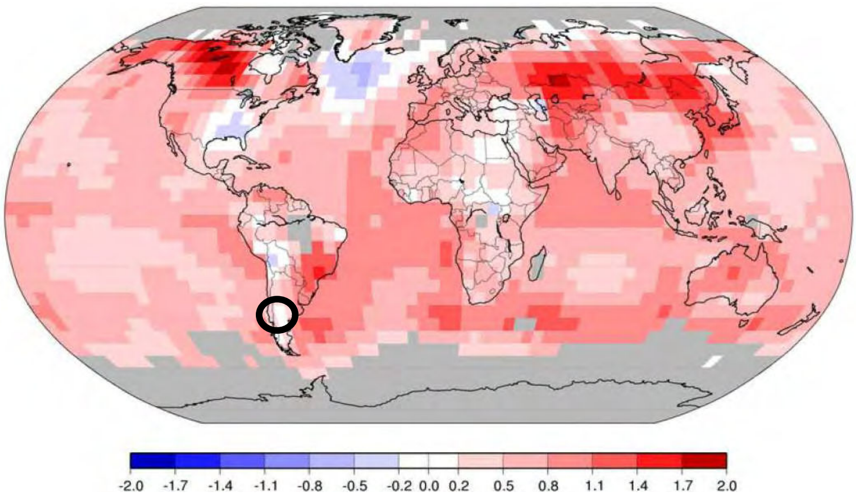

Fig. 1: IPCC expected climate change

In the international climate change panel a global map of the expected scene for the next 20 or 50 years can bee see [Villalba, R. et alt.]. In the Fig. 1 we can easily observe that the global worming will be more intense in the north hemisphere than in the south. Additionally we must to note that each square in the gird has a huge surface and a more fine work must be made to know the impact of the global tendency in the small parts of this square.
This work is trying to motivate to other research teams to replicate this experiment in his local environment and to share the relevant evidence and establish the best practices. A closer look at the map of climate change can let us see that the southern hemisphere will be less impacted by climate change.

At least, about the temperature, we can be seen to be less high than in the north. However this does not imply that the problems will disappear. In fact the circled area (Fig. 1), where this work has been made, will have a new kind of problem. The lowered temperature of the ocean will bring less moisture and water vapour, which will mean less water for irrigation on ecosystems. Finally is necessary to remark that the low velocity of change in the south is a consequence of different mechanisms is Australia, New Zealand, South Africa, Argentina, and Chile.

In the circled area there are additional problems. In the middle of the grid we can find one of the highest mountain range. The Andes mountain have at this point the highest point of America. The Aconcagua is the highest mountain in the Americas at 6,962m (22,841ft). It is located in the Andes mountain range, in the Argentine province of Mendoza and it lies 112 kilometres west by north of its capital, the city of Mendoza, and is one of the geographic factor that can alter considerably the mean decrease of 0.8º Celcius degree expected for the region and simultaneously the explanation of the different behaviours between Chile and Argentina. Another factor that may be observed are the different climates change affect in the different season, and specially in the growing season, according to the needs of the vineyards [Gregory V. J.].

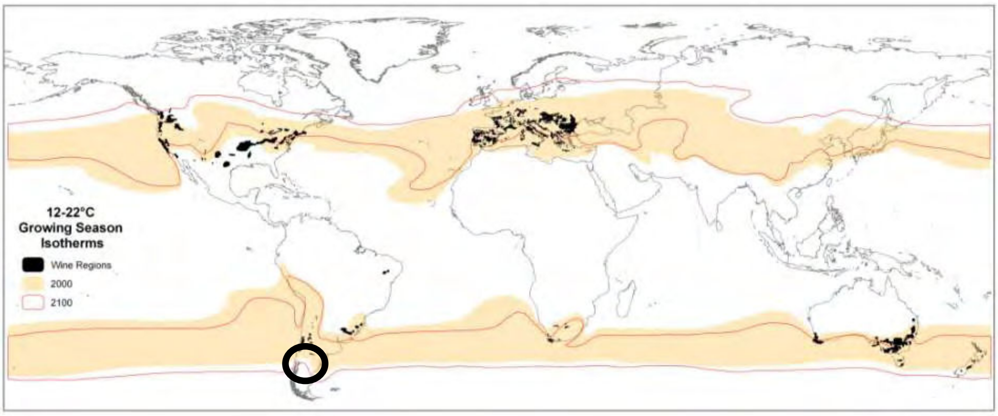

Fig. 2: Community Climate System Model (mid-range scenario)

A more detailed observation of the circled area show that the amount of water for irrigation will decrease as he consequence of the less amount of water vapour provided by the Pacific Ocean according [Villaba et alt.], showed in the Fig. 3. It can be see a line between Valparaiso (Chile) to Mendoza (Argentina) that goes from 72º to 68º latitude.

In the profile the elevation is showed in the bottom line and from west (left side) to east (rigth side) the shore range (Coastal mountain range), de central Andes range and the pre-mountain range can be seen. Between the shore range and the central range the Santiago de Chile valley can be seen and in the space between central Andes a pre-mountain range of Uspallata valley can be found. According to the research of climate change a decline in the rainfall and snow in the Central Andes can be hope. Also a reduction of the intake from permanent glacier water (that have tendency to disappear) can be expected.

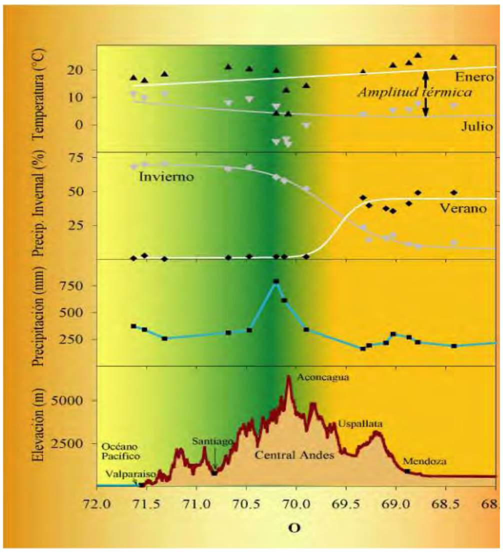

Fig. 3: Snow and precipitation

On the other hand the temperature elevation in the Atlantic ocean and the increase of the circulation form the Brazil can provide an extra quantity of water form the east that can produce snow in the pre-mountain range at the summertime and rainfall directly in Mendoza, that compensate the water reduction form winter snow accumulated in Central Andes range.

4. Impact over the phenology

The variations of the phenology (the study of cyclic and seasonal natural phenomena, especially in relation to climate and plant life), is a consequence of the variation on the climate, irrigation rates a variation on the growing a quality of the grape can be hope. On the other hand extreme climate phenomena can be more frequent and then many of the zones that are able to produce quality grapes for some kind of wine can reduce it inherit capacity or new ones can appear influences by new local climate conditions. Some of these changes, that not affect directly the phenololgy like Individual Weather Events (short-term/localized), hail, frost/freezes, heavy rain, etc., can increase the crop risk.
Others like Climate Variability (seasonal-decadal/regionalized) dry or wet & warm or cold periods will alter the production and quality variability. Also Climate Structure/Change (long-term/regional-global), average temperatures, rainfall regimes, warming, cooling, changes in moisture regimes. All theses factor can act over the final quality of individual species of grapes motivating the attitude or incapacity of some region to develop some variety of crops. Finally all these extern variables can establish zones where the crop can grow more quality and efficiently. In the Fig. 4, [Gregory V. J.] argues that in the world there is a trend to move (and migration) from some zone to other.

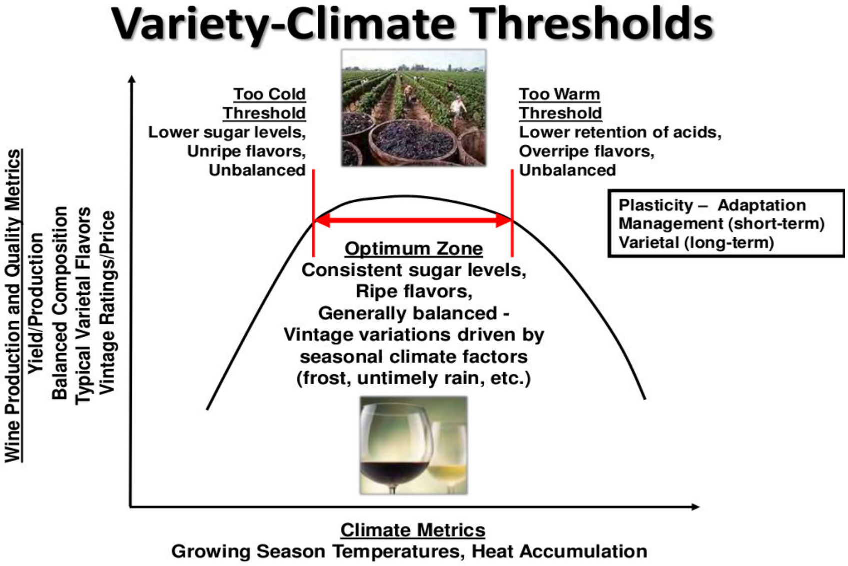

Fig. 4: Wine quality metrics vs Climate metrics

5. Impact over the Logistics

This preliminary work will think how to manage the transition period form now to the moment where the zones have been completely established in each region.

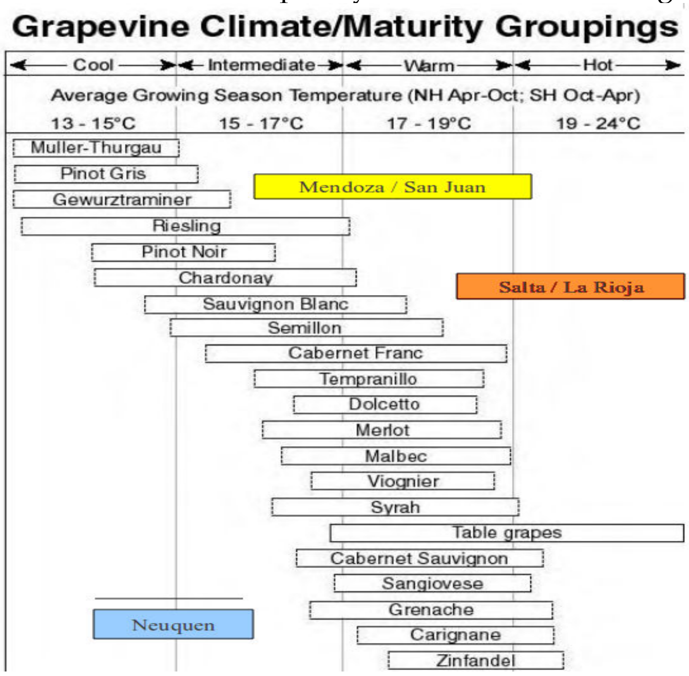

Fig. 5: Variety and zones in Argentina expected to 2020

In the Fig. 5, we can see the optimum temperature range for each wine variety. Also we have the temperature range in north, central and south zones. We are assuming that the wineries will remain in the actual location just the moment when more than 50% of the grape come form other region different were they are now.
For this way (In this moment) the migration of the wineries have the maximum logistics cost. This process can be initialized as a local migration but in a long time may appear a global migration of the company from one hemisphere to other.

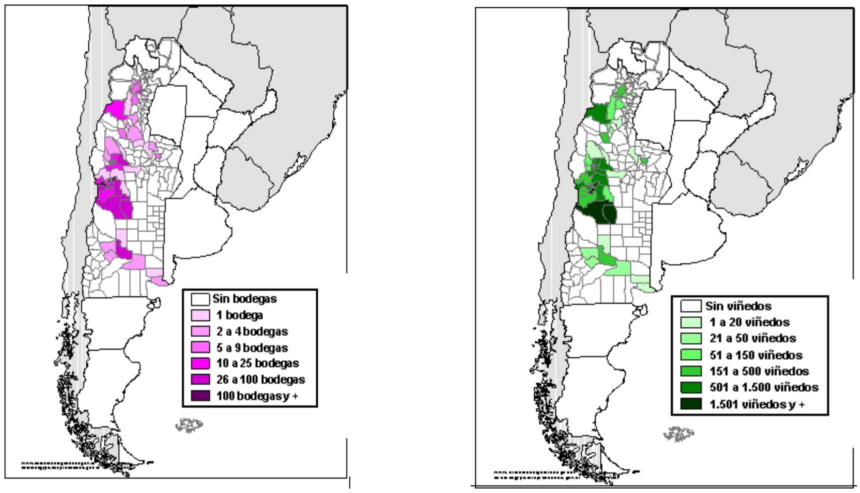

Fig. 6: Harvest (*green*) Wineries (*violet*) localization in Argentina

In the Fig. 6, we can observe the actual localization of the wineries in different districts. The region of the Mendoza is the most important at the moment with more than 100 wineries in a small area. In Mendoza province there is a great experience in the mobilization, because over 150 years the harvest have been artificial migrates through the application of different irrigation technologies.

6. Conclusion and final remarks

Take as input the last known harvest (2010) a simulation based in Motecarlo model have been made. Using as input a sample dataset form 20 wineries a transition matrix have been used to obtain the amount of production (grapes) and the amount of wine produced in each region. The sample set is representative of the capacity of growing of the region.
The transition matrix has several coefficients and their associate variance. The variance have been calculated by mean of the increment of the temperature plus an extra weighted factor that increase is value according to the probability of extreme climates events.
For this work, a zones regionalization has been made. The south region called Neuquen represent the zone that goes form Neuquen to south Buenos Aires (near Colorado river).

The Central zone remarks the influence zone of Mendoza and San Juan (showed as Mendoza in the graphic).
Finally the North zone, that include Salta and La Rioja provinces is called Salta in the graphics.

State Matrix	Will be elaborated in		
MALBEC 2010	Neuquen	Mendoza	Salta
Harvest produced in			
Neuquen	32	0	0
Mendoza / San Juan	0	125	0
La Rioja / Salta	0	0	60
	10,2483058	**177,3986867**	**29,35300746**

Table 1: Total production in 10^3 Hl of Malbec (2010 base)

With this information is possible to calculate the amount of the next harvest using the transition matrix showed in table 2. Each element in this matrix have an extra variance value not showed here.

Transition Matrix	Will be elaborated in		
MALBEC 2010	Neuquen	Mendoza	Salta
Harvest produced in			
Neuquen	65,00%	35,00%	0,00%
Mendoza / San Juan	2,00%	94,00%	4,00%
La Rioja / Salta	0,00%	25,00%	75,00%

Table 2: Transition matrix for grapes produced and the wine elaborated by region

Appling recursively this matrix product is possible to calculate the movement of production or wineries from one region to other. This process is summarized in the Tables 3 & 4, and Fig. 7.

Year	Neuquen	Mendoza	Salta
2010	10,32	176,98	29,70
2015	10,45	176,36	30,19
2020	10,68	175,42	30,90
2025	11,08	174,00	31,92
2050	11,76	171,84	33,40
2060	12,91	168,55	35,54
2065	14,83	163,51	38,67
2070	18,02	155,73	43,25
2075	23,30	143,70	50,00
2080	32,00	125,00	60,00

Table 3: Evolution of the Mabec production

	Neuquen	Mendoza	Salta
Mean Value	15,535259582	163,1085719	38,356168519
Max Value	22,650214986	169,0886847	41,596168519
Min Value	13,756520731	146,02253533	36,196168519

Table 4: Evolution of risk on malbec production showed as regional mean capacity and max/min asociate value

As is showed that the growing capacity of Neuquen and Salta impact in the amount of production of the central zone (Mendoza/San Juan). This affirmation is true meanwhile the demand of Malbec remain without change.

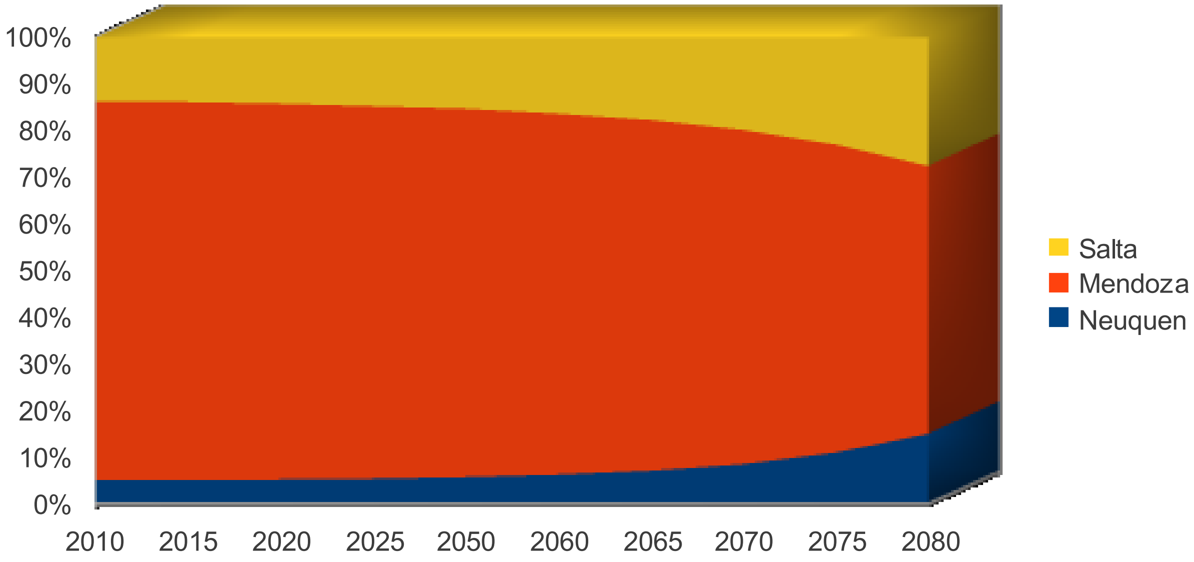

Fig. 7: Evolution of Malbec production capacity as percentage of total production by region

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SIMULATION ANALYSIS OF THE GRAPE RECEPTION PROCESS AT A WINERY

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Abstract

The wine maker is committed to achieving the best possible quality of grapes, so he pushes to have them harvested at the best possible time, and also arrive in the best possible conditions to the wine processing facilities. This is particularly true for white wine grapes, which are more sensitive to higher temperatures. In our research, transportation delays and discrepancies in the amounts actually shipped, resulted in several instances of batches of grapes that were subject to long delays, with the risk of an important loss of wine quality. To analyze the effect of these factors over the process, we developed a simulation model of the reception and pressing of the grapes. By working and experimenting with the model, we were able give a better estimation of the actual processing capacity of the facility, determine the effect of the transportation delays and discrepancies in the volume of reception and finally, determining that an adequate schedule for grape shipments arrival can significantly increase the capacity of the wine processing facilities.

Keywords: *Simulation, Grape reception, Wine production, processing capacity.*

1. Introduction

Making wine is a complex process, traditionally associated with an industry in which the specific know-how of the winemaker is of the outmost importance. In fact, the process of grapes selection, adequate fermentation and mixing, requires special abilities, many of them involving sensorial aspects. Although wine production is considered by many to be almost a craft process, it is really an industrial process and as such is subject to many of the problems which traditionally have been analyzed in the Operations Management area. Process variability and uncertainty is an important component in this industry, because of its origin in the biological nature of many of the processes, and the influence of weather. However, there are many sources of variability that have an industrial nature and are more related to management problems. It's in this context that the use of a simulation analysis could help improve the efficiency of the production processes.

The main objective of this work is to develop and validate a simulation model of the arrival and crushing of the grapes that will finally help improve the quality of the wine that is produced by a winery, while trying to minimize the costs of achieving this. Since one of the aspects that strongly influence the quality of the wine is the quality and condition of the grapes that are used to produce it. We will focus mainly on one factor that can be affected by harvesting decisions, which is the premature fermentation it may experience while waiting to be processed.

During the harvesting season, the oenologist must determine the best moment to harvest different vineyard blocks, considering fruit condition, color, tannin, brix (sugar), acid, pH, vine condition, current and impending weather, and availability of harvesting personnel. When it rains, for example, the grape may develop a fungus (botrytis) that makes it useless, unless it is quickly harvested. On the other hand, the oenologist must also be aware if there is sufficient processing capacity, such as reception pits, presses, and vats, to receive the grapes that arrive to the wine producing facilities. Otherwise, the grape may have to wait a long time to be processed, which may lead to premature fermentation of the grape, thus degrading the quality of the resulting wine. It is difficult to determine exactly how long it takes for the grape to start fermenting, since it depends on the temperature, the condition of the grape, and how it is stored. In the case of the winery that we studied, the grape had to travel by truck, sometimes for several hours. Further delays can be very risky, particularly for the case of white wine, which must be fermented at low temperatures, and without skin. To make things worse, the harvest is carried out at the end of the summer, when temperatures may still be high.

Although this problem is similar to that in many in other industrial sectors, in which unorganized arrivals of products and components generate congestion and delays. The fact that grapes must be harvested as close as possible to their optimal ripeness date, and the deterioration process of the grapes continue while they are transported and waiting to be processed, makes this problem particularly interesting, complicated and unique.

In the winery we studied, the oenologist specified one day on advance, which vineyard blocks should be harvested. As soon as these blocks were harvested, the grapes were loaded onto trucks and sent to the winery facilities. The grapes arrived, during the next day, but at varying times. Usually most trucks arrived around the same time, which caused congestion at the reception facilities. Also, the amounts of grapes that arrived were in general different from the amounts ordered. This was usually the result of errors in the estimation of the amount of grape that a particular vineyard block would produce. The combination of the random arrival time and the difference between the amounts ordered and those received, produced congestion that caused the grape to wait to be processed, sometimes even for many hours.

To produce an adequate representation of the reception process, we developed a simulation model, which in our opinion was the appropriate tool to use given the complexities and uncertainties present in the problem. The model was used to study the following aspects of the process:

1. Estimate the winery daily reception and pressing capacity.
2. Estimate the waiting time for the trucks transporting grapes to the winery.

3. Determine a schedule of deliveries during the day and evaluate alternative combinations of suppliers for that day, so as to obtain the best use of daily processing capacity.

We only modelled the reception and crushing process of white wine, which was the more critical problem faced by the winery we studied, since grapes for white wine must go quickly through several limited capacity stages (pressing and decanting) before fermentation begins. On the other hand, red wine production was less critical in these early stages of production.

2. Wine Supply Chain Simulation

Simulation has been extensively used to model different parts of the supply chain. Chang & Makatsoris, 2001 discuss the supply chain issues that can be analyzed using simulation. Jung et al, 2004 use simulation to determine safety stock levels to meet a desired level of customer satisfaction. Reiner, 2005 describes how process improvements can be dynamically evaluated taking into account customer-oriented performance measures using simulation. Sari, 2008 use simulation to compare two popular supply chain initiatives, CPFR (collaborative planning, forecasting, and replenishment) and VMI (vendor-managed inventory). Longo & Mirabelli, 2008 presents a modeling approach based on simulation for supporting supply chain management. More recently, Cimino et al, 2010 present a Supply Chain Order Performance Simulator (SCOPS), which can be used to analyze the inventory management problem of different types of supply chains. Finally, in their literature review on the impact of RFID technologies on supply chain management Sarac et al, 2010, list the different approaches that have been used to evaluate the benefits of RFID technologies in supply chains. One of them is the use of simulation models.

Applications that pertain to the agri food industry, in particular wine, are quite few. Cunningham, 2001 carried out a global literature survey, which identified only 123 formal, peer reviewed journal articles relating to chain management in the agri-food industry, published from 1987 to August 2000. These papers were distributed unevenly across industry sectors and parts of the world. In the case of the wine industry, only two papers were found. More recently, Ahumada & Villalobos, 2009 carried out a review of the application of planning models in the agri food supply chain, while Rajurkar & Jain, 2011 present a detailed review of literature on food supply chains based on 134 papers published in different journals between 1994 and 2009. They also present a framework for its classification and codification.

Nevertheless, there are several applications worth noting. Kleijnen & van der Vorst, 2005 studied the problem of reducing waste in a fresh-food supply chain using simulation. They note that many simulation models miss specific modeling characteristics needed to model food supply chains, such as submodels for quality variation and submodels for the quality decay of fresh food. Reiner & Trcka, 2004 analyze the use of simulation to improve the performance of a food industry supply chain. They show that the ideal robust supply chain setting depends on the type of demand faced by the supply chain. Georgiadis et al, 2005 describe the use of simulation to analyze capacity planning policies for a food supply chain.

Other approaches have been used to take into account uncertainty in fresh food supply chains. Dabbene et al, 2008a, for example, use a hybrid model, consisting of two parts: the first takes into account event-driven dynamics, while the second describes time-driven dynamics. For both parts analytical models are derived. Solving these models, which is shown in Dabbene et al, 2008b, although feasible, is in general not simple to do. Gigler et al, 2002 present a methodology for optimizing agri-chains using dynamic programming. Other approaches have also been used to analyze the supply chain. Peidro et al, 2010 present a fuzzy linear programming model for tactical supply chain planning. They apply it to an automobile supply chain. Ferrer et al, 2008 describe a mixed integer programming model used to optimize wine grape harvesting. Bohle et al, 2010 further developed this model to take into account uncertainty, by using a robust optimization approach.

3. White Wine Production

We will focus on the grape reception and crushing process for producing white wine. Although we will not describe the entire wine production process, it is important to note that there are some important differences between white and red wine production, in particular in the first stages of production. In the case of white wine, the grape juice is fermented without the skin, while in the case of red; the wine is fermented alongside with the skin of the grape.

3.1. Production Process

As noted earlier, we will focus on the first two stages of wine production process: first, the grape order planning and secondly, the grape reception at the wine producing facilities. We will now proceed to describe these processes.

Grape order planning

The productive process starts with ripeness level follow-up done by the oenologist, to the grapes in each block, regardless if these are produced by the wine producer or by external suppliers.

When the oenologist determines that a certain blocks is ready to be harvested, he or she estimates the volume of grapes that will be harvested and this dictates the number of bins required to store the grapes for transportation. However, generally most of the shipments by suppliers did not match the estimated by the oenologist. This was an important source of variability that complicated the planning process of press utilization and vat allocation, and required making last minute adjustments.

Also most suppliers sent one to three shipments of grapes a day, depending on their size and the pace of the grape harvest. Each supplier had its own truck arrival schedules and there was no coordination among them. This lack of coordination between suppliers induced congestion at certain hours, which led to increased waiting times for processing the grapes. Generally the trucks wait under the sun, subject to high temperatures, which affects the quality of the grapes.

Grape reception at the wine producing facilities

The process that we will analyze using simulation is the grape reception process at the wine producing facility. The whole process starts by first weighing the loaded truck and ends with taking the weight of the empty truck; this allows the winery to determine the total volume of reception (see Fig. 1).

Once weighed, grapes are unloaded, and trucks are loaded with the empty bins. Outbound trucks are weighed once again (see Fig. 2).

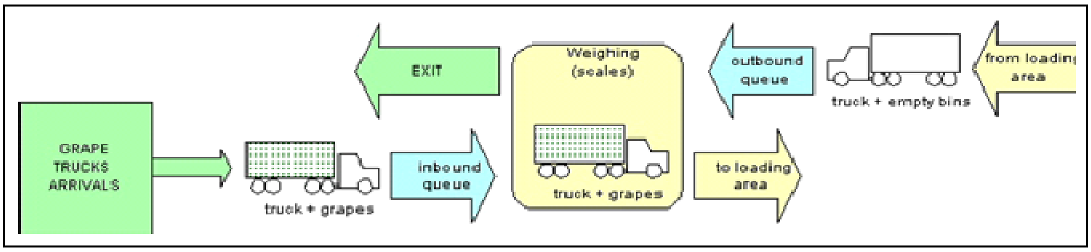

Fig. 1. Truck weighing

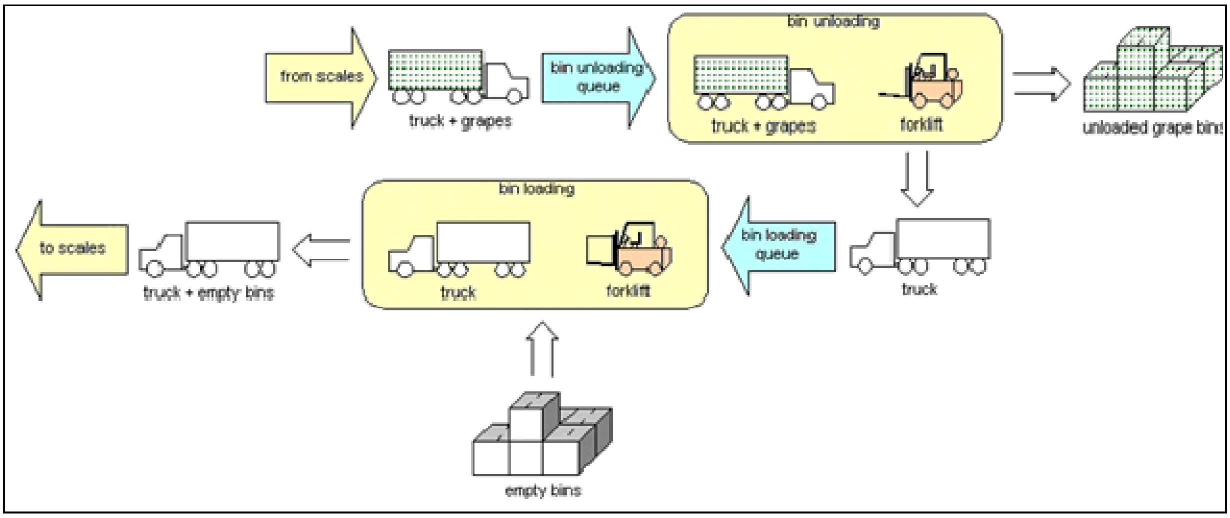

Fig. 2. Truck unloading

Incoming grapes are graded in a sampling area according to producer, variety, and number of kilograms to form the lots to be pressed. Once the lots are formed, they might be processed in the dumping pit or not, according to the availability of presses and the pit itself (see Fig. 3).

Fig. 4 shows the grape crushing process. Before dumping takes place, a press has already been allocated to that lot. As they are dumped into the pit, grapes are steeped and crushed, cooled and finally pressed.

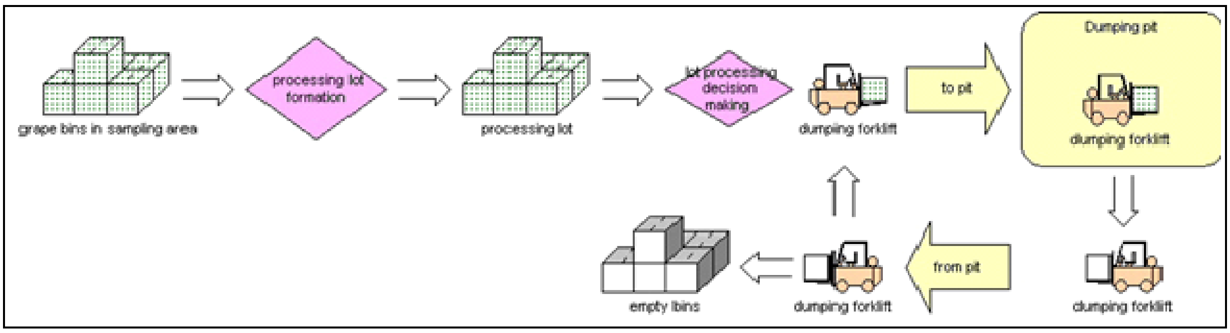

Fig. 3. Lot formation

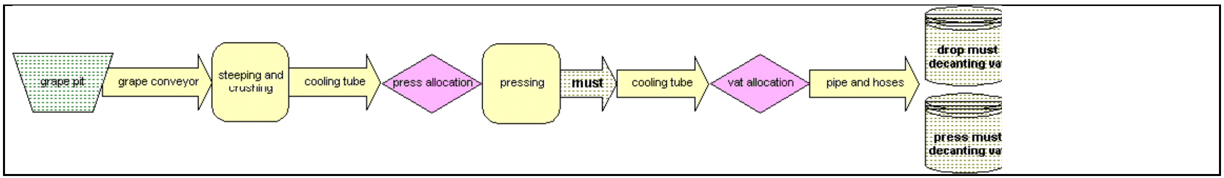

Fig. 4. Grape crushing.

3.2. Problems detected in process

In our initial diagnosis we determined that capacity restrictions are a key element in maintaining the quality of the grapes, since they generate delays in the processing of the grapes and hence damage the product. So harvest planning, grape reception, and grape pressing must be coordinated in order to avoid running into unnecessary delays.

The following capacity related problems were detected in the study:

- The exact daily amount of grapes received and the processing capacity available were uncertain. Oenologists estimated the total amount of grapes that could eventually be processed in a day, based mostly on their experience.
- Very often the amounts of grapes delivered by the suppliers did not match the amounts requested by the oenologist. One source of error was the variability of weight of each bin. However, the main source of variability was the accuracy of the estimation on the amount of grapes in the harvested blocks. Therefore, the actual number of bins arriving at the wine producing facilities was different from the expected one.
- As mentioned before, each supplier decides on their own schedule of when to send their trucks to the wine producing facilities. This generates congestion, at certain times, and idle facilities at others. Even though the suppliers were given a certain time window in which they should make their delivery, this window was too large and many times violated and there was no punishment for not making the time frame. This situation generates delays in the grape processing, as the amount of grapes frequently exceeded reception and processing capacity.

From the previous problems the following hypotheses arise:

1. Is it possible to determine or estimate more exactly the daily reception and processing capacity for white wine?
2. How do the uncoordinated delivery schedules of the suppliers affect the processing capacity?
3. Is it possible to increase grape reception while reducing or avoiding waiting time?

Since the origin of these questions lie on the uncertainty of certain aspects of the production process, a simulation model was developed to answer them.

4. Simulation Model

Given the sources of uncertainties that affect the problem and the large variability that we observed, we decided that the best approach to study the behaviour of the system was using simulation. The main objective will be to obtain a quantitative estimation, as accurate as possible, of the wine producing capacity and the average grape queuing time, for a certain planning horizon, given a specific harvest plan.

Because the focus of this study is on the daily operations, and since the harvest plan varies frequently during the harvest season, it was decided that a planning horizon of 5 days for processing and 3 days for grape reception would be used in the simulation analysis.
The model is divided into two large blocks: first, the grape truck arrival generator and second, the grape processing block. The first block represents the suppliers' response to the grape orders, which incorporates the grape shipment schedules and the amounts of grapes delivered. The second block represents the wine producing facilities and incorporates the inbound and outbound truck control, and grape processing.
The model assumes that the first 3 harvest days are initially planned for each producer-variety-kilogram of grapes. The amounts received are simulated to obtain the estimated finish time of the last pressing cycle of all the grapes received, that is, the moment when all the grapes have been processed; average grape queuing time in the sampling area before processing; and the average throughput in terms of processed kilograms of grapes per hour.
Regarding the hypothesis presented in section 3.2, they will be answered as follows:

1. Is it possible to determine or estimate with more accuracy the daily reception and processing capacity for white wine?

To give light into this question we will proceed to do a number of iterations on the simulator with an improved or ideal grape shipment situation, and the average amount of grapes that could be received and processed in a 24-hour period will correspond to the processing capacity.

2. Is it possible to increase grape reception while reducing or avoiding waiting time?

By comparing the current situation with the improved one and making small changes in the volume of reception on the previous experiment, we expect to determine if it's possible to increase the reception while reducing the waiting times.

3. How does the uncoordinated delivery (Volumes and schedules) of the suppliers affect the processing capacity?

First, we will analyze the variability in the system given by the current grape delivery method. This variability will be then compared to the variability of the entire system, indicating how much of the variability is due to the uncoordinated delivery schedules. Secondly, two different shipment methods will be compared; the current method, and an improved method. Variability will be measured on pressing cycle finish time and on average grape queuing time.

5. Computational experiments

The simulation model was built using the Extend discrete simulation environment software (Krahl, 2001). The model then was statistically validated by comparing the results it generated with the real problem. Once validated, we turned our attention to determining the variability in the amount of grapes received in each shipment, variability in the schedules of deliveries, and the combined variability.
Since the model is divided into two large blocks: first, the suppliers and second, the wine processing facility, they will be both analyzed separately. To improve the efficiency of the experiments, the Common Random Number (CRN) variance reduction technique suggested in (Law, 2000) will be used, so we will proceed to fix the seed value for the random number generation for all the random factors that are not being analyzed.

The analysis will be based on the data obtained on a representative date for the reception of white wines, which corresponds to March 1 and 2, in which a total amount of 460,000 kgs. of grape were requested from 7 different suppliers, in 3 varieties. Processing these grapes ended approximately at 18:00 on March 3.
All factors suitable of actual change or improvement, with respect to the suppliers, will be analyzed. This includes possible modification of some of the suppliers' current practices. .

6. Results

6.1. Process capacity

Now we will focus on determining if it is possible to determine or estimate with more accuracy the daily reception and processing capacity for white wine. In order to maximize processing capacity, while minimizing grape queuing time in the loading area, we need to receive the grapes in the correct amounts at the exact time they are required. Of course we have to take into account the number of presses available, their maximum capacity, the dumping time for each lot, how presses are allocated to each lot, and pressing cycle duration (from the moment the press is loaded until it is cleaned). For example, if we assume there is no randomness, we can estimate the maximum processing capacity assuming the following data:

- Number of presses: three (two 150 Hl units; one 100 Hl unit).
- Maximum capacity: 22,000 Kg (150 Hl press) and 12,000 Kg (100 Hl press).
- Lot allocation: Same used in simulation model.
- Dumping time: 1 hour.
- Pressing cycle (PC): 5 hours.

It will be also assumed that each bin contains exactly 500 kgs. of grape. Therefore, the capacity of the larger presses, in terms of bins, would be 44, and that of the smaller press, 24. Finally, system failures will not be considered, and delivery schedules will be exact, i.e., they will have not a probability distribution associated to them but a fixed value.
Under these ideal delivery and functioning conditions (random factors absent) lot processing order and schedule are shown in Figure 5, assuming that the first lot would be ready by the 10th hour on day 1 until the 34th hour (24 hour time window). To calculate the maximum processing capacity, or throughput (TP), the horizon starts the moment the first truck arrives and ends when the last pressing cycle is over. As shown in Fig. 5, 12 lots are processed in 23 hours, assuming the first truck arrives in the ninth hour. The 12 lots correspond to 224,000 kgs. of grapes, 88,000 kgs. in the two larger presses and 48,000 kgs. in the smaller press. This gives a TP of 9,739.13 kgs./hr. (224,000/23). Of course, this is an upper bound. In general the actual TP will be smaller.

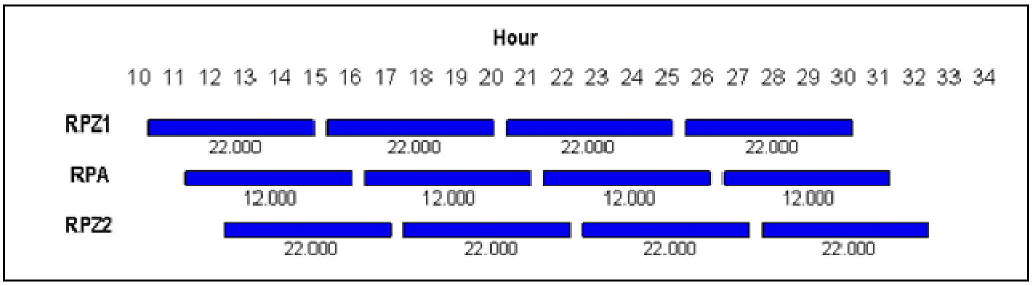

Fig. 5. Press processing under ideal delivery and system conditions.

In general the TP will be computed as follows:

$$TP = \frac{\text{Grapes processed, in kgs.}}{\text{First truck arrival hour} - \text{Last pressing cycle hour}}$$

A TP value will be computed for every simulation run using this formula. On the other hand, we know that the queuing time depends on the unloading time of the truck that brought the lot, the truck weighing time, the amount of grapes transferred from scales to presses, and press availability. In the case we studied, presses were available every 5 hours approximately, and press loading time is approximately 1 hour. Thus, if trucks arrive according to the schedule shown in Table 3, and maintaining all previous assumptions, we can obtain the following results from the simulation model:

- Queuing time in sampling area: 3.20 hrs. in average with a standard deviation of 0.27 hrs.
- Pressing cycle finish time: 32.16 hrs. in average with a standard deviation of 0.22 hrs.
- TP: 9,673.88 kgs./hr. in average with a standard deviation of 92.15 kgs./hr.
- Processed lots: 12.4 per press.

Arrival time	Bins carried	Kgs. per bin	Total kgs. in lot
9	44	500	22,000
10	68	500	34,000
11	44	500	22,000
14	68	500	34,000
15	44	500	22,000
16	68	500	34,000
19	44	500	22,000
20	68	500	34,000
Total			224,000

Table 1. Differences in bins received

Note that on average the TP value was smaller than the ideal one (9,739.13 Kg/hr.). So, going back to the question of whether it was possible to determine or estimate more exactly the wine producer's daily reception and processing capacity for white wine, we can indicate that the maximum reception and processing capacity is 224,000 kgs. for a time window of approximately 24 hours. That value could be obtained under the delivery conditions stated above, with no machine failures.

Next, we will compare the results obtained using two different plans for receiving the same amount of grape from the same suppliers, differing only in the truck arrival schedule. In order to make the comparison more realistic, the same random number generating seed will used for the wine processing facilities.

The base case will be the actual arrivals observed in the case studied. The next experiment will be the same, except that truck arrivals will be scheduled so that press utilization is improved. Inaccuracies in the number of bins shipped will not be considered so in both cases the total amount of bins requested will actually arrive. In other words, the current situation at the wine processing facilities, except for the inaccuracies in the number of bins

that arrive, will be compared to an improved system, where grape reception is better planned.
The plan for receiving 170,000 kgs. of grapes of variety 1, is shown in Table 2.

Supplier	Grapes Ordered (kgs.)
Supplier 1	25,000
Supplier 2	25,000
Supplier 3	20,000
Supplier 4	40,000
Supplier 5	30,000
Supplier 6	30,000

Table 2. Base case: plan for variety

The simulation model results for the base case were the following:

1. Queuing time in sampling area: 3.57 hrs. in average with a standard deviation of 1.17 hrs.
2. Pressing cycle finish time: 35.22 hrs. in average with a standard deviation of 1.65 hrs.
3. Amount of grapes received: 169,102.74 kgs.
4. TP: 7,275.45 kgs./hr. in average with a standard deviation of 491.35 kgs./hr.

The improved plan, for the same total amount of grapes, specifies arrival time of the trucks and number of bins, of 500 kgs. each. Time windows of one hour were considered for arrival schedules. The improved plan is shown in Table 3.

Arrival time	Supplier	Variety	Ordered bins
9:00-10:00	Supplier 1	Variety 1	30
9:30-10:30	Supplier 4	Variety 1	20
10:00-11:00	Supplier 2	Variety 1	30
13:00-14:00	Supplier 3	Variety 1	40
13:30-14:30	Supplier 4	Variety 1	20
14:00-15:00	Supplier 5	Variety 1	30
17:00-18:00	Supplier 1	Variety 1	20
17:30-18:30	Supplier 6	Variety 1	30
18:00-19:00	Supplier 5	Variety 1	30
21:00-22:00	Supplier 2	Variety 1	20
21:30-22:30	Supplier 6	Variety 1	30
22:00-23:00	Supplier 4	Variety 1	40

Table 3. Improved plan.

The simulation model results for the improved plan were the following:

- Queuing time in sampling area: 1.51 hrs. in average with a standard deviation of 0.32 hrs.
- Pressing cycle finish time: 30.73 hrs. in average with a standard deviation of 1.01 hrs.
- Amount of grapes received: 169,413.4 kgs.
- TP: 7,996.56 kgs./hr. in average with a standard deviation of 424.26 kgs./hr.

We can indicate that the average queuing time of the improved plan is less than the one for the base case, with a 95% confidence interval for the difference of [1.72, 2.41]. The expected pressing cycle finish time, for the improved plan, is also less than the one for the base case, with a 95% confidence interval for the difference of [3.94, 5.03]. Finally, the TP for the base plan is greater than that for the base case, with a 95% confidence interval for the difference of [−903.34, −538.88].
This result indicates that an adequate schedule for grape shipments arrival, and avoiding inaccuracies in the bin deliveries, can significantly increase the capacity of the wine processing facilities, thus increasing the amount of grapes processed and reducing the grape queuing time. So hypothesis 2, is it possible to increase grape reception while reducing or avoiding waiting time?, is true because we can increase the TP while reducing the queuing time.

6.2. Variability in the suppliers

We will look into the results regarding the variability of the suppliers with hypothesis 3: How does the uncoordinated delivery (Volumes and schedules) of the suppliers affect the processing capacity?. We will look first into the effect of the variability in the reception volumes and then we will look into the effect of the variability in delivery schedules. Finally we will look into the effect of the combined variability.

Variability in the Volumes

To determine the effect of the variability in the volume of reception on the capacity of the system we will take a value called the score (Highest and lowest), which indicates the percentage of shipments that had less or more volume than the requested. A highest score of 60, indicate that 60% of the shipments had less volume than requested, while a lowest of -40 indicates that 40% of the shipments had more volume than required.
A series of experiments were carried out to see the effect of reducing these scores that is, increasing the accuracy of bins received in each shipment.
Results of reducing the variability in the volume of arrival are shown in Table 4.

Highest Score	Lowest Score	Avg. Wait in Queue	Std. Dev.	Avg. pressing cycle time	Std. Dev.
60	-40	6.52	2.08	61.97	4.86
30	-20	7.70	1.46	64.51	3.14
15	-10	9.49	2.45	67.96	4.48
5	-5	10.20	1.05	70.08	2.18
1	-1	11.02	0.18	71.70	0.30

Table 4. Differences in bins received

From these results we can indicate that: as the variability of the number of bins received in each shipment decreases, that is, the suppliers tend to send the requested amount, the grape queuing time and pressing cycle finish time increase for the same daily grape reception plan. Nevertheless the standard deviations of the queuing time and processing cycle time are reduced significantly, indicating that the system is much more predictable.

Variability in the grape delivery schedules
To determine the effect of variability in the grape delivery schedules the only system variability that was introduced into the system was the time of arrival of the trucks. This means that the number of shipments, and the amount of grape received in each shipment, are invariant. Only the hour of the day in which the shipments arrived were altered.
The results showed that the base level of the standard deviation for the grape queuing time was 0.74. But when we increased the variability in the arrival time of the shipments the standard deviation for the grape queuing time increased to 2.08. So there was an increment of 181% in the variability of the grape queuing time.
If we look into the standard deviation for the pressing cycle finish time, the base case was 1.30 hours. When the variability was increased the standard deviation for the pressing cycle finish time rose to 4.86. This is an increment of 273%.
If we compare the absolute value changes in the standard deviation with the value changes in the volume variability we can conclude that varying delivery schedules introduces much less variability than changing the amount of grapes received, for the range of deviations considered.

Combined variability
Finally, we will analyze the effect of simultaneously varying the amount of grapes received, the delivery schedules, and the number of trips per suppliers. This will allow us to evaluate how suppliers' response affects the system as a whole.
The results obtained were a standard deviation for the grape queuing time of 1.70 hours and for the pressing cycle finish time of 3.80 hours. If we compare these values with the base case of: 0.74 for the grape queuing time, and of 1.30 for the pressing cycle, we can see that the increment in variability is similar to the one introduced by an inaccuracy in the amount of grapes received alone. Hence we can indicate that the variability in the system introduced by grape delivery by suppliers is due, to a significant level, to inaccuracies (higher or lower number of bins delivered) in the daily volume supply of grapes. So if the wine processing facility desires to reduce the system variability, in terms of the standard deviation of queuing time and pressing cycle time, they must concentrate their efforts in reducing the variability in the volume supply, rather than the variability in the arrival schedule.

7. Conclusion

For most wine makers, improving the quality of the wine is their main concern and one of the aspects that strongly influence the quality of the wine, is the grapes that are used in the process. To achieve the best quality of grapes they have to be harvested at the best possible time, and they also have to arrive in the best possible conditions to the wine processing facilities. This is particularly true for white wine grapes, which are more sensitive to higher temperatures.
During our research, it was observed that along the harvest season, loaded trucks had to wait for long periods of time before they could unload, due to congestion in the wine reception facilities. This was considered unacceptable by the wine maker, due to the possible impact on wine quality.
To better understand the issues and be able to analyze the impact of the process on the grape queuing time, a simulation model was developed. A group of experiments were run

to first, determine if it's possible to obtain a better forecast of the capacity in the wine processing facility; second, determine if it's possible to increase the reception of grapes while reducing the queuing time by a better planning of the process and third, how does the uncoordinated delivery (volumes and schedules) of the suppliers affect the processing capacity.

The first question was answered by building a detailed simulation model, which enabled the wine maker to determine its capacity and waiting times according to the expected arrival of grapes and the historical variability.

The second and third questions were analyzed by estimating the effect of the inaccuracies in the shipments, that is, that the amount of grapes received did not match the amount ordered, and the lack of an adequate schedule of truck arrivals, using the simulation model. Both inaccuracies turned out to have a significant effect on the capacity and predictability of the process. Also the simulation model results indicated that it would be possible to significantly increase the capacity of the wine processing facilities, thus increasing the amount of grapes processed and reducing the grape queuing time, by reducing the discrepancies of the amounts of grapes received, with respect to the requested amount, and by adequately scheduling the trucks arrivals. Another, much more expensive option, would have been expanding the wine processing facilities to include more presses and grape handling equipment.

The simulation model is currently in use by the winery. Also there is an ongoing effort to improve the interaction and collaboration with the suppliers, so they understand the importance of following the procedures that would be necessary in order to generate the results.

8. Acknowledgements

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Some suggestions for the producers after the simulation of an oil journey: the risk can be oxidation The *Food Supply Chain* project at Bologna University

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Abstract
Which are the effects on quality and safety of foodstuffs due to their journey from the producer to the consumer? This is the focus and challenge of the first step of the study discussed in this paper. In particular, it deals with the monitoring and analysis of shipments of olive oil, extra virgin olive oil and grapeseed oil, from Italy to different countries worldwide, e.g. Taiwan, USA and Japan. The aim is the identification of possible effects on foodstuffs, e.g. oil, due to transportation issues, shipment duration and condition, packaging decisions, etc.
A case study presenting a critical shipment of different bottles of oil from Italy to Taiwan is illustrated. The results from a simulation analysis conducted on a sample of oil bottles following the monitored temperature are discussed. Oils in bottles, which have had a simulation of transport, have been analysed chemically and compared with not simulated ones of the same production batches.

Keywords: logistics, transportation, vegetable oils, oxidation, temperature, simulator

1. Introduction

It is well-known that the shelf-life of a bottled vegetable oil is limited by two main processes that are lipolysis and, mostly, oxidation. Endogenous and exogenous lipases, responsible of the first degradation, act when the oil is still in the fruits, before the extraction, especially if olives are damaged, injured or not well-preserved and give rise to the formation of free fatty acids (Boskou, 1996). On the other hand, oxidation occurs mainly during the extraction process and later, when the oil is stored (Morales & Przybylski, 2000). The degree of unsaturation of the fatty acids of a vegetable oil is directly proportional to the rate of the oxidation process. In fact, the auto-oxidation and the photo-oxidation of unsaturated fatty acids originate hydroperoxides (primary oxidation products), which are easily decomposed into different compounds (secondary oxidation compounds), some of which are volatile and responsible for the sensory degradation of the oil, especially rancidity (Frankel, 1990). Extra virgin olive is evaluated as an excellent foodstuff among all the other vegetable oils, since it shows a high oxidative stability (Velasco & Dobarganes, 2002). This particular behaviour is strictly related to its high content of monounsaturated and saturated fatty acids and to the low amounts of polyunsaturated fatty acids, together with a high concentration of antioxidant compounds, especially phenols. Beside this, pure olive oils are blends between refined and virgin olive oils (E.E.C. Reg. 2568/1991) and, for this reason, they generally show an overall quality lower than extra virgin olive oil. To date, the research community has studied how several factors such as temperature, light, pigments, oxygen availability, enzymes, metal contamination and microorganisms affect the oxidation process. In particular, several works showed the effect of different storage conditions on the quality of olive oils (De Leonardis e Macciola, 1998; Cinquanta et al., 2001; Caponio et al., 2005; Stefanoudaki et al., 2010). The effect of packaging material on the oxidation process of different vegetable oils, especially virgin olive oil, has been recently studied in several works (Méndez & Falqué, 2007; Sacchi et al., 2008), adopting also a predictive approach (Del Nobile et al., 2003). Materials, which have been used for packaging of vegetable oils, include glass, metals (tin-coated steel) and more recently plastics (PET, LDPE, PP), brick-type cartons, bag-in-box pouches and plastics coated paperboard/ alufoil laminates (Pristouri et al., 2010).

The main aim of the Food Supply Chain project at Bologna University is to trace and study the terms and conditions of transportation of important foodstuffs. In particular the project focuses on the analysis of the Supply Chain of wine, vegetable oil/olive oil and other foodstuffs to identify weaknesses and opportunities to improve the quality and safety of transportation activities. In particular, the following factors are traced and analysed on the finished products during the transportation from Italy to a generic consumer located in EC or in an extra European country: temperature, humidity, vibrations, and light.

The project, for the first time in Italy, tries to involve many food companies of various Italian regions with the aim to safeguard and promote exports of local products and ensure quality and traceability to protect and safe final consumers.

The main question at the basis of the project aims and expectations is the following: which is the role and criticality of logistics on the quality and safety issues of food products?

Particularly, in this paper the preliminary results obtained by the monitoring of temperature of some oil bottles during the transportation from the producer to the consumer, are reported. The case study here discussed refers to a critical journey from Italy to Taiwan (unsaturated oils, olive oils of a medium low quality, many changes of temperature). The results illustrate the existence of a significant influence of transportation issues on the oil quality at the consumer location.

2. Problem Statement

The Food Supply Chain (FSC) is a research project to 1) measure the effects of transportation and storage issues on quality and safety of food products and to 2) identify and develop effective solutions to control both quality and safety especially in presence of significantly critical journeys of food from the origin farm and/or production system location to the consumer's location. In particular, the FSC project involves the department of Industrial Mechanical Plants at the Faculty of Engineering and the department of Food Science at the Faculty of Agriculture. This is the first study on the chemical analysis of food products in relation with the journey and transportation/packaging decisions.

This study has been conducted on a specific case of shipment oil bottles from Italy to Taiwan by the support of a company leader in the worldwide distribution of oils for food. The sequence of decisional steps is:

- *Monitoring* temperature during the shipment to the consumer's location. This activity is supported by the introduction of data logger and tracking technologies (e.g. black box) in several shipments of goods from different starting points, e.g. sites of origin and/or production of food products, to different destination points worldwide.
- *Analysis* of collected data.
- *Simulation* of the transport/shipment conditions in a laboratory by using a simulator developed ad-hoc by the group of research in order to simulate historical and monitored temperature profiles. The simulation is conducted on the so-called "zero-time" bottles of the same lots of products shipped to consumer locations and whose temperature profile has been properly monitored. In the study object of this paper only temperature values have been collected and simulated by the use of the simulator. A discussion on the opportunity of monitoring and simulating other physical variables e.g. humidity, vibrations, light, etc. is presented in the further research section.
- *Chemical and sensory analysis* in a food science laboratory (University of Bologna) in order to measure the impact on product quality due to the transport conditions.

3. Case study. A journey from Italy to Taiwan

The case study discussed in this paper refers to products shipped from Italy to Taiwan.

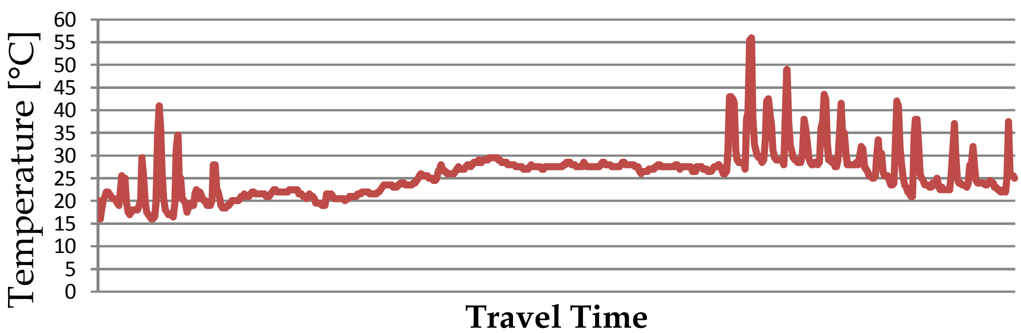

Figure 1. Temperature profile in Celsius degrees, monitored from Italy to Taiwan within 50 days.

The maximum level of temperature was about 56 °C a few times when the container of products was waiting to be collected at the seaport in Taiwan.

Samples One extravirgin (EV), one olive oil (GD) and two grapeseed oils (named TD and QU) were subjected to the simulation and analysed, before and after the simulation, following the analysis plan described below. The research group who carried out the chemical analysis didn't know that the two samples of grapeseed oil were actually the same oil, but packaged in different bottles (blind test), as reported in Table 1.

EV0	Extra virgin olive oil, 0.5 L dark glass bottle, before the simulation
EV1	Extra virgin olive oil, 0.5 L dark glass bottle, after the simulation
OL0	Pure olive oil, 1L transparent clear glass bottle, before the simulation
OL1	Pure olive oil, 1L transparent clear glass bottle, after the simulation
GA0	Grapeseed oil, 0.5 L dark glass bottle, before the simulation
GA1	Grapeseed oil, 0.5 L dark glass bottle, after the simulation
GB0	Grapeseed oil, 0.5 L transparent clear glass bottle, before the simulation
GB1	Grapeseed oil, 0.5 L transparent clear glass bottle, after the simulation

Table 1. List of the samples analyzed and their description.

Analysis plan

Free acidity, peroxide number and determination of fatty acids were evaluated for all the analyzed samples. UV spectrophotometric indexes (k232, k270, ΔK), extraction of phenolic compounds and determination of their total amount and of ortho-diphenols were performed for extravirgin (EV) and pure olive oil (GD) samples, in order to evaluate the effect of the journey on the chemical properties of these samples.

Basic quality indexes

Free acidity, peroxide value and UV spectrophotometric indices (k232, k270) were carried out according to the official methods described in E.E.C. Reg. 2568/91 and the following amendments of the European Union Commission. All parameters were determined in two replicates for each sample.

Fatty acid composition

Fatty acid composition of oil samples was determined as fatty acid methyl esters (FAMEs) after alkaline treatment, obtained by mixing 0.05 g of oil dissolved in 2 mL of n-hexane with 1 mL of 2 N potassium hydroxide in methanol, and subsequent gas chromatographic analysis, according to Bendini et al. (2006), with slight modifications. The results were expressed as percentage of fatty acid on the total fatty acid content.

Extraction of Polar Phenolic Extracts

The liquid-liquid extraction (LLE) procedure was carried out according to the method reported in Carrasco-Pancorbo et al. (2004). Briefly, 60 g of oil was dissolved in 60 mL of n-hexane, and the solution was extracted successively with four 20 mL portions of methanol/water (60:40, v/v). The combined extracts of the hydrophilic layer were brought to dryness in a rotary evaporator under reduced pressure at 40 ºC. This extraction procedure was performed in two replicates for each samples. Extracts were stored at -43 °C before analysis.

Spectrophotometric determination of total phenol and *ortho*-diphenols content

The total phenol (TP) content of the extracts was carried out spectrophotometrically using Folin-Ciocalteu reagent and the absorbance was determined at 750 nm (Bendini et al., 2006). The *ortho*-diphenols content was determined by the procedure described in Cerretani et al. (2005). Total phenols and *ortho*-diphenols were both quantified using two different gallic acid calibration curve (TP: r^2 = 0.997; *ortho*-diphenols: r^2 = 0.994). The results were both expressed as mg of gallic acid kg^{-1} of oil.

Sensory Analysis

The sensory analysis has been carried out only on the EV0 and EV1 samples by the Commission Regulation 2568/91 and subsequent amendments. Only for extravirgin olive oil the sensory control is mandatory.

Statistical Analysis

Means and standard deviations were calculated with Statistica 6.0 (2001, Starsoft, Tulsa, OK) statistical software. Statistica was used to perform one-way analysis of variance, and Tukey's honest significant difference test at a 95% confidence level (p<0.05) to identify differences among groups.

Results

The samples showed a typical fatty acid composition according to their respective botanical origins (Table 2 and 3), and they were in the compositional range suggested by the literature and the Codex Alimentarius (CODEX-STAN 210, 2005).

% Fatty acids	EV	OL
C16:0	10.53	11.99
C16:1 n-7	0.12	0.00
C16:1 n-5	0.75	0.16
C17:0	0.09	0.00
C17:1	0.14	0.15
C18:0	3.09	3.01
C18:1 n-9	73.95	70.82
C18:1 n-7	2.02	2.60
C18:2	7.76	9.74
C20:0	0.42	0.44
C18:3	0.70	0.67
C20:1	0.27	0.25
C22:0	0.11	0.18
C24:0	0.05	n.d.

Table 2. Fatty acids composition of the extra virgin (EV) and olive oil (GD) samples. Data are expressed as percentage on the total fatty acid content.

% Fatty acids	GA	GB
C16:0	7.36	7.24
C16:1	0.09	0.09
C17:0	0.07	0.07
C18:0	3.63	3.80
C18:1 n-9	20.12	19.79
C18:1 n-7	0.90	0.76
C18:2 trans	0.83	0.96
C18:2	65.73	66.34
C20:0	0.31	0.27
C18:3	0.52	0.47
C20:2	0.18	n.d.
C20:1	0.15	0.21
C22:0	0.13	n.d.

Table 3. Fatty acids composition of the grapeseed oil samples (QU and TD). Data are expressed as percentage on the total fatty acid content.

For the grapeseed oil samples (QU and TD), the free acidity values obtained by the official method (and expressed as g oleic acid in 100 g of oil) have been mathematically converted in mg KOH/g of oil, to standardize and to compare the results with the limits reported by the Codex alimentarius for vegetable oils (CODEX-STAN 210, 2005) (Table 4). The acidity of the grapeseed oil samples, QU and TD, before the journey were below the limit adopted by the Codex alimentarius for vegetables oil, which is 0.6 mg KOH/g for refined oils (CODEX-STAN 210, 2005). For the samples EV and GD, free acidity values were also below the legal limit for extra virgin and olive oil (E.E.C. Reg. 2568/1991), which are respectively 0,8% and 1% (expressed as oleic acid). For all the samples, except for TD, no significant variations of free acidity was observed after the simulation of the journey, suggesting that a substantial hydrolytic process didn't occur (Table 4).
Regarding oxidation, for the grapeseed oil samples (QU and TD), the peroxide number, index of the primary products of oxidation, was within the range adopted by the Codex alimentarius (CODEX-STAN 210, 2005), which is fixed at 10 meq O_2/kg oil for refined oils, both before (QU0 and TD0) and after (QU1 and TD1) the simulation. EV0 showed a high value of peroxide number, but below the legal limit for extra virgin olive oil of 20 meq O_2/kg oil (E.E.C. Reg. 2568/1991). For the samples TD, EV and QU, the simulation apparently caused a weak increase (not significant) of the peroxide number; all of them remained below the legal limit also after the simulation of transport (TD1, EV1 and QU1). The pure olive oil sample, GD0, showed a peroxide number exceeding, from the beginning (before the simulation of transport) the legal limit for olive oil (15 meq O_2/kg oil, E.E.C. Reg. 2568/1991), indicating an advanced stage of oxidation; after the simulation, it's interesting to observe a significant decrease of the peroxide number. Should be reminded that peroxide number is an index measuring the rate of primary oxidation products; its reduction can be explained by following the Gaussian curve describing the trend of primary products during an oxidation process: when the oxidation progresses, peroxides start to generate products of

evolution and demolition (secondary products) (Frankel, 1990), so peroxide value is not able itself anymore to express the oxidative quality of an oil. The advanced status of oxidation of GD0 and of its counterpart "transport-simulated" GD1 is confirmed by the high values of k_{232} and k_{270} indexes (Table 5), even if k_{270} was below the above the legal limits for olive oils, which is 0.9 (E.E.C. Reg. 2568/1991). For both the extra virgin olive oil samples (EV1 and GD1), the k_{232} values decreased significantly after the simulation, probably for a conversion of dienes into secondary products of oxidation, such as aldehydes and ketones, as reported in literature (Bester, 2008). The sensory analysis required for the classification of the oil as extra virgin classified the sample EV0 as extra virgin and the sample (transport-simultated) EV1 as virgin, with a defect of rancid.

Total phenols and *ortho*-diphenols (Table 5) were low for both olive oil (extravirgin and refined) from the beginning, especially for GD. During the simulated transport this small amount of antioxidants is not able to protect the oil and the simulation produces measurable progress of oxidation. No decreases of phenols were observed after the simulation process (Table 5), suggesting that the conditions reached during this simulation were not able to degrade directly them.

Samples	**Free acidity**		**Peroxide number**	
	Mean ± s.d.	*T*	*Mean ± s.d.*	*T*
EV0	0.49 ± 0.02	*a*	17.47 ± 0.04	*a*
EV1	0.48 ± 0.00	*a*	18.73 ± 1.81	*a*
OL0	0.32 ± 0.02	*a*	22.20 ± 0.37	*a*
OL1	0.30 ± 0.02	*a*	10.38 ± 0.17	*b*
GA0	0.22 ± 0.00	*a*	6.11 ± 0.88	*a*
GA1	0.17 ± 0.00	*b*	6.85 ± 0.89	*a*
GB0	0.20 ± 0.04	*a*	7.13 ± 0.22	*a*
GB1	0.11 ± 0.00	*a*	9.10 ± 1.20	*a*

Table 4. Oils' free acidity and peroxide number. Free acidity is expressed as g oleic acid/100 g of oil for extravirgin (EV) and olive (GD) oil samples and as mg KOH/g of oil for grapeseed oil samples (TD and QD), as reported in the Codex Alimentarius (CODEX-STAN 210, 2005). Peroxide number is expressed as meq O_2 /kg oil. Means ± standard deviations are shown (n = 2). For each samples, within each column means followed by different letters are significantly different according to Tukey's test (p<0.05), before and after the simulation.

Samples	k_{232}		k_{270}		**TP**		***ortho*-diphenols**	
	Mean ± s.d.	*T*	*Mean ± s.d.*	*T*	*Mean ± s.d.*	*T*	*Mean ± s.d.*	*T*
EV0	2.93 ± 0.04	*a*	0.18 ± 0.02	*a*	74.24 ± 4.29	*a*	31.83 ± 1.91	*a*
EV1	1.55 ± 0.02	*b*	0.19 ± 0.00	*a*	98.96 ± 7.30	*a*	35.94 ± 1.39	*a*
OL0	2.92 ± 0.02	*a*	0.71 ± 0.01	*a*	17.69 ± 1.82	*a*	10.89 ± 1.40	*a*
OL1	2.68 ± 0.02	*b*	0.70 ± 0.00	*a*	15.29 ± 2.22	*a*	7.26 ± 1.98	*a*

Table 5. UV-spectrophotometric indexes, total phenols (TP, mg of gallic acid kg^{-1} of oil) and *ortho*-diphenols content (mg of gallic acid kg^{-1} of oil) in the extravirgin (EV) and olive (GD)

oil samples. For each samples, within each column means followed by different letters are significantly different according to Tukey' s test (p<0.05), before and after the simulation.

4. Conclusions and further research

In conclusion, this first simulation performed on different oils in terms of quality and saturation index (some, by choice, of a medium-low quality) did not result in a significant increase of the number of peroxide, and did not show significant progress of the first phase of oxidation (from acylglycerols to peroxides). Nevertheless it has accelerated (final blow) the oxidation and produced (in one case) a slight defect of rancid in oils that already reached an advanced level of primary oxidation (high peroxides before the simulated transport).
Some tips useful for producers, when long and critical transport are planned, are to protect the oil from light (visible, infrared and ultraviolet) by using obscured bottles and to commercialize impeccable oils in terms of oxidation, possibly protected by phenols (virgin olive oils) as natural antioxidants. As a matter of fact the transport can accelerate an oxidative process in progress, bringing the product outside the legal limits.
The grapeseed oil GB0 and the corresponding "transport-simulated" GB1, which were respectively equal (blind test) to the samples of grapeseed oil in different bottles named GA0 and GA1, did not differ significantly before and after the simulation of transport. Moreover, the samples GA1 and GB1 did not show a significant different value of peroxide number: it seems that, in the specific case of simulation of transport and for the analytical insights realized, the different packaging did not affect the final quality.

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The challenge of traditional pickled eel, typical product of Emilia-Romagna: when the food quality makes the difference between the survival or the extinction of a species

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Abstract
The European eel is an endangered species living in Europe and Mediterranean coasts. The European Union imposes an Eel Management Plan (EMP) to be implemented in every Member State, however no technical and financial supports to implementation of EMP are provided. On the other hand, a recovery of an economic importance of eel fishery, in association with a sustainable management of the stock, would be extremely important for the conservation of this species.
The Lagoon of Comacchio (North Adriatic Sea, Italy) hosts an extensive breeding of eel that provides small amounts of fish still used for production of Traditional Pickled Eel of Lagoon of Comacchio, a typical food produced by the Po Delta Park Authority and recognized by the Italian Nature Park Federation and the SlowFood Association.
Since the EMP states that 40% of captures have to be released, we are developing a parametric index to select specimens with the highest probability to complete the oceanic reproductive migration. As to the remaining 60%, samples with high score could be used for food industry. The money earned from such a high quality product could provide funds for supporting restocking actions. The industrial process is well established, and the quality of the product will be improved on the basis of the above index. Nevertheless, also transport and storage at 4°C are critical steps, that need appropriated solutions. The quality of the final product will determine the economic sustainability of the typical product, and dramatically influence the destiny of this species.

Keywords: *European eel, food quality, pickled eel, storage, transport, typical product,*

1. Introduction

European eel (Anguilla anguilla, L.) is a catadromous fish species with its spawning grounds in the Sargasso Sea that in the last forty years has suffered a rapid decline in the Lagoon of Comacchio, similarly to other European lagoon systems (Moriarty and Dekker 1997; Feunteun 2002; Dekker 2004) and nowadays the stock is at a minimum level. This species is included in the Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) since March 2009 (CITES, 2007) and thus it has been classified as “endangered species”. The European Union imposes the definition and application of an Eel Management Plan, for monitoring and restocking.

The lagoon of Comacchio hosts an extensive farm of European eel (Tesch, 2003) and is included in a NATURA2000 site, in a regional protected area called Po Delta Park Emilia-Romagna and in the UNESCO World's Heritage site of “Ferrara, city of Renaissance and its Po Delta”. During the last centuries, the food industry based on this fish has developed the “pickled eel”, that has became a typical product and is widely famous in the world. The Traditional Pickled Eel of Lagoon of Comacchio (Fig. 1) is produced with “silver eel” (mature female specimen) cooked at fireplace and stored in can, with a brine of vinegar, water and salt; the canned fish have to be stored at 4°C and the whole process was standardized in 2004. The quality of the product, behind factory's process, is strongly influenced by two main factor: (1) quality of harvested fish and (2) storage at constant low temperature of cans. The quality of captured fish is evaluated by a panel of indexes, so that is possible to select fish to set free (as defined by the EMP – Reg. 1100/2007 - the 40% of total amount of fishery) and fish to use in food industry (specimens of good quality exceeding EMP target). In fact, the pickled eel, a value-added product (“value-added” is used to characterize food products that are converted from raw product through processes that give the resulting product an “incremental value” in the market place – Steven, 2008), is produced by the Po Delta Park authority and is part of a larger programme for conservation of European eel, that includes a self-financing of protected area by commerce of typical products. The product is recognized by the Italian law (national list of traditional agriculture products, decree June 16th 2008), SlowFood (Presidium of Traditional Pickled Eel of Lagoon of Comacchio) and Italian Nature Park Federation (*Atlas of typical products of Parks* in association con SlowFood); Figure 2 shows the logo applied by the Po Delta Park on local high quality food products.

Fig. 1: the label of the traditional pickled eel

Fig. 2: the logo applied by the Po Delta Park for high quality food products.

2. Critical control points in food supply chain for value-added pickled eel

2.1 Storage and transport for pickled eel

The quality of canned fish (other than those of the industrial process) depends on storage and transport, the two main steps of the food supply chain, that have to be done at controlled temperature, 4°C, without temperature shock. Because of during the transport several vehicles can be used, the main task is the control of thermal shock; nowadays no control is performed on industrial production of this type of product, probably due to the low value addressed to canned fish and to the scarce attention paid by some retailers. But the public awareness on food quality and safety is increasing and it is necessary to develop strategies and tools for assuring the food quality of high-value products, like the one produced in Comacchio (figure 3). Although the industrial packaging does not include any system to monitor these critical points, we argue that some solutions for an appropriated thermal monitoring are available and should be used. In order to provide effectively the storage and the transport of value-added pickled eel, we propose two solution: i) use of an appropriated secondary packaging and ii) use of a time-temperature indicators.

Fig. 3: cans of traditional pickled eel of the Lagoon of Comacchio.

2.2 Proposed solution for secondary packaging

Actually industries use low cost cardboard paper as secondary packaging (SP) that easily defends only by a little thermal shock. Instead, a stronger SP is necessary, such as ones using a combination of wood and plastics, with appearance similar to that of wooden barrel used in the last century for pickled eel of Comacchio. Anyway, the SP should includes from 4 to 12 cans, should be resistant to light and handling, as well as to water and to overload; it should be realized in recycled material (as much as possible, with an affordable cost). It may include historical images that, if well designed, can be showed on the showcases by retailers or at home by customers; so, the SP could be a further promotional tool for the product.

2.3 Proposed solution for thermal monitoring

Time-temperature integrator is a simple device attached to the food product that gives a visible response to the temperature resulting from an irreversible mechanical, chemical, electrochemical change; the TTI response, that reflect the effect of temperature on food deterioration, was studied on several fish species (Nuin *et al.*, 2008). TTIs are commercially available and should be used both for storage and transport of value-added pickled eel: in fact, TTIs provide alert when products have been exposed to temperatures beyond a defined threshold and are used primarily for SP to help monitor temperature-sensitive shipments including food, vaccines, drugs, chemicals, and signal when product quality should be checked due to exposure to high temperature. Adhesive and easy to place indicators are commercially available and the use of TTIs on secondary packaging represents a little cost that should be easily recharged on final cost. TTIs are available with several temperature threshold (e.g. at -15, 5 and 10°C) and time scale (e.g. at 48 hours, 1 week and 2 weeks). Because of the storage of pickled eel range from 2 weeks to 12 months, an appropriated TTI should clearly show the state of the product and quickly inform on food safety emergencies. For the transport can be acceptable a TTI with a temperature threshold at 10°C and a time scale at 48 hours or 1 week, depending on destination of the delivery.

2.4 Thresholds for HACCP system using proposed solutions

The Hazard Analysis and Critical Control Point (HACCP) is a method that identifies, evaluates and controls hazards that are significant for food safety (Codex Alimentarus, 2003) The solutions proposed above should be included in the HACCP system of organisations involved into the Food Supply Chain: producer, processor, distributor, wholesaler and retailer. The HACCP systems have to define adequate control parameters and, as the first should be the brine's pH (pH<4,5; FAO, 1985), the second should be the temperature of product/primary packaging. In order to provide an appropriated food safety, we argue to avoid temperature higher than 10°C. Experiments conducted in 2004 in association with Stazione Sperimentale delle Conserve Alimentari (SSICA, Ichthyological Laboratory, Parma - Italy), proved that Traditional Pickled Eel can be stored for more than 12 months and possible abuses, provided for short times, do not reduce this life-time.

3. Conclusion

Value-added fishery products show many of the most important topics of food safety and these are important study-cases, because the consumers' health is a priority of the European Union. Furthermore, high quality food products are important because (as stated by Steven, 2008) the producers are not only interchangeable (and exploitable) input suppliers, but they are "strategic partners" with rights and responsibilities related to value chain information, risk-taking, governance, and decision-making. Critical points in food supply chain for value-added pickled eel are the same for all value-added fishery products, and in this paper we propose two easy technical solutions, for temperature controlled storage and transport, that can be used for increasing the quality of canned fish.

In the future this kind of solution will be considered in association with quality control on raw material (harvested fish) and process' quality control, in order to complete a wide quality monitoring on all chain. The final result will be the HACCP system of the complete food process of pickled eel, from the water to the table.

The Traditional Pickled Eel of the Lagoon of Comacchio is used for supporting the restocking of this endangered species and the commercial success of this product could be crucial for the survival of the eel, not only in Comacchio. The survival of this species could be important at the European level and, because of this and similar actions, the EU could represents a strategic opinion leader for food issues in the world. In a global world, where the economic rules are money-driven, an effort to improve of local products should be done with more energy.

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Cold Supply Chain Eco-efficiency

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Abstract
The growing attention to environmental issues has led many organizations to increase their knowledge in sustainability and eco-efficiency concepts. From the supply chain point of view, increasing eco-efficiency means not only offering products and services that produce the highest customer satisfaction but at the same time, minimizing the impact on the environment quality. All actors of the chain should monitor their economic performance as well as their environmental ones, both contributing to the definition of the eco-efficiency results of the chain.
The term "cold chain", refers to a supply chain in which the products are treated, stocked and transported to controlled temperatures. It is therefore clear that the concepts of temperature control is closely related to energy consumption and consequently to the concept of eco-efficiency.
The main goal of this study is to develop a model for the optimization of eco-efficiency results related to a typical FSC (Food Supply Chain) as a particular case of cold chain. Inventory holding costs, transport costs and energy consumption costs are included in the model for the evaluation of the economic performance of the chain, while other environmental parameters are jointly considered for the evaluation of the environmental performance.
A numerical study that considers different frozen food products supply chain configurations and their relative eco-efficiency results is presented.

Keywords: *eco-efficiency, cold chain, frozen food*

1. Introduction

The growing attention to environmental issues has led many organizations to increase their knowledge in sustainability and eco-efficiency concepts. From the supply chain point of view, developing eco-efficiency means not only offering products and services that produce the highest customer satisfaction but at the same time, minimizing the impact on the environment.
Moreover, especially in frozen food supply chain, energy plays a strategic role, as it is fundamental to guarantee quality of food, thus influencing both economic and environmental performance of the whole chain.

The main goal of this study is to develop a model for the eco-efficiency assessment related to a typical FSC (Food Supply Chain) as a particular case of cold chain. Inventory holding costs, transport costs and energy consumption costs are included in the model for accounting the economic performance of the chain, while CO_2 emissions are considered for accounting the environmental performance.
The paper is organized as follows. Section 2 will introduce the problem, and a brief review of the main literature regarding eco-efficiency, eco-efficiency of supply chains and frozen food supply chain. In section 3 the process of harvesting, deep-freezing and distribution frozen food is described, while in Section 4 the developed model is presented in detail. A numerical study that considers different frozen green peas supply chain configurations and their relative eco-efficiency results is presented in Section 5, and finally some considerations as well as future developments are given in Section 6.

2. Frozen food supply chains eco-efficiency: main concepts and literature review

2.1 Eco-efficiency in supply chains

Two main aspects should be considered while considering the eco-efficiency of supply chains: the economic performance of the chain, and the environmental one. As defined by the WBCSD (World Business Council for Sustainable Development), the eco-efficiency is "*the delivery of competitively priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impact and resource intensity throughout the life cycle, to a level at least in line with the earth's estimated carrying capacity*" (DeSimone & Popoff, 1997). The purpose of eco-efficiency is to maximize value creation, while having minimized the use of resources and emissions of pollutants (Michelsen et al., 2006). Underlining the strong connection between the economic and the environmental components of eco-efficiency, it is in most cases expressed by the ratio (product or service value) / environmental influence.
Many different authors proposed different methodologies to combine economic and environmental performance, in a way to evaluate the overall eco-efficiency result of the analysed system. Michelsen & Fet (2010) proposed a three-step methodology for the improvement of supply chain environmental performance based on eco-efficiency results: LCA (Life Cycle Assessment) and LCC (Life Cycle Costing) results are combined in order to determine the eco-efficiency of a furniture production supply chain in Norway. Saling et al., (2002) proposed a similar methodology, on the base of which they also developed a tool known as the BASF eco-efficiency analysis tool.
The evidence of a trade-off between economic and environmental results, led to the conceptualization of *eco-efficient frontier*, based on the well known Pareto frontier. The idea of eco-efficient frontier was firstly proposed by Huppes & Ishikawa (2005). Moreover, Quariguasi et al. (2007) presented a methodology to assess this frontier and trade-offs between costs and a single environmental impact factor. Finally, Venkat (2007) presented a methodology for formulating and analyzing costs and emissions across supply chains, based on modelling and simulation techniques.

2.2 Calculating Eco-efficiency for the supply chain

When using eco-efficiency indicators to compare products, processes or supply chain configurations, it is preferable to avoid the usage a single value indicator, e.g. the ratio between economic and environmental performance values (Michelsen et al., 2006). In accordance with the method developed and used by BASF (Saling et al., 2002), it is better to graphically present both economic and environmental performance relative indicators values in order to highlight the existence of a trade-off between them. The use of relative indicators values is necessary to make economic and environmental performance values comparable.

The relative indicator value for a particular scenario S_k (product, supply chain configuration alternative) is computed by the formula, both for economic and environmental indicators:

$$(\text{relative value})_k = \frac{(\text{absolute value})_k}{\sum_{k=1}^{K}(\text{absolute value})_k}$$

The results are presented in a 0-1 normalized XY-diagrams that highlights the existence of a trade-off between economic and environmental performance of the considered alternatives. Michelsen et al. (2006) suggested that using a graphical presentation makes it unnecessary to merge the value of economic and environmental performance values to one single indicator, which has been widely criticized (e.g. Azapagic & Perdan, 2000).

2.3 Frozen food supply chains

Considering a frozen food supply chain as a particular case of cold chain, the main aspects that has to be introduced is the concept of temperature-dependent perishability of products: even when optimal temperature of products are maintained along the whole cold chain, the quality of products decreases over time. Quality degradation of stored food products depends mainly on the storage time and on storage temperature T (for more details see Labuza, 1982). Temperature plays a primary role in product quality degradation: the link between rate of quality degradation k and temperature T can be expressed recalling the Arrhenius equation, which general form is:

$$k = k_0 \cdot e^{-\frac{E_A}{R}} \quad (1)$$

where k_0 is a constant, E_A the activation energy (an empirical parameter characterizing the exponential temperature dependence), R the gas constant, and T the absolute temperature.

Moreover it should be noted that the temperature along the cold chain could not be always uniform (James et al., 2006). Therefore, the total quality decrease may be related to the original quality and it can be determined by summing the quality decrease at every step of the chain (on the base of the temperature level at each supply chain stages).

So as to predict the quality levels, equation (1) suggests that it is possible to estimate the quality level of a product, based on a given initial quality (Q_0), while varying the storage time interval t and the degradation rate k, thus leading to the following formula:

$$Q(T,t) = Q_0 \cdot e^{-k_0 t \cdot e^{-\frac{E_A}{R}}} \quad (2)$$

Moreover, Peleg et al., 2002 proposed to use a Weibull-power law model to describe the isothermal degradation of food quality, depending on storage temperature and time, according to the following equation:

$$Q(T,t) = Q_0 \cdot e^{-b(T) \cdot t^{a(T)}} \quad (3)$$

where b(T) and a(T) are temperature-dependent coefficients.
Some examples of the applications of the equations above are shown hereafter for different food products (Hui et al., 2004).
When considering not only storage, but also delivery time from treatment plants to distribution centres, or from distribution centres to retailers, quality degradation of food products must be taken into consideration for both time interval (storage time and delivery time).

3. The process

The system considered consists of a producer that procures fresh food from a group of farmers (F) and treats the products inside the producer-owned Treatment Plant (TP) carrying out a deep-freezing process on them. The frozen food is then stored for a certain time period in the TP, and then transported to a certain number (n) of Distribution Centres (DC). After the storage period by the considered DC, the frozen food is transported to the m retailers (R), where it is kept on stock until it is sold to the final customer.

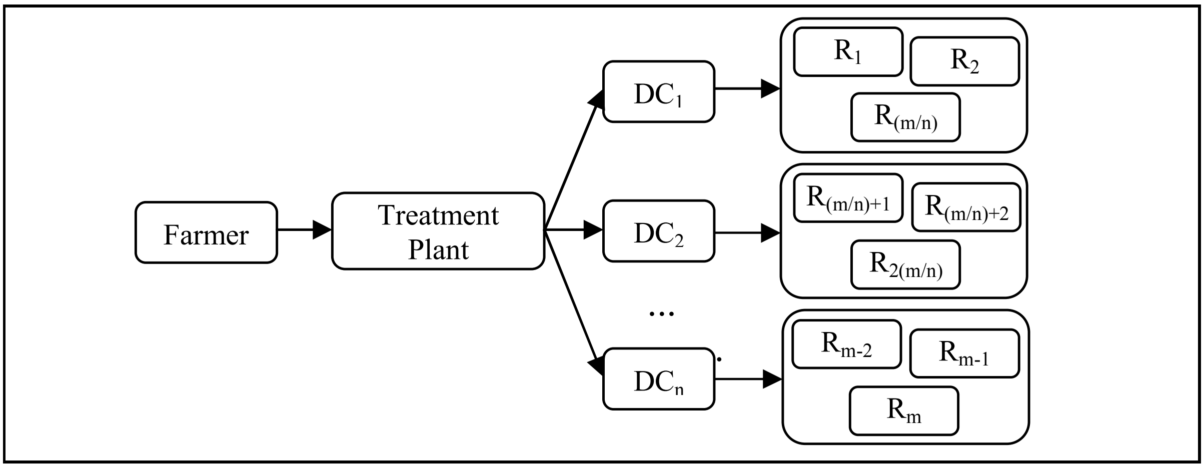

Fig. 1. Schematic representation of the considered frozen food supply chain.

The aim of the study is to evaluate the trade-off between economic and environmental impacts of the frozen food supply chain, considering different configuration of the distribution network.
In order to determine the main economic (cost) and environmental impact contributions, we will briefly describe the process of harvesting, processing (deep-freezing), and distributing frozen vegetables. For each supply chain stage, we will then associate cost and environmental impact contributions.

3.1Harvesting and delivery to the TP

During the harvesting period the F collects a certain amount of products every day, named $q_{F\text{-}TP}$ (delivery lot size from F to TP) , which are immediately sent to the TP in order to limit as much as possible the quality depletion of products; for the same reason the time required to deliver the daily harvested quantity of fresh vegetable is limited in a few hours, so that at the end of each harvesting period day the amount of fresh vegetables harvested by the F reaches the TP.

The costs faced by the F to sow, grow, and harvest vegetables are not considered in the proposed model, while costs of quality depletion of food during the daily harvesting activity, as well as costs of quality depletion during the transport from the F to the TP, and the delivery transport costs are the main economic contributions considered. As the delivery of harvested products is carried out by trucks characterized by a fixed carrying capacity which is smaller than $q_{F\text{-}TP}$, a certain number of trucks are required every day (during the harvesting period) for this activity: this should be taken into consideration for the computation of costs as well as of environmental impacts related to the delivery from F to TP.

3.2 Deep-freezing and storing of frozen products by the TP

Once received the daily harvested quantity of fresh food, the TP process them as soon as possible, in order to limit the quality depletion of products.

The main costs faced by the TP are related to the energy required for the deep-freezing process, and the setup costs involved in the same process, as the process is batch based and the batch size (named $q_{treatment}$) is limited: so, in order to perform deep-freezing activities on the daily received quantity of fresh products ($q_{F\text{-}TP}$), it is necessary to consider different batches, and so setup costs to start the each of them occur several times during the processing activity of the daily received quantity: the number of setups can be easily computed as the ratio $q_{F\text{-}TP}/q_{treatment}$.

Near to processing (energy and setup) costs, also inventory holding costs of quality depletion of processed frozen products are included in the cost function, while environmental impacts accounting is based only on the energy required by the deep-freezing process activities, as all other environmental contribution can be considered negligible.

3.3 Delivery from the TP to DCs and storing at DCs

After a limited period storage at the TP, the frozen food is daily sent to the *i*-th DCs: this quantity is named $q_{TP\text{-}DCi}$. Each delivery from the TP to a particular DC is carried out by trucks, with a fixed capacity. Transport costs and quality depletion of frozen products during the delivery from TP to each DC are included in the cost function, as well as environmental impacts generated by trucks are counted towards the environmental performance of transport activity.

The number of DCs is the most relevant decision variable when determining different distribution network configurations. Moreover, when increasing the number of DCs, the delivery lot size $q_{TP\text{-}DCi}$ decreases, but it does not necessarily the number of delivery trucks, as at least one truck every day must reach the *i*-th DC, even if not full-loaded: this fact may increase the transport costs and environmental impacts for the delivery from TP to all DCs.

The proposed model considers that each DC works as a decoupling point of frozen products between TP and its region-based market (represented by the retailers (Rs) included in the region). During the harvesting-processing period each DC receives daily a quantity $q_{TP\text{-}DCi}$ from the TP, but it delivers to the Rs included in the region during the whole year. So inventory holding costs and quality depletion of stored frozen products are included into the costs function, while the contribution of energy required to store frozen products is counted towards the environmental performance.

3.4 Delivery from *i*-th DC to all Rs included in the *i*-th market region

As the *i*-th DC works as a decoupling point of frozen products between TP and all Rs included in the *i*-th market region, deliveries of frozen products may occur between the *i*-th DC and the *j*-th R only to satisfy the demand of the *j*-th R (continuous profile during the whole year), determining a repeated cycle of deliveries from the DC to all Rs included in its reference market region, as well as a cyclic pattern inventory level of each R.

Differently from the deliveries performed from TP to DCs (single DC served by each delivery), shipments from the *i*-th DC are performed through full-loaded trucks to a certain number of Rs, named *m**. The magnitude of *m** is computed on the base of the limit of one day availability to visit *m** Rs in a single routing (considering the distances between Rs included into the single routing, and loading-unloading activities of *m** delivery lots $q_{DCi\text{-}Rj}$). Given *m**, the number of routing necessary to perform deliveries to all Rs included into the *i*-th market region corresponds to the number of full-loaded trucks that leaves the *i*-th DC on the shipment day; moreover shipment days from the *i*-th DC occur several times during the year (and their number depends on the lot size $q_{DCi\text{-}Rj}$): transport costs and environmental impacts of this forth chain stage mainly depends on these aspects. At the *j*-th R, inventory holding costs and quality depletion of frozen products costs considered, while energy required to keep on stock frozen products is counted towards the environmental performance.

4. The model

To determine the economic performance of a specific network configuration we developed an economic model, where the main costs related to processing, transporting, storing frozen vegetables and opening new DCs are considered, while the environmental performance are evaluated using GEMIS 4.5 software and Database.

4.1Harvesting and delivery to the TP

The main cost related to harvesting and delivery fresh food from the F to the TP are cost of quality depletion of products (during the harvesting activity, and during the delivery time from F to TP) and the transport costs.

$$COST_{dep.Q.(F)} = V_{MP} \cdot \left(\frac{D}{q_{F-TP}}\right) \cdot \left[q_{F-TP} - \left(\frac{pr}{k_{F-TP}}\right) \cdot \left(1 - e^{-\frac{(k_{F-TP})\cdot(q_{F-TP})}{pr}}\right)\right] \quad (4)$$

where:

V_{MP} is the initial value of food (€/ton)

D is the global demand rate (ton/day)

$q_{F\text{-}TP}$ is lot size delivered from F to TP every harvesting-period day (ton)

pr is the harvesting rate (ton/day)

$k_{F\text{-}TP}$ is the quality depletion rate at the delivery temperature $T_{F\text{-}TP}$ (day^{-1})

$$COST_{Transp.(F\text{-}TP)} = \left[\frac{\left(K^{tr}_{F-TP} + c^{tr}_{F-TP} \cdot dist_{F-TP} \right)}{truck\_cap._{F-TP}} \right] \cdot D \tag{5}$$

with

$K^{tr}_{F\text{-}TP}$ is the distance-independent cost of transport (€)
$c^{tr}_{F\text{-}TP}$ is the distance-dependent cost of transport (€/km)
$dist_{F\text{-}TP}$ is the distance between F and TP (km)
$truck\_cap._{F\text{-}TP}$ is the loading capacity of trucks used for (F-TP) deliveries (ton)

$$COST_{Dep.Q.(F\text{-}TP)} = V_{F,out} \cdot \left(\frac{D}{q_{F-TP}} \right) \cdot \left(1 - e^{-\frac{(k_{F-TP}) \cdot (dist_{F-TP})}{vel_{F-TP}}} \right) \tag{6}$$

$V_{F,out}$ is the value of harvested products (€/ton)

$$V_{F,out} = V_{MP} + \frac{\left(COST_{DEp.Q.(F-TP)} \right)}{D} \tag{7}$$

$vel_{F\text{-}TP}$ (km/h) is the speed limit for the road between F and TP: this value it is necessary to compute the delivery time from F to TP $t_{F\text{-}TP}$ (km):

$$t_{F-TP} = \frac{dist_{F-TP}}{vel_{F-TP}} \tag{8}$$

The main environmental contribution related to harvesting and delivery fresh food from the F to the TP is CO_2 emission of the transportation that can be calculated using GEMIS 4.5.

4.2 Deep-freezing and storing of frozen products by the TP

The main cost related to deep-freezing and storing frozen food by the TP are energy cost of processing (deep-freezing) food, setup costs of processing resources, frozen inventory holding costs and costs of quality depletion of products.

$$COST_{Energy(TP)} = \left(SEC \cdot ec \cdot 1000 \cdot D \right) \cdot \rho_{treatment} \tag{9}$$

SEC represents the Specific Energy Consumption of the deep-freezing process (kWh/kg), while ec is energy cost (€/kWh). $\rho_{treatment}$ is computed as the ratio $COP_{T,ref.}/COP_{T,treatment}$. $COP_{T,ref.}$ is the COP computed for the reference temperature ($T_{,ref.}$) while $COP_{T,treatment}$ is the COP computed for the treatment (deep-freezing) temperature. The value $\rho_{treatment}$ gives information on required energy to carry out the deep-freezing process (decreasing the temperature until it corresponds to $T_{,treatment}$). Similarly to $\rho_{treatment}$ other values have been computed for the model.

$$COST_{Setup(TP)} = \frac{\left(K^{setup} \cdot D \cdot \rho_{treatment} \right)}{q_{treatment}} \tag{10}$$

where K^{setup} is the setup cost (€) related to start the deep-freezing process on a treatment lot sized $q_{treatment}$ (ton).

$$COST_{Holding(TP)} = \left(K^{st}_{TP} + h^{st}_{TP} \cdot \rho^{st}_{TP} + V_{TP,in} \cdot \tau_{TP}\right) \cdot \frac{q_{F-TP}}{2} \quad (11)$$

K^{st}_{TP} is temperature-independent inventory holding cost (€/(ton·day))
h^{st}_{TP} is temperature-dependent inventory holding cost (€/(ton·day))
ρ^{st}_{TP} is the ratio $COP_{T,ref.}/COP_{T,stock(TP)}$
$V_{TP,in}$ is the value of products entering the TP (€/ton):

$$V_{TP,in} = V_{F,out} + \frac{\left(COST_{Transp.(F-TP)} + COST_{Dep.Q.(F-TP)}\right)}{D} \quad (12)$$

τ_{TP} is the interest rate at the TP (%)

$$COST_{Dep.Q.(TP)} = V_{TP,in} \cdot \left[q_{F-TP} - \left(\frac{D}{k_{TP}}\right) \cdot \left(1 - e^{-\frac{(k_{TP}) \cdot (q_{F-TP})}{D}}\right)\right] \cdot \left(\frac{D}{q_{F-TP}}\right) \quad (13)$$

k_{TP} is the quality depletion rate of deep-freezing process (processing temperature T_{TP})

The main environmental contributions related to the deep-freezing process and for the storage by the TP are computed on the base of energy requirements of performing such processes (decreasing product temperature, and maintaining stock temperature, respectively), evaluated by GEMIS 4.5 in kg of CO_2 equiv./kg of processed (stored) products.

4.3 Delivery from the TP to DCs and storing at DCs

The main costs related to delivering frozen food from TP to the *i*-th DC (named DC_i) and storing them by the same DC_i are the following.

$$COST_{Transp.(TP\text{-}DCi)} = \left(K^{tr}_{TP\text{-}DCi} + c^{tr}_{TP\text{-}DCi} \cdot dist_{TP\text{-}DCi}\right) \cdot \left[int.sup.\left(\frac{q_{TP-DCi}}{truck\_cap._{TP-DCi}}\right)\right] \cdot \left(\frac{D}{q_{F-TP}}\right) \quad (14)$$

with
$K^{tr}_{TP\text{-}DCi}$ is the distance-independent cost of transport (€)
$c^{tr}_{TP\text{-}DCi}$ is the distance-dependent cost of transport (€/km)
$truck\_cap._{TP\text{-}DCi}$ is the loading capacity of trucks used for (TP-DC_i) deliveries (ton)
$dist_{TP\text{-}DCi}$ is the mean distance between TP and DC_i (km)

$$dist_{TP\text{-}DCi} = \sqrt{\frac{Area_{TOT}}{n}} \quad (15)$$

where $Area_{TOT}$ is the total area of the whole considered market region (km^2) and n is the total number of DCs.

$$COST_{Dep.Q.(TP\text{-}DCi)} = V_{TP,out} \cdot \left(1 - e^{-\frac{(k_{TP\text{-}DCi}) \cdot (dist_{TP\text{-}DCi})}{vel_{TP\text{-}DCi}}}\right) \cdot \left(\frac{D_{DCi}}{q_{TP-DCi}}\right) \quad (16)$$

D_{DCi} is the demand rate associated to each DC_i (ton/day)

$$D_{DCi} = \frac{D}{n} \tag{17}$$

while $V_{TP,out}$ (€/ton) is the value of frozen products leaving TP computed as follows:

$$V_{TP,out} = V_{TP,in} + \frac{\left(COST_{Energy(TP)} + COST_{Setup(TP)} + COST_{Holding(TP)} + COST_{Dep.Q.(TP)}\right)}{D} \tag{18}$$

$k_{TP\text{-}DCi}$ (day^{-1}) is the quality depletion rate for the delivery from TP to DC_i
$vel_{TP\text{-}DCi}$ (km/day) is the speed limit for the road between TP and DC_i
$q_{TP\text{-}DCi}$ (ton) is the batch size of lots delivered from TP to DC_i

$$q_{TP\text{-}DCi} = \frac{q_{F-TP}}{n} \tag{19}$$

$$COST_{Holding(DCi)} = \left(K^{st}_{DCi} + h^{st}_{DCi} \cdot \rho^{st}_{DCi} + V_{DCi,in} \cdot \tau_{DCi}\right) \cdot \frac{inv_{DCi}}{2} \tag{20}$$

K^{st}_{DCi} is temperature-independent inventory holding cost for DC_i (€/(ton·day))
h^{st}_{DCi} is temperature-dependent inventory holding cost for DC_i (€/(ton·day))
ρ^{st}_{DCi} is the ratio $COP_{T,ref.}/COP_{T,stock(DCi)}$
τ_{DCi} is the interest rate at the DC_i (%)
$V_{DCi,in}$ (€/ton) is the value of products entering DCi
inv_{Dci} is the maximum inventory level reached by DC_i (ton)

$$V_{DCi,in} = V_{TP,out} + \frac{\left(COST_{Transp.(TP-DCi)} + COST_{Dep.Q.(TP-DCi)}\right)}{D_{DCi}} \tag{21}$$

$$inv_{DCi} = \frac{\left(q_{TP-DCi} - D_{DCi}\right) \cdot D \cdot 365}{pr} \tag{22}$$

$$COST_{Dep.Q.(DCi)} = V_{DCi,in} \cdot \left[D_{DCi} - D_{DCi} \cdot \left(1 - e^{-\frac{k_{DCi} \cdot (inv_{DCi}/2)}{D_{DCi}}}\right)\right] \cdot \left(\frac{D_{DCi}}{q_{TP-DCi}}\right) \tag{23}$$

with k_{DCi} (day^{-1}) is the quality depletion rate for stored products at DC_i

The main environmental contributions related to the transportation of products from TP to each DC_i and to the storage activities at each DC_i are calcutated on the base of trucks environmental impacts and on energy requirements for maintaining stock temperature at DC_i, respectively.

4.4 Delivery from *i*-th DC to all Rs included in the *i*-th market region

The main costs related to delivering frozen food from the *i*-th DC (named DC_i) to the *j*-th R (named R_j) included into the *i*-th market region, and storing them by the same R_j are the following.

$$COST_{Transp.(DCi\text{-}Rj)} = \left(K^{tr}_{DCi\text{-}Rj} + c^{tr}_{DCi\text{-}Rj} \cdot GZ_{DCi}\right) \cdot \left(\frac{1}{m^* \cdot t_{Rj}}\right) \tag{24}$$

with
$K^{tr}_{DCi\text{-}Rj}$ is the distance-independent cost of transport (€)
$c^{tr}_{DCi\text{-}Rj}$ is the distance-dependent cost of transport (€/km)
t_{Rj} (day) is the time required for consuming a lot $q_{DCi\text{-}Rj}$ (ton) from the inventory R_j, that is subjected to a demand rate D_{Rj} (= D/m) (ton/day).

GZ_{DCi} (km), which is the path length related to the visit of m^* retailers included into the *i*-th market region, considering a speed limit $vel_{DCi\text{-}Rj}$ (km/day), and unloading activities of m^* delivery lots of size $q_{DCi\text{-}Rj}$ (ton), is an approximation, based on Daganzo, 2005, computed as follows:

$$GZ_{DCi} = \frac{0.9 \cdot \left(m^* + 1\right)}{\sqrt{\frac{\left(m^* + 1\right)}{Area_{DCi}}}} \tag{25}$$

with

$$Area_{DCi} = \frac{Area_{TOT}}{n} \tag{26}$$

Moreover, as the number of retailer visited in one routing m^* is not *a-priori* known, GZ_{DCi} has been also defined as

$$GZ_{DCi} = vel_{DCi-Rj} \cdot \left(travelling\_time_{DCi-Rj} - unloading\_time_{Rj} \cdot m^*\right) \tag{27}$$

Thanks to Eq.(27) and Eq.(28) it is possible to determine m^*.
The batch size $q_{DCi\text{-}Rj}$ (ton) is computed by the following equation:

$$q_{DCi\text{-}Rj} = \frac{truck\_cap._{DCi-Rj}}{m^*} \tag{28}$$

As usual we also compute depletion of quality for during the delivery from DC_i and R_j:

$$COST_{Dep.Q.(DCi\text{-}Rj)} = V_{DCi,out} \cdot \left(1 - e^{-\frac{k_{DCi\text{-}Rj}}{m^*}}\right) \cdot \left(\frac{D_{Rj}}{q_{DCi\text{-}Rj}}\right) \tag{29}$$

with $k_{DCi\text{-}Rj}$ (day^{-1}) is the quality depletion rate for delivering products from DC_i to R_j
$V_{DC,out}$ (€/ton)is the value of products leaving DC_i

$$V_{DCi,out} = V_{DC,in} + \frac{\left(COST_{Holding(DCi)} + COST_{Dep.Q.(DCi)}\right)}{D_{DCi}} \tag{30}$$

Considering also the storage at the R_j:

$$COST_{Holding(Rj)} = \left(K^{st}_{Rj} + h^{st}_{Rj} \cdot \rho^{st}_{Rj} + V_{Rj,in} \cdot \tau_{Rj}\right) \cdot \frac{q_{DCi\text{-}Rj}}{2} \tag{31}$$

K^{st}_{Rj} is temperature-independent inventory holding cost for R_j (€/(ton·day))
h^{st}_{Rj} is temperature-dependent inventory holding cost for R_j (€/(ton·day))
ρ^{st}_{Rj} is the ratio $COP_{T,ref.}/COP_{T,stock(Rj)}$
τ_{Rj} is the interest rate at the R_j (%)
$V_{Rj,in}$ is the value of products entering R_j (€/ton)

$$V_{Rj,in} = V_{DC,out} + \frac{\left(COST_{Transp.(DCi\text{-}Rj)} + COST_{Dep.Q.(DCi\text{-}Rj)}\right)}{D_{Rj}} \tag{32}$$

and

$$COST_{Dep.Q.(Rj)} = V_{Rj,in} \cdot \left[q_{DCi-Rj} - \left(\frac{D_{Rj}}{k_{Rj}}\right) \cdot \left(1 - e^{-\frac{(k_{Rj})\cdot(q_{DCi-Rj})}{D_{Rj}}}\right)\right] \cdot \left(\frac{D_{Rj}}{q_{DCi\text{-}Rj}}\right) \tag{33}$$

with k_{Rj} (day^{-1}) is the quality depletion rate for stored products at R_j

Moreover, the main environmental contributions related to delivering products from DC_i to each R_j included into the *i*-th market region, and to the storage activities at each R_j are computed on the base of trucks environmental impacts and on energy requirements for maintaining stock temperature at R_j, respectively.

5. Numerical example

In order to show the usefulness of the proposed model, the present section offers a numerical example referred to frozen vegetables (green peas) distribution. The process consists in procuring and harvesting fresh green peas by a group of farmers (F), deep-freezing them at the treatment plant (TP) and distributing them to a given number of retailers (R), involving in the distribution network a certain number of distribution centres (DC). We developed a model for the eco-efficiency results evaluation of the considered network configuration involving: an economic model, where the main costs related to processing, transporting, storing frozen green peas are considered; then the environmental performance in terms of CO_2 emissions of the chain are calculated using GEMIS 4.5 software and Database.
Six different scenarios, involving 10, 20, 30, 40, 50, and 60 DCs, respectively, have been analysed. Considering the first scenario (e.g. n = 10 DCs), Figure 2 shows the relative contribution of each process involved in the supply chain, both for economic (costs) and environmental (CO_2 equivalent emissions) performance values. In the right part of the figure are reported single percentage contributions values, while in the left part of the same figure are reported cumulative percentage values.
Figure 3 illustrates the results for the six different scenarios: where economic (total costs of the distribution chain) and environmental impact (kg of CO_2 equivalent emissions) are jointly presented in a 0-1 normalized XY-diagram.

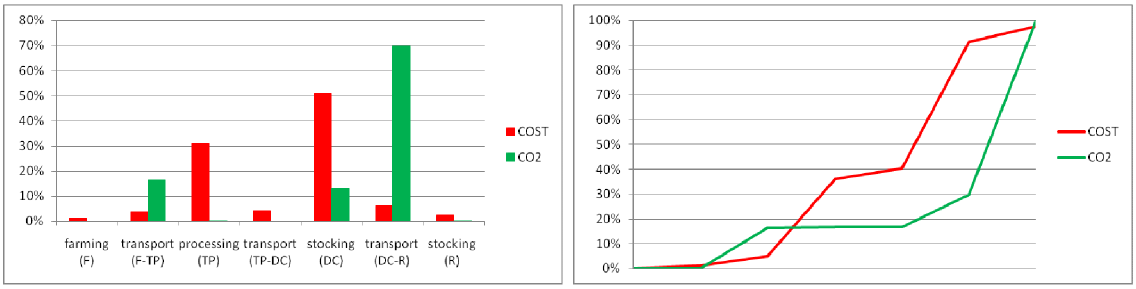

Fig. 2. Relative contribution of processes to costs and CO_2 equivalent emissions.

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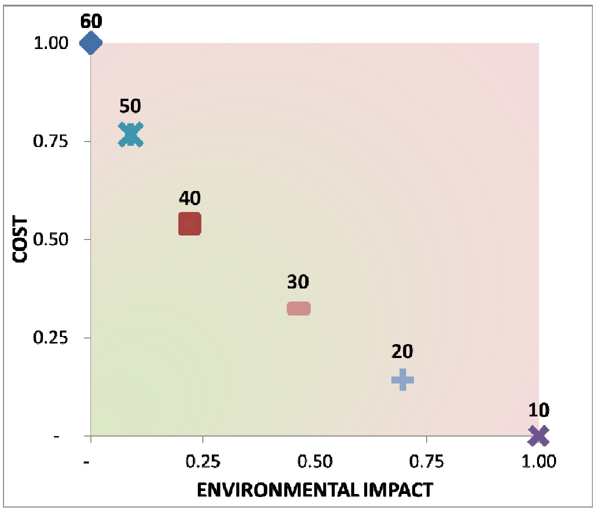

Fig. 3. Relative eco-efficiency of the six scenarios.

Results of Figure 3 indicates that Scenario 1 (n = 10 DCs) is the best in terms of economic performance (lowest cost value), but it is the worst in terms of environmental performance, while Scenario 6 (n = 60 DCs) is the worst in terms of costs and the best in terms of CO_2 equivalent emissions. So, it can be observed that increasing the number of DCs has a negative impact on costs, but it determines favourable conditions for reducing environmental impacts of the supply chain. Thus a trade-off between the economic and the environmental impacts clearly exists while choosing the configuration of the distribution supply chain of green peas and this should be carefully considered by the different stakeholders involved in the decision.

6. Conclusions

The paper addressed the problem of the eco-efficiency evaluation of different alternative of Cold Supply Chain configurations considering the temperature and storage time and their related impact on the product quality, costs and environmental impact at different stages of the chain. The introduction of eco-efficiency as a factor of the chain optimisation implies an increased attention for the sustainability of the chain considered. From this point of view and under the assumptions made, the model proposed allows the understanding of the relationships between costs and environmental impact while using a different arrangement of the distribution network (i.e. the number of DC considered) addressing a possible approach to the chain optimisation.

The results from the numerical study offer useful information, in particular for the evaluation of the trade-off between economic and environmental performance of supply chains in the case of the production and distribution of green peas.
Future developments of the proposed model may include the study of the influence of temperature in different processes considered (treatment and stocking) and its impact on the eco-efficiency trade-off.

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Farmers' Markets: Addressing the Carbon Footprint Dilemma

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Abstract

American consumers' growing taste for locally produced food has resulted in the proliferation of farmers' markets in the U.S. While benefits abound, the very success of these markets has created an inefficient network; farmers drive long distances with small cargos multiple times each week. Not only does this increase costs, but on a per unit basis, the energy usage and resultant greenhouse gas emissions associated with supplying farmers' markets can be greater than those associated with the equivalent supermarket distribution.

We investigate the outbound journey of food from a farm to a farmers' market and compare it to corresponding conventional journeys, finding farmers' market distribution indeed shows greater emissions. We then model Northern California's farmers' market network, solving a transportation problem to minimize the aggregate distance products are transported.

We next insert a consolidation center. Farmers can transport goods either directly to the market or to this center for aggregation with other farmers' offerings. We resolve the model and find we can achieve significant savings. While theoretical and admittedly rife with implementation barriers, such a solution could enable small farmers to profit from economies of scale while still retaining their independence and would preserve the diversity of the markets. We view this study as a first step towards creating a system that would allow consumers and producers alike to enjoy the benefits of farmers' markets while reducing costs and emissions.

Keywords: *farmers' markets, greenhouse gas emissions, outbound logistics, network optimization, supply chains, distribution.*

1. Introduction

In recent years mainstream American consumers have become more concerned about the pedigree of their food and have started to show interest in locally produced food. Such foods, especially produce, are perceived to be healthier, taste better, and to be more socially and environmentally friendly than foodstuffs from distant or foreign large scale producers. Likewise, farmers can often obtain significant price premiums. These benefits and more have been thoroughly documented by others, including Brown (2002), Kremen et al. (2004) and Hunt (2007). While the definition of "local" varies, and the consumer perception of its boundaries is the subject of academic research (Giovannuci et al., 2010), it is clear that this food category is experiencing rapid sales growth. An industry study (Porjes, 2007) estimates the ''local'' food category, worth 4 billion dollars United States in 2002, is expected grow to 7 billion dollars by 2011. Once the purview of only health food stores, local foods are appearing everywhere; Wal-Mart has announced a local sourcing initiative for their produce, and even institutional food providers such as hospitals and prisons are working to create menus with such products (Hardesty, 2008).

1.1 Farmers' Markets

Just over nine tenths of U.S. farms can be classified as "small family farms," defined as having annual sales below $250,000, and such farms produce approximately one quarter of the national agricultural output (USDA 2005). These small businesses face daunting economies of scale issues within the food supply chain, especially those that compete directly with the 10% of the farms which produce the other three-fourths of total U.S. agricultural output! While some large retailers do buy from smaller farms, Cantor & Strochlic (2009) document that entry barriers are substantial, and small to midsized farms often have had more success with selling directly to the consumer. Farmers have several potential direct-to-consumer sales channels: providing roadside stands or pick-your-own fields, sourcing to Community Supported Agriculture (CSA) subscribers and attending farmers' markets. Cantor & Strochlic (2009) find that farmers' markets are the most common of these direct channels, with 69% of respondents attending such markets. Zepeda & Reid (2004) find farmers' markets to be the channel of choice for most consumers, as other direct channels require greater consumer involvement.

We consider California, the state that leads the United States in both the number of farmers' markets and the concentration of small farms (Cantor & Strochlic, 2009). These markets were established in California in 1977, when state law permitted farmers to sell at a state certified farmers' markets, without requiring either packaging or labeling (Certified Farmers Market Program, 2011). A farmers' market authority verifies that the farmer is indeed from California and is the primary producer; California follows a 'producer only model' and disallows resellers. According to the USDA (2011), the nation hosts 6132 farmers' markets as of 2010, a tripling from 1994. The importance of this channel is showcased by their 2005 survey, which found both that sales at farmers markets totaled over $1 billion that year and that more than a quarter of vendors at the surveyed markets derived their sole source of farm income from these markets (USDA 2011). In California alone, approximately 2,200 certified producers attend 700 certified farmers' markets, half of which occur regularly throughout the year (Certified Farmers Market Program, 2011).

1.2 An Underlying Problem

The proliferation in these markets might seem to be a blessing for farmers, who would appear to have more opportunity to reach consumers. However, the reality is more complex. Along with the number of markets, the competition from other vendors in markets has also increased. In fact, in today's markets the farmers are not always from a nearby local location. Farmers from any part of California can attend any market in California, which can lead to some large distances travelled. Worthen (2010) reports that the increase in such markets has resulted in lower profits for many farmers, who have to make more trips to sell the same amount of product as in prior years. In particular, Worthen (2010) interviews a few farmers who often do not make enough money to cover the costs of attending these multiple markets.

Fig. 1: Subset of California Farmers' Markets and Participating Farms, Source: Jog (2010)

One of the dominant culprits is clearly geography. California is a large state with the majority of farms and farmers' markets well separated from each other. This distribution is illustrated in Figure 1, which depicts a representative subset of farmers' markets and certified participating farms that service them. The populous and relatively affluent Bay Area and Los Angeles metropolitan areas provide the densest concentration of farmers' markets, while the majority of farms are found in or near the Central Valley, a fertile but sparsely populated and less affluent area.

Cantor & Strochlic (2009) survey producers with respect to their difficulties, finding a major complaint concerns the distances to the profitable farmers' markets; these large distances preclude greater participation and limit profits for those who do attend. In their argument in support of shopping at farmers' markets, CUESA (2009) profiles different types of produce vendors at the San Francisco Ferry Plaza Farmers' Market, showing they average a one-way travel distance between 100km to 300km. Yet distances such as these are still considerable.

The Pacific Coast Farmers' Market directory (PCFMA, 2011) allows us to investigate a farm's reach; for example, Schletewitz Farms, a third generation fruit and tomato producer located in Sanger, frequents several farmers' markets, including 5 that occur weekly throughout the year in Belmont, Cupertino, Pleasanton, San Francisco, and San Mateo. Assuming separate trips are necessary for each market visit, the total round trip weekly distances sum to approximately 3000 km. Furthermore, they visit several other markets when more of their fruits are in season, such as the Palo Alto's Farmers' Market (PA Market, 2011). We can also investigate from a market level view. Jog (2010) inventories the vendors at Jack London Square farmers' market, a year-round Sunday market in Oakland, and reports that some hail as far as San Diego, over 750 km away.

Such distances are not always insurmountable, but it should be realized that most small farmers do not enjoy the economies of scale available to larger producers. Typically these farmers drive smaller vehicles, often pick-up trucks, and each trip to a market represents a separate journey. These distances not only serve as market barriers and increase overall costs, but they also create another problem. When considered on a per unit basis, even a moderate distance transport in low capacity vehicles results in a comparatively high rate of energy utilization and corresponding greenhouse gas emissions. Such transportation inefficiencies greatly contribute to what is known in the vernacular as the *carbon footprint*. While admittedly many benefits derive from the purchase and consumption of farmers' market produce over that which has been imported from distant large-scale farms, we shall see that lower carbon impacts are not one of them.

The remainder of this paper is organized as follows. We quantify this problem further, providing context and summarizing the contributions of other researchers. With the help of analytical software, we model the outbound logistics associated with fruit and vegetable distribution. We compare scenario results and show how different supply chain configurations can impact emissions. We propose a solution that would result in significant savings. Lastly, we suggest directions for future research.

2 Further Problem Delineation and Literature Review

While a full lifecycle analysis (LCA) for most agricultural products would entail evaluation of many different environmental and even social indicators, this paper focuses solely on energy usage and resultant greenhouse gas emissions as measured in carbon dioxide equivalents, CO_2e. Narrow though it may be, this sub-category of environmental impact deserves attention. Heller & Keoleian (2000) estimate that transportation, namely diesel fuels from trucking, accounts for a quarter of the energy consumed within the U.S. food system. Given the predominant use of fossil fuels in transport, high energy usage is synonymous with large greenhouse gas emissions. We should note that although energy usage and greenhouse gas emissions are different entities, they are highly correlated in practice. Unless we are switching to a radically different fuel stock, such as derived from solar or wind energy, increasing energy intensity leads to greater greenhouse gas emissions. In the remainder of this paper, we will effectively equate energy usage with emissions.

We first consider others who investigate the link between food and energy/emissions. Energy usage varies greatly between food types; Weber & Matthews (2008) calculate that food transportation may account for half of total CO_2e emissions for many fruits and vegetables but less than 10% for red meat products. Production methods may impact energy and emissions even for the same types of food. Carlsson-Kanyama et al. (2003) study Swedish tomatoes, finding those produced locally in greenhouses require 10 times the energy as field-grown tomatoes imported from Southern Europe. Saunders and Barber (2007) find that milk solids produced for local use in the United Kingdom generate over a third more emissions than the same product imported from New Zealand, despite the long-distance transport required for the latter. This result reflects the more energy-intensive dairy production system in the United Kingdom. Milà i Canals et al. (2007) note that the resultant yield from long term storage can lead to importing apples having lower overall emissions profile than local produce that is harvested and stored for several months. All of these studies demonstrate surprising results to those who might expect long distances to dominate in emissions calculations, including the proponents of food-miles.

One of the reasons that long distance food supply chains are often more energy efficient has to do with the economies of scale. Van Hauwermeiren et al. (2007) demonstrate that the organically grown food is not necessarily more carbon efficient than its conventional counterpart; the smaller firms that are often involved with the former may make the latter less intensive to transport, thus skewing the net carbon impact. Schlich & Fleissner (2005) provide examples of how the international sourcing of some food products can be less energy intensive on a per-unit basis than the local (German) equivalent and posit the existence of an "ecology of scale." For example, Brazil's climate is naturally more conducive to fruit production than most European climates, and Brazilian juice production occurs on a much large scale than European producers typically support. Consequently, Schlich & Fleissner (2005) calculate that the lower emissions due to producing in juice in Brazil rather than Europe more than offset the emissions associated with transporting the juice from Brazil to Europe.

Coley et al. (2009) compare the carbon emissions associated with the supply chain for food purchases at a U.K. supermarket to those associated with a hypothetical small local farm shop. They set the frame as post-production at the farm all the way to the customer's home and consider that the supermarket may offer a home delivery service. In a detailed carbon audit, they find that the former is substantially more energy efficient per box of goods delivered than the latter. While some might argue with last stage differentiation between these two supply chains, Coley et al. (2009) show that even when the frame is adjusted to be cradle-to-gate, the efficiencies realized by the supermarket distribution system render it more energy and emissions efficient than the alternative system.

In their study of the U.S. dairy industry, Nicholson et al. (2011) lament that while there is increased interest in localization of the food supply chain, few professionals have studied the costs associated with such localization. They create a transshipment model to analyze a multiple stage supply chain for different products, some of which can serve both as finished goods and intermediate inputs for other products. They find that minimizing distance travelled is not the most cost-effective solution, due to increased inefficiencies. Furthermore, in such a scenario, consumers would bear these cost increases unequally within different regions. Although they focus more on cost considerations than emissions, it is clear from the context that their findings also hold for resultant emissions.

Not all such research is academic in nature. In a government-funded study intended to guide investment and public policy, Cantor & Strochlic (2009) analyze the barriers that small to medium sized organic farmers face in all sales channels. They find the dominant problems are: managing volumes, getting access to appropriate markets, and competing on a cost basis with larger scale farmers or otherwise earning an appropriate price premium. While Cantor & Strochlic (2009) report that farmers are concerned with the over proliferation of farmers' markets, their proposal with respect to this sales channel involves a limited solution that focuses solely on education, regulation and labeling. Likewise, King et al. (2010) in their EPA-funded case studies of local food sourcing find that the total energy used per unit of product is more closely related to supply chain structure and size than to the distance food products must travel. Additionally, they note that although farmers retain most of the retail price in direct-to-consumer channels such as farmers' markets, the costs associated with bringing products to market can range between 13% to over 60% of this price, reducing the viability of selling in such markets. They also investigate some intermediated sales channels, such as cooperative retail stores.

Although many researchers such as Hunt et al. (2007) and Conner et al. (2009) document the benefits of farmers' markets, and others such as Darby et al. (2008) and Carpio & Isengildina-Massa (2009) investigate consumers' willingness to pay price premiums, we find fewer studies given to systematic consideration of the inherent increased energy usage associated with maintaining such a network as compared to mainstream food distribution. We add to the body of literature by quantifying the underlying problem and then proposing a solution that enables consumers and producers alike to enjoy the best of both worlds: the provision of fresh, locally-sourced produce from family farms to urban consumers with improved costs and decreased emissions resulting from greater system efficiencies.

3 Research Methodologies and Results

3.1 Illustrating the Supply Chain

We investigate the outbound logistics involved in meeting the demand of a San Francisco consumer who seeks to purchase a kilogram of tomatoes, either at the neighborhood Safeway in the Castro district or at a nearby farmers' market such as the one at San Francisco's Ferry Plaza. We set the system boundaries as farm to retail gate. From personal experience, we can emphasize that the difficulties and expense of driving and parking in San Francisco often encourage shoppers to use public transport or cycle to downtown destinations. We thus avoid the problem that others such as Browne et al. (2005), Cholette and Venkat (2009), and Coley et al. (2009) find with the consideration of a larger frame; namely that the retailer-to-consumer link can be the most energy intensive and also the hardest to both measure and to influence. We first consider some scenarios representing a single farm and then move to modeling the overall supply chain network.

Fig. 2: Family Farm at a Farmers' Market, Source: PA Market (2011)

3.1.1 Initial Scenarios

We initially consider four scenarios. The first two scenarios involve sourcing from the previously mentioned Schletewitz Farms. This third-generation small family farm provides fruits, including tomatoes, to several Bay Area farmers' markets, per Figure 2. The first scenario starts with one of the Schletewitz family members driving from Sanger at 2 a.m. (PA Market, 2011) to the weekly market in San Francisco, a significant distance of 320 km. We assume usage of a large gasoline-powered pickup truck with no special cooling in transit. Of course, some farmers may use larger vehicles, but the payload of a large pickup truck (with an effective 600 kg weight limit) is likely the most appropriate for a single trip. For all vehicles used in each of the scenarios we shall assume a 90% utilization rate and no backhaul, i.e. vehicles return empty.

In the second scenario Schletewitz Farms now provides its tomatoes to Safeway. According to Safeway's 'Locally Grown' campaign, up to a third of its produce sales are locally sourced, including through partnerships with small regional farms (Greenbiz, 2009). Likewise, Cantor & Strochlic (2009) document that small to midsized organic farms have achieved some measure of success with such wholesale sourcing. For this scenario, Schletewitz Farms would drive the pickup truck to Safeway's regional distribution center (DC) located on the edge of the metropolitan Bay Area, in Tracy, CA. We assume the product would rest in cooled storage at the DC until Safeway restocks the retail stores in San Francisco using their fleet of heavy duty diesel trucks. Given the mixed payload, we assume some cooling is needed in the fleet truck.

For the third scenario; Safeway instead sources from a larger, neighboring farm, and this larger farm's size results in the use of a midsized commercial diesel truck to bring produce to the Tracy DC. While able to carry over 10 times the weight of a large pickup truck, these midsized trucks are much smaller than the heavy duty trucks used for interstate transport and large-scale delivery. For the final scenario we select a different conventional source; importing tomatoes from Mexico via a heavy duty truck. We specify a distance of 2000 km, more than sufficient to reach Sonora, one of the Mexican states with the most prolific agricultural output. No matter which farm Safeway sources from, we assume all channel partners deliver to the Tracy DC. The four scenarios are summarized in Table 1, and all distances are generated using the routing algorithm provided by GoogleMap.

	Local Small Farm->Farmers' Market		Local Small Farm->Safeway Sourcing		Local Larger Farm -> Safeway Sourcing		Safeway Sourcing from Mexico	
	transport mode	*one-way distance (km)*	*transport mode*	*one-way distance (km)*	*transport mode*	*one-way distance (km)*	*transport mode*	*one-way distance (km)*
link #1: transport from the farm	Large Pickup Truck, Gasoline	320	Large Pickup Truck, Gasoline	225	Midsize Truck, Diesel	225	Heavy duty Truck, Diesel	2000
link #2: transport to the market		n/a	Heavy duty Truck, Diesel, Cooler	100	Heavy duty Truck, Diesel, Cooler	100	Heavy duty Truck, Diesel, Cooler	100

Table 1: Distances and Modes Summarized for Initial Scenarios

3.1.2 CargoScope: Introducing the Software

To be usable by non-specialists, models should balance simplicity and usability with analytic power. Developed by CleanMetrics, CargoScope is a web-based tool that allows users to create a supply chain network. Storage, transit and processing parameters can be defined for every echelon. While many websites offer calculators for determining personal carbon footprints, few online tools allow users to configure a supply chain. CargoScope is selected for this study because it is a low cost solution that allows for specific accounting of utilization and backhaul rates, as well as mode of transportation, level of climate control, and distance travelled. The software also provides for the configuration of supply chain echelons to function either as production or storage nodes, although all production energy usage and emissions must be calculated exogenously. CargoScope's parameters are based on data from U.S. governmental and international agencies, and more detailed information on this tool can be found at CleanMetrics's website (2011) and Venkat (2007). Users can create, share and revise their models, and CargoScope will calculate and display the energy used and carbon dioxide equivalents emitted.

3.1.3 Scenario Results

Given the information for the four scenarios as defined, CargoScope calculates the emissions that result from the transportation and storage of a kilogram of tomatoes. These results are displayed in Figure 3, a stacked bar chart with transport links and storage echelons shown explicitly. We first note that transportation from the farm is the dominant component in all four scenarios. Likewise, emissions associated with transportation in all stages dwarf those associated with climate control for storage, a finding that is echoed by Coley et al. (2009).

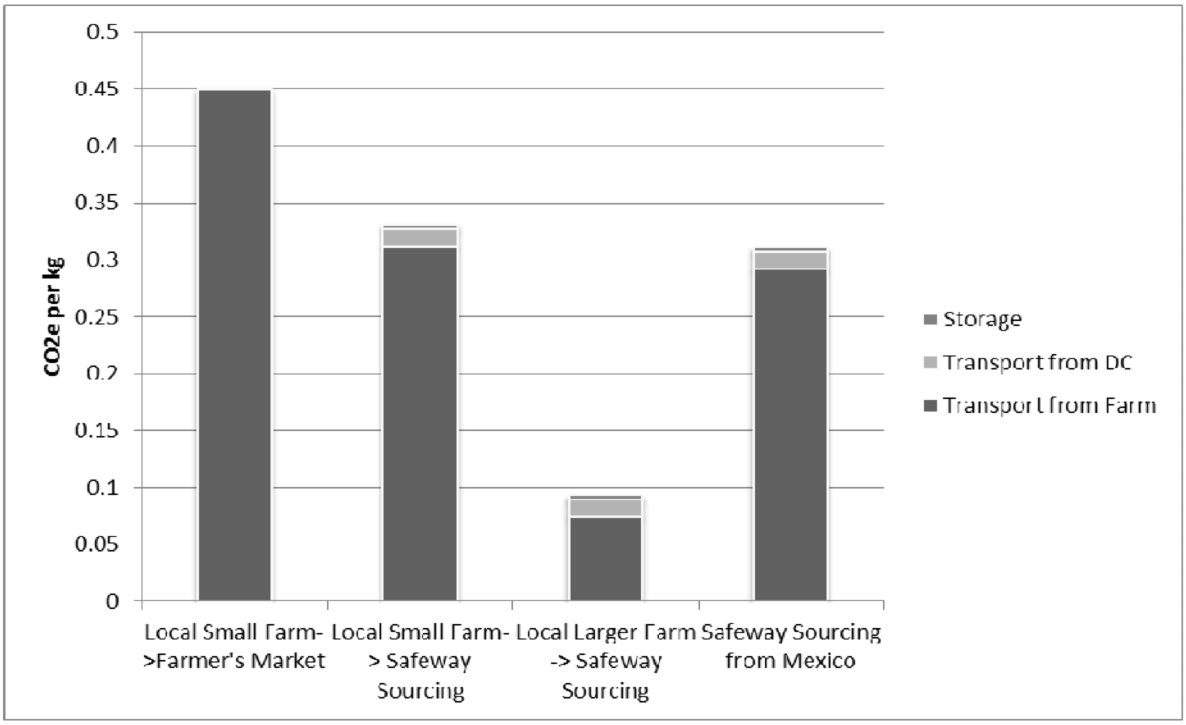

Fig. 3: Outbound Logistics Emissions Profiles for Four Initial Sourcing Scenarios

We can also see that the most emission intensive scenario is that of direct sales to the farmers' market even though it involves the least distance travelled. This result can be attributed to the fact that produce is transported entirely by large pickup truck, a mode that is less efficient than larger vehicles, assuming similar utilization. For example, in CargoScope the fuel usage rate for the midsized truck is approximately 34 liters of diesel for every 100 km travelled, slightly more than twice that associated with the pick-up truck, at just under 16 liters/100km. Yet the midsized diesel truck has nearly ten times the cargo capacity of the pickup truck. This discrepancy in vehicular efficiency is illustrated in the comparison of the results for scenarios 2 and 3, which differ only in how produce is transported from the farm to Safeway's distribution center for wholesale sales. The efficiencies of scale reported by Colby et al. (2009) and Cantor & Strochlic (2009), among others, are clearly illustrated here. Even long distance transport from Mexico is more emissions-efficient per kilogram of product than local, small-scale distribution.

3.2 Modeling the Supply Chain Network

Given the previous results for one farm, we wish to determine whether these results can be considered representative. We next model the supply chain network for Californian farmers' markets. Figure 1 shows that the market concentration occurs in two distinct regions, suggesting that these regional networks are effectively separable. We accordingly limit the scope of the problem to the 135 regularly recurring Bay Area markets and the farmers sourcing them, as found by Jog (2010). While this list of farmers totals to 1297, we consolidate farms within the same zip code into one representative farm, noting the number of farms comprised by each of the 203 representative farms. Rather than manually determining the 27,405 potential distances between these farms and their markets, the distances are automatically estimated using a Microsoft Excel add in provided by Spheresoft, which calculates distances between two zip codes. We assign a floor of a 3km distance for the few cases where farms and markets are within the same zip code.

As farmers' markets and farms comprise a bipartite graph, we can formulate a spatially-disaggregated transshipment model of the farmers' market network to illustrate the linkage between sourcing and energy/emissions intensity. Several simplifications and assumptions are necessary to keep the problem tractable. Like Nicholson et al. (2011) we assume a single decision maker, when, of course, in reality each farm makes its own decisions as to the markets serviced. However, our purpose is to represent high-level weighted distances of goods transported. Also, we consider but one single, homogenous good, as do other researchers of similar large scale problems, such as Cruz (2008). We can avoid the use of multiple goods as used by Nicholson et al. (2011), since we have no intermediate nodes with transformation processes and since many other types of fruits and vegetables have similar volume-to-weight ratios to tomatoes. Of course, a real farmers' market sells a variety of produce, and supplying tomatoes to one market and apples to another would not provide for sufficient variety. But we ignore this detail.

We need not only create the network, but also model the flow of goods, requiring supply or demand data as appropriate to each node. As we had previously combined farms within the same zip code, we assume that all single farms are comparable in size, and that the aggregated farm representative of the zip code is a multiple of the number of the single farms found with. We simulate a demand distribution for the farmers' markets, assigning them as small, medium or high volume based on a combination of factors: city size, day of occurrence, and proximity to other markets. For instance, the San Francisco Ferry Plaza market on Saturday would be likely to generate far more sales than a market in Livermore, especially one that takes place on Thursdays. With these mappings, about half of the markets are small, requiring the equivalent of about pickup truck worth of produce, and 20 markets, 15% of the total, are considered large. Their demand is set such that they could be effectively serviced by a larger vehicle.

Government studies (Cantor & Strochlic, 2009) and trade articles (Worthen 2010), suggest aggregate available supply is much greater than total demand at the markets. In keeping with these reports we check that the aggregate farmers' market demand is approximately two-thirds of total supply. While all these parametric settings are at best approximations, we are interested in modeling the potential flow through the network as a whole, not in capturing the specific details for a particular market or farm.

3.2.1 Initial Formulation

We formulate the problem as follows. We define two sets of variables, the kilograms of produce x_{fm} sourced from farm *f* to serve market *m*, and the number of $\boldsymbol{trucks_{fm}}$ that are used to transport produce from farm *f* to market *m*. Given set *F* for farms and *M* for farmers' markets, we seek to minimize the total distance travelled, ***z***:

$$z = \sum_{f}^{F} \sum_{m}^{M} DIST_{f,m} * trucks_{f,m} \tag{1}$$

We respect the constraints that follow. First, the farm's supply of produce cannot be exceeded.

$$S_f \geq \sum_{m}^{M} x_{f,m} \forall f \in F \tag{2}$$

Next, we must meet the demand at the farmers' markets. As we have made certain that aggregate supply exceeds total demand, we know that this constraint will not render the formulation infeasible.

$$D_m = \sum_{f}^{F} x_{f,m} \forall m \in M \tag{3}$$

We utilize CargoScope's parameters for all transport modes, so the capacity of a pickup truck is set at 600kg. As tomatoes have a high water content and are relatively dense, we need consider only weight limits for vehicles, as these limits will be more restrictive than volumetric limits.

$$600 * trucks_{f,m} \geq x_{f,m} \quad \forall f \in F, \forall m \in M \tag{4}$$

If we set $\textbf{\textit{trucks}}_{f,m}$ to be integer, we would have a classic mixed integer transportation minimization problem, minimizing the aggregate cost of meeting all demand requirements. One caveat in our solution process must be mentioned; given limitations on the available open source solver, we have relaxed the integer requirement on pickup trucks for the optimization, and perform post-optimization calculations to bring the number of trucks used to integer values (i.e. instead of 1.4 trucks we would use 2 trucks). Such relaxations will not necessarily translate to the optimal integer solution were a powerful solver available to handle a problem containing over 27 thousand integer variables. However, we are attempting to approximate the network and the overall flow of regional traffic within it, rather than find a precise solution for a scenario with very accurate supply and demand data.

3.2.2 Summary of Results

We first consider how close the relaxed solution mimics a real solution, with whole numbers of vehicles. Post-solver calculations find the total one-way distance driven by all trucks, at 76 thousand km, resulting in a solution relatively close the LP relaxation, at 64 thousand total kilometers driven. The aggregate distance from the relaxation is within 84% of the total distance driven within the post-optimization integer solution.

Considering the number of trucks (590) necessary to support supplying all market demand, the average one-way distance driven would fall just below 110 km. This represents the low end of the average range of 100 to 300km as quoted by CUESA (2009). In fact, the largest distance travelled in this solution would be just below 200km, when some of the potential distances between farmers and markets are over 400km. By minimizing aggregate distance in a scenario with excess supply, we essentially cut the more distant farmers out of the market. Again, we must reiterate that this solution is an idealized optimization.

This idealization is reflected both on the demand and supply side. For the demand side, one can consider the vendor diversity at each farmers' market at the optimal solution; more than half of the markets would receive visits from at most 2 of the 203 possible suppliers represented. While these suppliers do represent an aggregation of the 1297 farmers certified, an unbundling of the suppliers would result in these smaller markets being serviced by about a dozen separate farmers. The story from the supply side is even more telling; with this optimization more than 40% of the suppliers would not be granted access to a farmers' market. Furthermore, less than a quarter of the suppliers would be granted access to more than three such markets.

While many of the underrepresented farmers may be closer to Los Angeles or near other markets, the fact that the vast majority of farmers currently sourcing Bay Area markets would be shut out or granted limited access is clearly neither fair nor realistic. This solution should rather be interpreted as the theoretical upper bound on the efficiency possible within the current logistical structure, i.e. pickup trucks driving direct from farms to markets. We present this solution because we shall next explore ways of improving this logistical structure, and we plan to measure our improvement to a potential baseline.

3.3 An Alternative Logistical Structure

We investigate the insertion of a consolidation center into the supply chain, where farmers could transport goods, rather than driving them all the way to the farmers' markets. These centers would allow for aggregation with other farmers' offerings over a few days, and then final transportation to the farmers' markets could occur on larger trucks. King et al. (2010) make similar suggestions for improving efficiencies in their analysis of intermediated distribution of local foods, although they do not consider farmers' markets. This paper addresses only the transportation and storage considerations of such a supply chain option; not financial and other considerations. We will assume for now that farmers would be paid on a consignment basis, prorated for a share in storage, personnel and transport costs.

Fig. 4: Northern California Network, with two potential DCs

One of the first considerations for such a center is where to place it. Although locational analysis techniques such as gravity weighting, or even a nonlinear optimization problem could be formulated to determine placement, we invoke more pragmatic considerations. Highway layout and the need for a location near a population center suggest a finite number of realistic warehouse locations. For example, Figure 4 shows a subset of the Northern California farms and farmers' markets with two potential DC/consolidation centers: one in Tracy and one, further south, at Cantua Creek. Jog (2010) studies several locations for such a center and finds that Cantua Creek, a Central Valley town with access to I-5 and several existing warehouses, to be a likely candidate.

3.3.1 Alternative Model Formulation

To analyze whether the consolidation center increases the efficiency of the distribution network, we must first modify the formulation to include this additional logistical option. Farmers will now be allowed both to transport their produce directly to markets and also to send it to the consolidation center, where it will then be aggregated with others shipments and sent to various farmers' markets, using a larger vehicle than a pickup truck. We select a midsized diesel truck, with an effective cargo limit of 6250 kg and a higher fuel usage. This vehicle is still much smaller than the heavy-duty trucks that Safeway uses to restock its retail stores, with an effective cargo limit of over 17 thousand kilograms.

With the introduction of an intermediate node, our formulation alters into a more generalized transshipment problem. The modified formulation follows. We must augment our sets of variables; while we still allow for kilograms of produce, x_{fm}, sourced from farm f to serve market m, and provide $\boldsymbol{trucks_{fm}}$ to transport this produce from farm f to market m, we also use trucks to go from farms to the DC, $\boldsymbol{tfdc_f}$ to transport $\boldsymbol{xfdc_f}$ and to go from the DC to markets, $\boldsymbol{tdcm_m}$ to transport $\boldsymbol{xdcm_m}$. Lastly, we need to equate the distance travelled by the midsized trucks servicing the markets from the consolidation center. We must now account for the difference between the carrying capacity and fuel usage between the trucks; the parameter $\boldsymbol{R}$ represents the ratio in fuel usage between these larger vehicles and the pickup trucks used elsewhere. We modify the objective function, **z**, as follows:

$$z = \sum_{f}^{F} \sum_{m}^{M} DIST_{f,m} * trucks_{f,m} + \sum_{f}^{F} DIST_{f} * tfdc_{f} + R * \sum_{m}^{M} DIST_{m} * tdcm_{m} \tag{5}$$

The constraints also require adjustment. As farms can either send produce directly to the market or to the consolidation center, the supply constraint from (2) becomes as follows:

$$S_f \geq \sum_{m}^{M} x_{f,m} + xfdc_f \forall f \in F \tag{6}$$

Likewise market demand can be met either directly from the farm or from the consolidation center, so equation (3) is altered accordingly:

$$D_m = \sum_{f}^{F} x_{f,m} + xdcm_m \forall m \in M \tag{7}$$

The supply into the consolidation center must equal or exceed its output, requiring a new constraint. We inherently assume there is no effective limit on the center's handling capacity:

$$\sum_{f}^{F} xfdc_f \geq \sum_{m}^{M} xdcm_m \tag{8}$$

Lastly, we continue to enforce the capacity limits for all vehicles, where the capacity of a pickup truck is 600kg and a midsized truck is 6250kg, as per CargoScope:

$$\begin{aligned} &600 * trucks_{f,m} \geq x_{f,m} \forall f \in F, \forall m \in M \\ &600 * tfdc_f \geq xfdc_f \forall f \in F \\ &6250 * tdcm_m \geq xdcm_m \forall m \in M \end{aligned} \tag{9}$$

Given the larger size of the midsized trucks and their inherent economies of scale advantages when highly utilized, the use of a fractional number of such trucks would make the solution highly questionable. We thus restrict the variable set $\boldsymbol{tdcm}_{\mathrm{m}}$ to take binary values. The market demands are sufficiently that sending more than one midsized truck would not be efficient, so we need not bother with integer values beyond one. Our open source solver is still able to solve the problem in under a minute, as this formulation has only 135 distinct binary variables, one for each farmers' market. We continue to leave both pickup- related variable sets $\boldsymbol{trucks}_{fm}$ and $\boldsymbol{tfdc}_{\mathrm{f}}$ as linear.

3.3.2 Alternative Model Results

We again consider how closely the relaxed solution mimics a solution with a whole numbers of vehicles. The relaxed solution has 84% of the aggregate weighted distance of the fully integer solution determined in post-solver calculations. Satisfied with the relative closeness, we next compare the results the alternate scenario to those from section 3.2.2.

The consolidation center has a large impact on the flow of produce through the system. Of the 590 pickup trucks that originally drive to the markets directly, 209 would now instead head to Cantua Creek. From there, midsized trucks service 20 farmers' markets, noticeably all of the largest markets. In total, our solution routes 36% of all of the produce through this consolidation center. It should be noted that sales volumes within the medium and small markets are too small to merit the effective use of these midsized trucks. Should there be greater volumes in the end markets or, for that matter, comparatively smaller volumes of produce from farmers, the solution would favor even greater usage of the consolidation center.

The new solution results in a total one-way distance of 59 thousand km, a 23% reduction when compared to the base scenario. Of this mileage, just over 4 thousand km are driven from the distribution center to the markets. As the midsized trucks use about twice as much fuel as pickup trucks per distance driven, we must apply a multiplier when considering total fuel used and resultant emissions. When this calculation our new solution still utilizes 17% less energy than in the baseline scenario.

It should also be noted that a side benefit of a consolidation center is the opportunity for enhanced vendor diversity at the markets. In the base scenario, these larger markets are each serviced by 12 suppliers, but with the consolidation center such markets could, in theory, receive goods from each of the 209 producers that deliver to the center. While such a variety would likely be impractical and overwhelming for most suppliers and buyers of produce respectively, it would enable small suppliers of niche products to enjoy a more widespread market reach. In our solution these larger markets are also supplied by a few farmers directly.

4. Proposed Solution

Comparing the results between scenarios, we see that the addition of the consolidation center appears to be a decided improvement. At the optimal solution we can decrease the total distance travelled by 23%, improving fuel usage by 17%. We even increase vendor diversity at the larger farmers' markets.

We now return to our original analytic approach from section 3.1, revisiting our CargoScope scenarios to see how such a center would impact the farm we profile, Schletewitz Family Farms. We define a fifth scenario that depicts the use the Cantua Creek consolidation center. A Schletewitz employee would drive a pickup truck 95km to Cantua Creek, where a midsized truck would then transport their produce and that of others to the San Francisco Farmers' Market, 270 km distant. We continue the use of 90% utilization and no backhaul for all vehicles. Figure 5 shows that on a per-kilogram basis, the use of a consolidation center effectively halves the emissions of supplying the farmers' market.

Figure 5 shows also that while the emissions from the Cantua Creek center to the market are significant, they are more than offset by the decreased emissions associated with the transport link from the farm. It should be noted that the efficiency gains modeled come primarily from the substitution of midsized trucks for the smaller pickup trucks for more of the distance. This new scenario is the more efficient than all but scenario #3, which assumes a larger scale producer, allowing for use of more efficient vehicles through the entire supply network. For farmers that are too small to realize any efficiency gains to transporting goods from their farms via larger vehicles, a nearby consolidation center is likely to be a more realistic solution to reduce transport costs and emissions.

It should also be noted that the placement of the distribution center can have a great effect on efficiency. Although the organizational mechanisms differ, Scenarios 2 and 5 are similar in logistical structure, differing primarily in where the intermediate center has been placed and what transport mode is used in transporting to the retail market. Locating a consolidation center closer to the farmer minimizes the distance travelled by the least efficient mode, pickup truck. Thus, we see scenario 5 is more energy and emissions efficient than scenario 2.

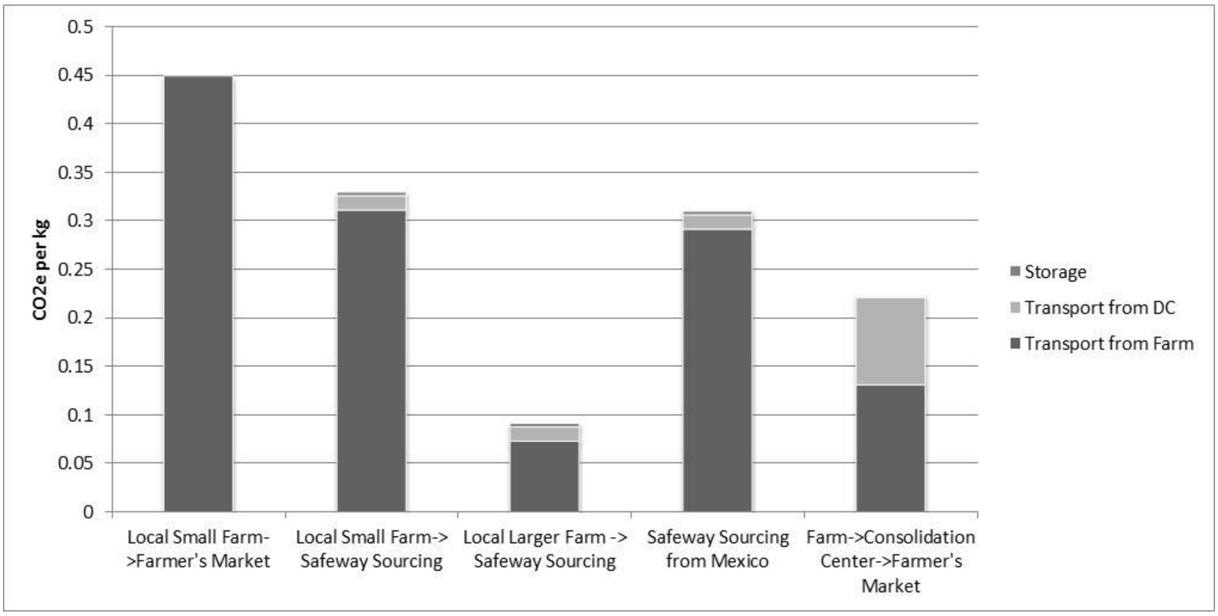

Fig. 5: Outbound Logistics Emissions Profiles for all Scenarios, Including a Consolidation Center for Farmers' Markets

5. Conclusions and Future Research

We analyze the energy and resultant emissions necessary to support the current network of Northern Californian farmers' markets. We demonstrate that a consolidation center can result in significant improvements by these metrics, by enabling small farmers to take advantage of economies of scale. In particular, the transshipment optimization shows a 23% reduction in mileage driven and a 17% improvement in fuel usage over the optimal baseline solution, itself an idealized version of the inefficient network as realized in practice. The profile of Schletewitz Family Farms illustrates that insertion of a consolidation center at Cantua Creek into the supply chain can halve their per kilogram emissions as compared to directly driving to the farmers' market. Instead of being the most energy and emissions intensive configuration, including that of long-distance importation from foreign industrial-scale farms, our alternative farmers' market supply chain would permit this small producer to experience efficiencies typical of larger establishments. In short, such a consolidation center would enable producers and consumers alike to enjoy economies of scale while still retaining the benefits of a system supplied by small family farms of the region.

The solution has several limitations that must be acknowledged. While the placement of farms and markets is based upon real data, the supply and demand volumes have been simulated. For instance, if demand is greater at more of the farmers' markets, the use of additional large vehicles would be justified, suggesting that a consolidation center could rightfully capture an even greater portion of the network traffic. On the other hand, consider farmers who are sufficiently large in both production and their share of a market's sales; such farmers may be able to justify use of larger vehicles for direct to market deliveries, reducing the benefits derived from the consolidation center. Additionally, the availability and use of an industrial solver able to handle large scale mixed-integer problems would be a welcome improvement.

However, before we invest in more computational resources and data collection, we must note the existence of substantial practical barriers to our theoretical solution. The first barrier is that California farmers' markets are classified as producer-only. To accommodate such an arrangement as this research proposes, the underlying regulations governing these markets would need to be changed. Of course, such changes would need to be performed delicately and might lead to undesirable repercussions; opening farmers' markets to a much broader participant base could result in food scalpers and other resellers that could detract from the product quality and the overall market experience. Other states have fewer restrictions on vendors, so it would behoove policy makers to study which of these more open markets appear to be the most effective in terms of maintaining desired marketplace attributes while still allowing for vendor freedom.

Whether such a farmers' market, with a combination of individual and consolidation-center suppliers would find acceptance with producers needs further investigation. Some producers, especially those who are closer to the high value urban markets, might resent a change to the market infrastructure that effectively levels the playing field, negating their inherent geographical advantage. An open question remains as to whether farmers would welcome the opportunity to collaborate, even those who should, in theory, benefit from such a change. Hunt et al. (2010) in their examination of intermediated supply chains found that the consolidation stage was initiated by a variety of agents along the supply chain: retailers, food-service operators, or entrepreneurs, but such action was never initiated by group of producers. A feasibility study would need to address these concerns among more prosaic issues.

Likewise, consumers' potential acceptance would need to be evaluated, as such a solution will likely result in consumers having less personal contact with farmers at the markets. However, this lack of direct interaction may not greatly influence the majority of local food buyers; Zepeda and Li's (2006) extensive survey examines why consumers shop for local foods. Their findings indicate that direct contact with the farmers is not the main draw, but rather that such foods are perceived by these shoppers as being of superior quality.

Although the potential barriers to implementation are formidable, we conclude that such a logistical solution is worth further investigation. Cantor & Strochlic (2009) posit that consolidation hubs and marketing cooperatives would help farmers in their attempts to compete with larger-scale suppliers in the wholesale market. With respect to direct marketing channels, Cantor & Strochlic (2009) suggest that CSA subscriptions that source from several farms have proven advantageous. If one such direct-to-consumer channel has gained market acceptance, it seems that there may be opportunites for others. The recent years' expansion of farmers' markets has occurred despite the presence of cooperatives, even in states that do not enforce producer-only rules. Clearly if farmers' markets are to remain a viable and sustainable channel for small Californian family farms in the longer term, the underlying logistics that support them are ripe for improvement.

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Economical and Environmental Assessment of Multi-Use Package within Food Catering Chain: an Italian Case Study

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Abstract

Nowadays the change within people life-style contributes to develop the food catering sector and restaurants and canteens become a significant source of waste due to packaging. The present manuscript explores the main features and procedures of the logistic network involving vendors, DCs and restaurants throughout the Italian catering chain. Packaging waste issue might be addressed through the adoption of a Reusable Plastic Containers (RPC) as well as has already applied within the grocery chain. An Italian case study is presented and results of both economical and environmental assessments are proposed and discussed.

Keywords: Packaging, Food Chain, Life Cycle Assessment

1. Introduction

During the last decade, one of the most popular and worldwide felt trouble concerns with the promotion of a sustainable development, allowing to guarantee to the next generations the same growth opportunities that we are actually experiencing.

Any organization belonging to public or industry sector ought to rearrange the current working routine in order to highlight and point out real or potential waste sources throughout the supply chain.

Packaging has became an integral part of modern society considering its main role in protecting, distributing and offering information about product in industry, in business and for the consumer (Bovea et. al., 2006).

Most of the debate about packaging and its environmental impacts has focused on grocery and food retail sector. Indeed packaging allows to save and preserve the chemical, physical and nutritional conditions of the food produces as well as purchasing, inbound logistics and warehouse activities, transportation throughout the farm to fork chain (Verghese & Lewis, 2007).

However after his working cycle, packaging has environmental impacts that are not sustainable in the long term. These effects include consumption of non-renewable resources, air emission due to manufacturing, transportation and use, and production of solid waste.
The increasing volumes of package treated and managed at the end of food chain suggest governments and institutions to develop policies and laws in order to regulate the system. Even industry focuses more and more on packaging shape and material in order to ensure cheap and efficient handling and shipping operations and to reduce the overall costs due to working cycle activities and end-life treatments.
Nowadays change of purchasing habits has inevitably increased the production of waste and garbage due to packaging. Meanwhile people use to get meals away, so that catering and restaurants service, canteens, cookhouses are quickly developing and increasing their business volume and products flow, becoming some of the most source of waste of primary and secondary packages.
The proposed study analyzes the fresh food flow throughout the food catering chain from the local vendors to the final customer in order to point out the opportunity to experience new plastic multi-use packaging system, i.e. Reusable Plastic Container (RPC).
Despite of the grocery and retail sector where RPCs are diffuse and nowadays applied, the catering chain use to adopt single-use wood, plastic and carton packages. This approach is due to the huge number of nodes, levels and general markets which products pass through, each of them devoted to collecting, storing and shipping operations. Therefore all these steps increase costs due to packing, storing, transportation, and at least environmental costs and externalities and reduce the opportunity to manage a reverse cycle of multi-use empty packages.
In grocery and retail sector volumes are high and constant, produces demand is accurately foreseeable and delivery points, e.g. distribution centres (DC) primarily devoted to cross-docking and consolidation, are few and known. Therefore the adoption of RPC system is already providing significant economic and environmental benefits for stakeholders and either society.
On converse, within the catering sector volumes are lower, the huge amount of points of demand, e.g. restaurants, canteens, bars, and the numerous owners throughout the chain, represent some critical issues able to affect the multi-use packaging management.
The aim of this paper is to enquire the economical returns and the environmental impacts of the application of a multi-cycle packaging on particular quality and add-value commodities as biological produces. For these specific produces indeed, the supply chain is shorter and each step requires to be managed monitored and certified to respond to strictly regulations.
The reminder of this paper is organized as follows. In Section 2 the scenario of the analysis concerning with food catering current chain is proposed. In Section 3 a list of the criticism affecting the fresh food management is reported. Section 4 deals with the characteristic and features of both single-use packaging and RPC system. The economical return is estimated through the differential cost analysis of packaging, storing and transportation processes and is the aim of Section 5. The environmental benefit is evaluated through a Life Cycle Assessment (LCA) approach and a resulting carbon footprint differential analysis comparing the current and the new packaging regimes is explored in Section 6.

2. Scenario of Analysis

Actually the food catering chain service does not use to adopt reusable packaging. The main issues avoiding the exploitation of this environmental care solution consist on the following points: the low managed volume per order; the lack of a centralized logistic network and the huge amount of customers to fulfil; the particular profile of customer demand requiring less than unit picks; the wide and complex multi-owning supply system.

The aim of the present manuscript is to enquire ad evaluate both the economical and the environmental returns of the adoption of RPC within the food catering chain involving particular biologic fruits and vegetables. Differential capital and operative costs investments and economical and ecological incomes due to those packaging regime will be estimated considering the main DC and a cluster of selected vendors and customers. The actual logistic network consists on the following steps and nodes, as illustrated in Figure 1.

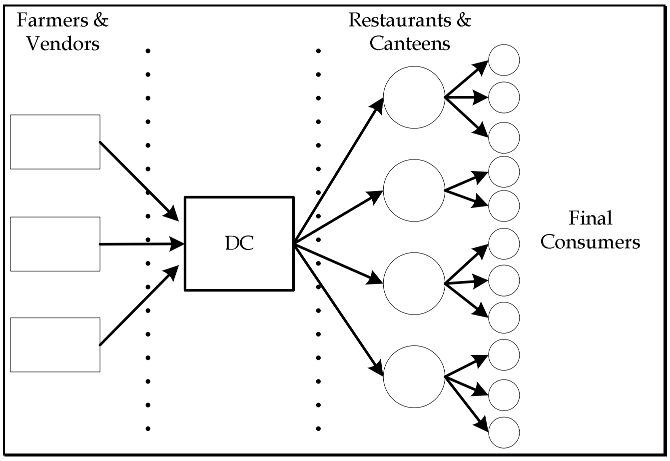


Fig. 1. Current biologic items catering supply chain

Generally for biologic produces the supplying chain is meanly shorter than for other products and the vendors are typically the local farmers. Indeed the shorter is the chain, the higher and accurate is the traceability and quality control of processes.

The DC is responsible to receive products from vendors, put away and storing activities, picking and consolidation. Finally shippers are devoted to transportation activities along the chain.

The following scheme, illustrated in Figure 2, focuses on the detailed steps experienced by forward and reverse physical (dark line) and informative (dot line) flows along the current supply chain. Each step, with particular focus on the DC, generates costs which are take into account in the economical analysis and which might be classified as follows:

i. Purchasing costs.
ii. Storing costs.
iii. Distribution costs.
iv. Outdates costs.

The purchasing costs include order issuance costs, products and packages purchases, shipping and receiving related costs. The storing costs consider investment cost on storage and handling equipment, capital costs due to inventory, and stock out related risk and cost.

Distribution costs are related to shipping activities, usually outsourced to shippers or courier operators. Outdates costs throughout the supply chain refer to all the fresh food items that get spoiled and cannot be sold or delivered to customers.

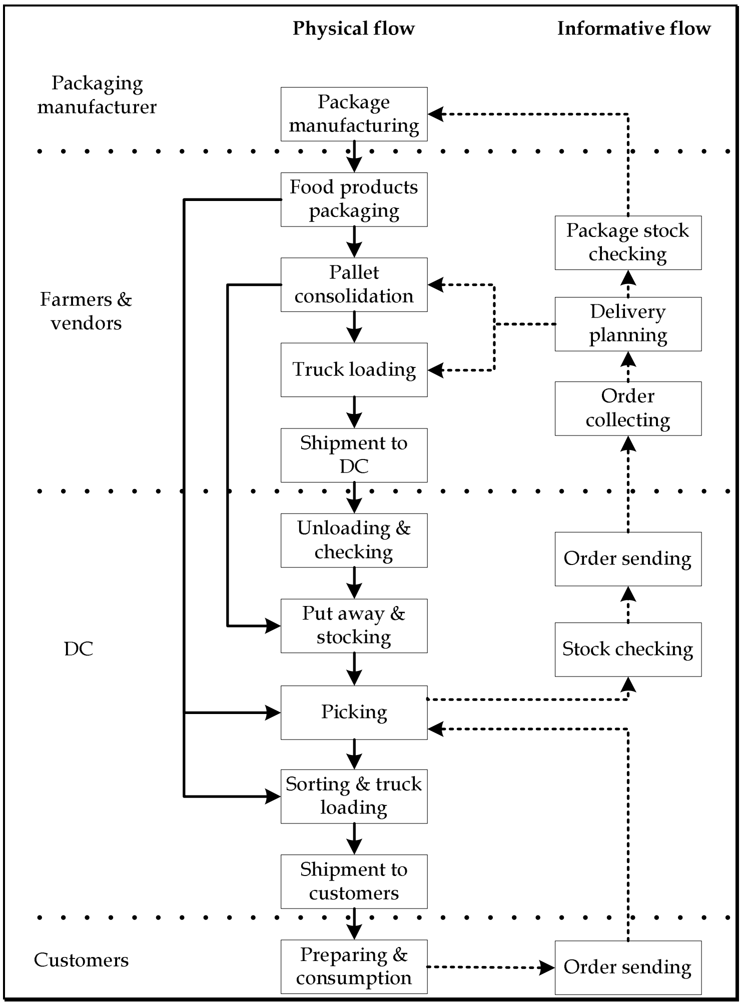


Fig. 2. Detailed activities along the supply chain

The previously introduced costs might be affected by two parameters characterizing the product: *product value density*, i.e. the economical value per volume unit of product, and *package density*, i.e. the mass of package per volume unit of product. Typically items with high value density cause increasing capital costs due to inventory, whereas high package density products add storing and handling costs. The sector of fresh food crops, i.e. fruits and vegetables, is characterized by high value of inbound and outbound logistic costs due to the huge variability of size and shape of the handled items and the low economical value of each single item.

In comparison with the network proposed in Figure 2, the new packaging system requires to involve a new agent, named the pooler, who is responsible of packages supplying, recovery treatments as washing and maintenance and overall cycle management. The pooler company allows enclosing the supply chain cycle thanks to a reverse empty package flow able to convey RPCs from DC to vendors after recovery treatment. In order to consider the role of the pooler, the network configuration ought to be rearranged according to the steps illustrated within Figure 3.

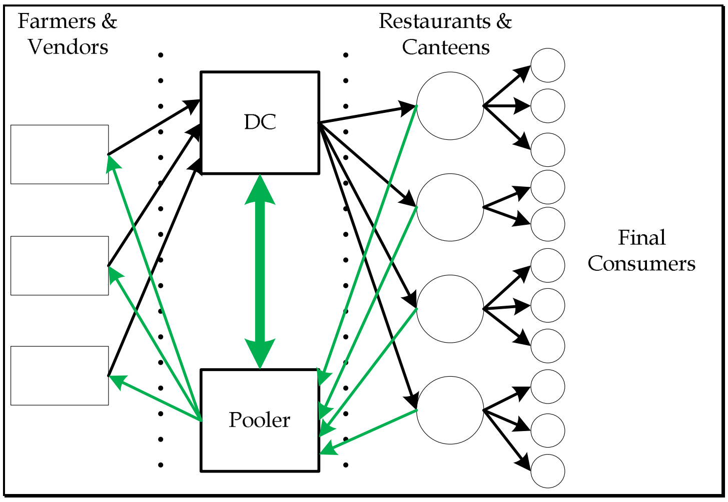


Fig. 3. New biologic items catering supply chain

3. Fresh Products Management

Despite of manufacturing industry, the overall logistic network, the design and management strategy within the fresh food chain are generally affected by the particular characteristic of fresh produces.

The perishability of fresh food items is the main factor affecting logistic design and infrastructure decision. Indeed special purpose devices must be applied in order to ensure do not break down the whole cold chain throughout transportation either storing and handling operations. Furthermore the supplying network configuration tend to be shorter and to involve few consolidated partners to allow process and product tracking and checking. Even inventory turns within storage systems used to address the perishability issue.

Whereas perishability is the main issue for fresh produces management, seasonality is obviously a significant factor which needs to be handled. The available products depend on the seasons cycle and climate profile, i.e. air humidity, weather conditions, temperature, so that storage equipment and distribution system need to be designed to match and fit these trends.

Since each item is not standardized and might change type, size and quality year by year depending on climate conditions, necessary planning activities as demand forecasting or resource scheduling, operative and strategic choices, as respectively those concerned with size and material of package or handling equipment, become a serious issue.

4. Packaging Volumes and Features

Packaging allows containing products, to facilitate handling and shipping operations and maintain and preserve quality, safety and nutritional conditions of food item along the food supply chain. Within the Italian sector of food sector the fraction of single-use packages is high as illustrated by statistics in Table 1.

Material	Billion €	tons · 10^{-3}
Steel	0.869	508
Aluminium	1.383	70
Paper	4.212	3,272
Wood	1.015	1,628
Plastic	7.221	3,997
Glass	0.796	2,331
Others	1.099	220
Total	16.594	12,026

Tab.1. Packaging Italian values and volumes due to food chain

The most popular materials applied in food secondary packaging are paper, glass and plastic respectively for their specific cheapness, strength and resistance to the humidity (Packaging Italian Institute Report, 2010). Furthermore the part strictly in contact with food, often consists on plastic films to respect sanitary and healthy performance and parameters.

The most adopted sizes, addressing the food distribution needs, are 400x600 mm, 300x500 mm and 300x400 mm able to fit with the standard 1000 x 1200 mm EPAL 3.

4.1 Paper, Plastic, Wood Mono-Use Packages

Cartons hold almost 40% of total flow package weight handled within the food supply channel due to costs savings and related marketing opportunities, e.g. logos printing. The manufacturing process consists on the use of a paper cover, named kraftliner, able to contain the paper wave and of a specific semi-chemistry fluting composed by paper and glue.

Plastic package are diffuse because their characteristic stackability and typical strength able to support numerous working cycles. The most applied materials are polypropylene (PP) or Polyethylene Terephthalate (PET) particular convenient for recycling post life treatments.

Finally wood packages are adopted especially for low related costs and their strength. Some pictures of single-use packages used by the analyzed supply chain are proposed in Figure 4.

Fig. 4. Carton, plastic and wood secondary packaging

4.2 Plastic Multi-Use Packages

Despite of single-use packages, RPCs are available with two standardized sizes: 400x600 mm and 300x400 mm. These packages are made by Polypropylene polymers (PP) so that they are completely recyclable after their life cycle. RCP allows to facilitate loading and unloading operations, either retrieving activities and consolidation of orders within the storage system. Furthermore the opportunity to reduce and bend the package side banks allows RPC to gain space efficiency for either inbound and outbound operations. Is estimated that usually RPC packages may support almost 110 working cycles before to receive end-life treatments, i.e. recycling. A sample of RPC package is illustrated within Figure 5.

Fig. 5. RPC packaging

5. Economical Assessment

In session 2 the scenario of analysis and the logistic network of the catering supply chain have been proposed.
Traceability, RPC losses risk, reverse flows balancing and data management are the most critical aspect to take care through the system control. Therefore in order to address to these criticisms accuracy and service level must be ensured.
The complexity of the problem and huge amount of nodes and operators do not manage to adopt and evaluate the RPC package conversion benefits regarding all flows and volumes of fresh food handled by the DC. Therefore the overall improvements due to a complete change from single-use paper, plastic, wood secondary packages system to a RPC packaging system is not the goal of the proposed analysis.
Indeed the pilot project developed and reported in the manuscript takes into account a tight group of vendors or farmers supplying only biologic produces. These particular items experience a tracked and monitored supply channel, shorter than for other products, whose main suppliers are often even the farmers.
The decision to change the package system influences even the relationship and agreements among the agents. Indeed it is necessary to create a straight connection among vendors, distribution centre and customers so that the foodstuff delivery flows and, especially the reverse empty RPC flows might be guarantee. To achieve this goal, in order to select a more convenient and suitable logistic network, a vendors rearrangement and rationalization planning has been actuated.
Biologic products are responsible of almost 1200 tons moved per year, a significant fraction of the total annual volumes handled by the DC and are shipped to 320 different points of demand. The typical less than unit picking for the catering and restaurants service requires to provide the DC an empty RPCs amount either to comply small and fractionated customer orders.

Fig. 6. Pictures of both packaging systems within the DC

The new packaging system induces the review of actual practises and processes that enable to get the biologic items delivered to the DC, stored, picked and shipped to the customers. As sample, new reverse flows are generate by the empty RPC from customer to the DC and the pooling company. Furthermore despite of the space efficiency achievable by the adoption of RPC packages, more space within the DC is required to place and jointly manage two different packaging systems (for biologic and not biologic produces), and new operative activities as RPC side edges opening might increase overall time and costs. Figure 6 illustrates samples of both packaging systems applied within the DC. The new procedures and the activities illustrated in Figure 2 allow to realize a differential costs analysis per each single agent involved throughout the farm to fork chain. Table 2 summarized the overall differential costs balance for each node of supply chain.

Vendors	Costs (€/Year)	DC	Costs (€/Year)	Customers	Costs (€/Year)
Old package purchasing	-68,100	Truck unloading	800	Sanitary	-5,300
New package leasing	38,500	Income reg.	8,000	New package reg. in	4,700
Old package activity	-3,300	Restocking	6,200	New pack. reg. out	4,700
New package activity	6,700	Picking	1,300	End-life treatments	-8,600
New package preparing	-300	Old package purch.	-2,700	Package preparing	6,900
New weight reg.	6,700	New package reg. out	4,700	Losses	18,000
Truck loading	5,500	New package check	6,400		
New packaging reg.	800	New package reg. in	4,700		
New packaging tracking	1,000	New package pallet	8,000		
Mistakes	1,000	Truck loading	300		
From vendors to DC	24,800	Return from Pooler	-7,000		
From pooler to vendors	11,500	Administration	21,000		
Losses	3,000	Human resources	7,900		
		Losses	3,000		
Total	**27,800**	**Total**	**62,600**	**Total**	**20,400**

Table 2. Differential costs analysis report

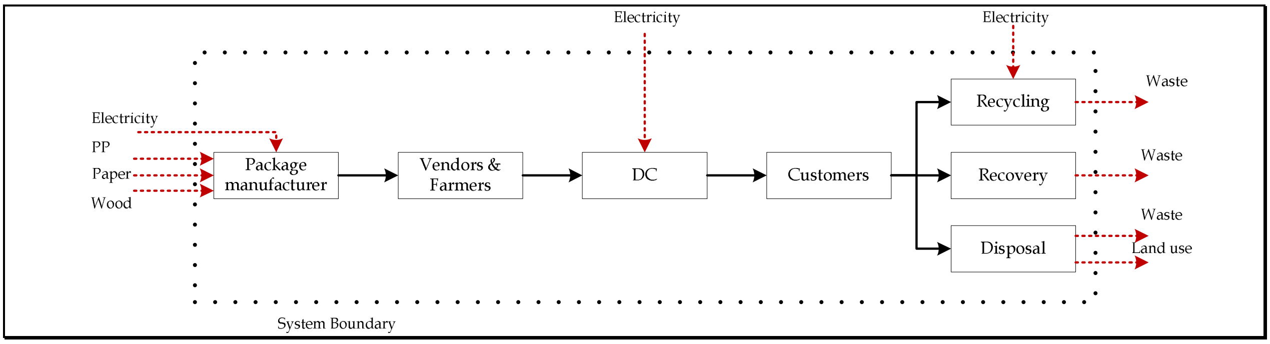
As reported within Table 2 an economical loss shared by all the partners of the food catering chain is experienced. The DC, with a total annual cost of 62,600 €, suffers more than the other nodes the adoption of the new multi-use packaging regime, since is called to jointly manage both packaging systems for, the old one and the new devoted to biologic fresh items. The chance to assign the overall change and logistic costs to municipalities or final consumer might cause an increase of price of 0.092 €/Kg of biologic products purchased.

6. Environmental Assessment

The environmental performance of the proposed multi-use packaging system can be evaluated by applying the life cycle assessment (LCA) methodology. The approach mainly consists on a 4 step analysis as follows: goal and scope definition; life cycle inventory; life cycle analysis; and interpretation of the results.

6.1 Goal and Scope definition

The goal of this study is to evaluate the environmental impacts of the adoption of mono-use packaging system currently adopted for biologic stuffs compared with impacts due to the proposed RPC multi-use packaging system.
LCA methodology is apply to assess the environmental profile of the actual packaging concerning with manufacturing and management processes through the identification of the elements, materials and activities that contribute mostly to its effects on the environment. A comparative analysis is presented in order to quantify the percentage of improvement due to the new package and related new supply flows and procedures.
The functional unit (FU) for packaging ought to reflect the aim of the assessment. Previous American studies (Franklin Associates, 2004) enquired the differential environmental costs of the adoption of RPC compared with a single-use display-ready corrugated container (DRC) used for fresh food grocery chain. Assuming the flows of 1000 tons of fresh product shipped from vendors to customers as FU, the analysis shows that RPCs require 39% of energy less, generate 95% of waste less and reduce the air emissions of 29%.
The selected FU in the present analysis consists on the annual flow of biologic products, i.e. 1200 tons, passing through the catering chain from farmers to customers across the DC. The differential carbon footprints, or equivalent carbon dioxide CO_2 emission, due to the two packaging profiles are the results of the proposed assessment.
The boundaries that define the system under study take into account the following stages: package manufacturing; packaging distribution activities; garbage and waste transportation; the package washing; and the post life treatments as recycling; energy recovery and disposal. The complete scheme of the system is illustrated in Figures 6.



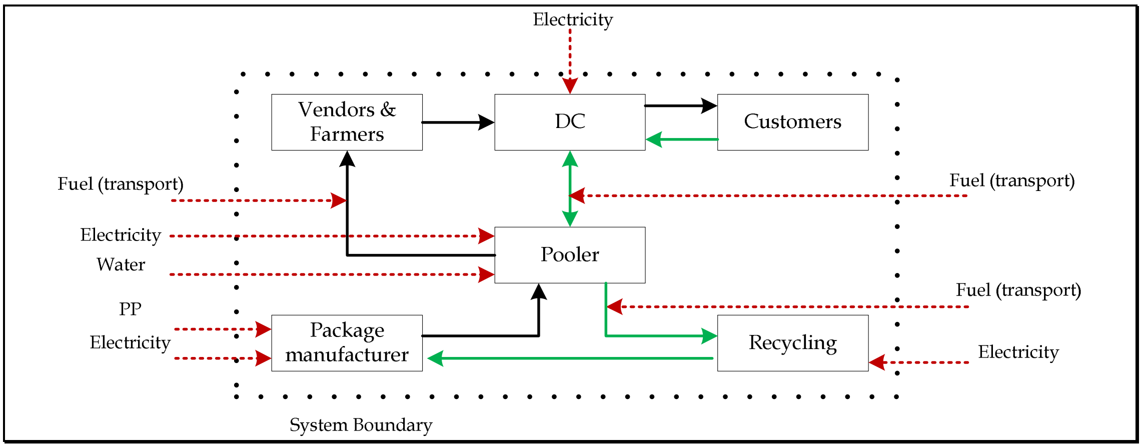


Fig.6. Boundaries of the analyzed systems: (a) Old system; (b) Biologic-RPC system

Within the system boundary dark line represents the physical packaging flow, whereas red dot line shows the resource inputs of the processes and generated wastes. The adoption of RPC packaging system allows to close the physical cycle, through the development of new flows (green line) within the logistic network, and set to zero the chunk of packaging due to recovery treatment or disposal.

6.2 Life Cycle Inventory

The life cycle inventory (LCI) consists on a detailed collection off all environmental inputs (both raw material and energy) and outputs (air, water, and solid emission) during each steps of the overall packaging life cycle. As well as presented within the Figure 6 each single step is analyzed in order to point out the system inventory:

i. The manufacturing process for both mono-use and RPC packages exploits the necessary tons of raw material to package 1200 tons of biologic products. Even adding packages to enable less than unit picking have been considered. The amount of each material per FU that makes up the two packaging profiles is summarized in Table 3. Furthermore the equivalent CO_2 emissions per unit of weight of material applied by manufacturer are reported in accordance with Idemat data bank.

ii. The transportation of raw material from supplier to manufacture facilities is not take into account. Even the shipments from vendors to DC are the same for both packaging systems so that they are useless within a comparative differential carbon footprint analysis. The differential travelled distanced due to the trips from the package producer to the pooler facility, those from the pooling platform to the farmers and those from the DC to the washing facility are considered per FU and reported within Table 3. The equivalent CO_2 emission per Km travelled, is resulting from different road modes data, i.e. highway, rural, urban, as provided by SINANET data bank.

iii. Water and electricity differential consumption due to washing process and inbound handling activities are take into account.

iv. Finally post life cycle treatments as recycling, energy recovery and disposal are take into account. The opportunity of the single-use packages completely recycle is not realistic whereas all the RPC packages are 100% recycled after the working cycle. Therefore according to the fraction suggested by Italian recycling companies as COMIECO, COREPLA and RILEGNO the differential impacts on carbon footprints of the two packaging regimes are proposed. Flows in output from the system are reported in term of tons per FU in Table 3. The equivalent CO_2 emissions per unit of weight of material sent to landfill are reported in accordance with I-LCA data bank.

Materials & Processes	Flows (tons/year)	LCI Database	Eq. Kg CO_2/Kg
Manufacturing			
Poplar, pine wood	36.80	FEFCO	0.150
Corrugated cardboard (paper)	38.40	Idemat	1.050
PP	14.15	Idemat	2.290
PP $_{\text{due to RPC}}$	2.05	Idemat	3.200
Transportation	**(Km/year)**		**Eq. Kg CO_2/Km**
Truck traveling	2,191	SINANET	0.779
Truck traveling $_{\text{due to RPC}}$	22,279	SINANET	0.779
End-life treatments	**(tons/year)**		**Eq. Kg CO_2/Kg**
Recycling			
Paper	30.87	FEFCO	-0.177
Wood	28.70	I-LCA	-0.135
PP	4.67	I-LCA	-1.300
PP $_{\text{due to RPC}}$	2.05	I-LCA	-1.300
Recovery			
Paper	3.07	I-LCA	-0.528
Wood	1.47	I-LCA	-0.602
PP	4.67	I-LCA	1.160
Disposal			
Paper	4.46	ETH-ESU	0.00824
Wood	6.63	ETH-ESU	0.00824
PP	4.76	ETH-ESU	0.00824

Table 3. Annual flows per FU throughout the system.

6.3 Life Cycle Impact Analysis

The life cycle impact analysis (LCIA) stage aims to quantify the flows explained in the life cycle inventory and represents them in term of equivalent CO_2 differential emission, in accordance with the available and updated data banks. Table 4 illustrates the results of the analysis.

Processes & Treatments	Differential Carbon Footprints (tons eq. CO_2)
Packaging manufacturing	-71.56
Transportation	17.05
Handling operations	1.34
Washing operations	7.44
Post-life treatments	-0.10
Total	-45.83

Table 4. Overall carbon footprint results

The computer software SimaPro 7.1 has been used to model the proposed scenario in order to obtain the differential environmental assessment of the proposed packaging system. Under the hypotheses taken the RPC packaging system succeeds to save more than 45 tons of equivalent CO_2 emission in comparison with the mono-use packaging system to manage the annual flows of biologic products throughout the food catering chain object of the analysis.

7. Conclusions and Further studies

The proposed case study focuses on the economical and environmental assessment of the adoption of a RPC system within the food catering supply chain. The multi-use packaging has been tested and applied to the annual biologic produce flows handled by the DC object of analysis. The related operative and capital costs for each node of the supply chain, i.e. vendors, DC, customers, have estimated as well as the overall environmental differential carbon footprints. The analysis shows as the reduction of the environmental impacts in terms of air emission does not ensure and guarantee an economical benefit, as proofed by the overall experienced losses of 0.092 €/Kg of biologic items handled.
The factor that mostly affects this result consists on not considering the overall fresh food flows crossing the chain, but just the biologic produces. Indeed the opportunity to involve either the complete palette of products, vendors and customers might convey to achieve the scale benefits and related economical returns.
Further research might regard the application on the same case study of the game theory approach in order to point out the equilibrium of the system, considering the group of vendors, customers and DCs as players of the game (i.e. *how many vendors ought to get involved in order to gain the overall economical benefit?*).
On the other hand, as reported in numerous literature studies, the externalities related to air emission can significantly affect the level of society health and increase medical expenses, i.e. 65 €/ton of CO_2 emission (Eshet et. al., 2005). Therefore despite of unique private interests and investment returns, the overall economic, environmental and health benefits due to multi-use packaging ought to be considered.

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The potential of improved logistics in enhancing the performance of agri-food industries in developing countries

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Abstract
Agro-food industries are rapidly being modernized worldwide thus creating new managerial challenges to food processing firms. These challenges can be met by adoption of the proven business management concepts. Logistical management is one area whereby improvements in its efficiency are known to contribute to the competitiveness of agro-industries. However, while large agro-industrial firms have addressed logistics relatively well giving it the attention it deserves, small and medium scale enterprises in developing countries especially in Africa are more often constrained. On overall, majority of managers of agro-food industries in Africa are still unaware of the relevant concepts and of the potential benefits of improved logistical management. This paper discusses the logistical challenges facing agro-food industries in developing countries with emphasis on Africa and provides highlights on how this situation is hindering the growth of the agro-food processing sector in the continent. The challenges on pertinent logistical issues necessary to enable entrepreneurs to contribute effectively to the global agri-food systems are critically discussed. Other important challenges including difficulties in organizing the supply chains at small scale levels so as to ensure that the benefits of logistics are achieved are also discussed. The paper explores opportunities with potential to enhance the efficiency of agro-industries hence being able to contribute more in the global agricultural food systems. The paper concludes by providing highlights FAO's effort to address improvement of logistic management as a way of supporting agro–food industry operations in Sub Saharan Africa.

Keywords: *Agro-food industries, logistics, management, supply chains*

1. Introduction

Agricultural food systems are rapidly being modernized worldwide. This changing nature of the agricultural food business environment creates new managerial challenges for agro-industrial firms, which can be met by the adoption of proven business management concepts. Logistic systems are one area where improvements in efficiency are known to contribute to the competitiveness of agro-industries.

Wide definitions and understanding of the term logistics do exist. According to Cooper et al. (1997) "Logistics is the part of a supply chain process that plans, implements and controls the efficient, effective flow and storage of goods, services and related information from the point-of-origin to the point-of-consumption. Furthermore, FAO (2007) noted that logistics includes customer service, transportation, storage, plant site selection, inventory control, order processing, distribution, procurement, material handling, return goods handling and demand forecasting. These definitions seem to fit well with the concept of food supply chain management. It is clear from the above that logistics forms an important input to the success of any agro–food industry and especially in developing countries where one is likely to encounter with a multitude of constraints along the food supply chain. However, despite its importance, poor logistic systems and management continues to significantly contribute to the poor performance of agro-industries in developing countries and especially in Africa. Furthermore, the information on the size of the problem and/or efforts to alleviate the problem especially at small and medium scale agro-processing industries is not readily available. Nevertheless, according to Mariani (2007) the concept of local food and sustainable logistics are the two key issues in assuring the sustainability of the whole food supply chain. Therefore, logistics need to be given highest consideration as one of the main factors which contribute to the success of any food supply chains.

2. Review Logistics and Logistics Management in Africa

Over the years agro-industry development in Africa has been characterized and dominated by unprocessed agricultural produces i.e. raw materials being exported to industrialized world in other continents such as Europe, America and Asia with China being one of the upcoming importers of agricultural produces from Africa. According to UN (2007), the export of the agricultural produces is concentrated in a few commodities namely coffee, tea, cocoa, sugar, cotton and bananas. It is only in recent years that the continent has seen new advancement in agricultural development which involves value addition of the non traditional agricultural produces to make high value food products. For example, the World Bank (2008) indicated that agro industry contribution to the total manufacturing in agriculture based countries is about 61%. This is a very significant percentage which calls for efforts to be made to ensure that the industry performs well. Crops such as fresh vegetables and cut flowers are increasingly becoming important trade commodities in Sub Saharan countries such as Kenya, Ethiopia and Zambia. Under such a situation, efficient logistics and a functioning logistical management are critical for a well functioning supply chain and eventually successful trade and business development around these crops. The logistic systems need to involve functioning infrastructure including transportation, better materials handling, park and storage houses just to mention but a few. Unfortunately, the cost of logistics and especially transportation has continued to be a burden to agro processors. According to the UNESC (2008) the logistics services built around transport processes are one of the fundamental parts of the supply chain which continue to pose main challenges in trading in Africa. It is therefore not surprising that some of the main difficulties that are associated with agro–food industry in Africa are associated also with poor infrastructure.

According to a study conducted in 24 countries in Africa to investigate the status of infrastructure, it was revealed that the poor state of infrastructure in the Sub Saharan Africa, ranks high among the factors that tend to affect the logistic efficiency in the continent (Foster and Briceno-Garmendia, 2010). It is not surprising therefore that, infrastructure is responsible for a cut of 2% in economic terms which is responsible for reducing productivity of firms by up to 40% **(**Yepes et al, 2008)**.** The importance of logistics is further emphasized by the World Bank (2008 where it was noted that weak infrastructure and institutions tend to contribute significantly to the high trade along the supply value chain in Sub Saharan countries.

3. Main Logistics constraints and challenges in Africa problems

While the level of the constraints and challenges that developing countries are experiencing with respect to the logistics and its efficiency differ from one country to the other, on the overall countries in Sub Saharan Africa are significantly constrained. Some of the important areas of logistics in which countries are constrained are discussed below.

3.1 Materials handling

As noted earlier, handling of materials such as of raw materials, finished products, spare parts and other consumables poses major challenges to small and medium scale agro processors. For Africa, materials handling poses a greater challenge to many agro-food processors due to the fact that many farmers are small scale in nature thus there is a need of consolidation of products in the process of delivering produces to the processing point or to the assembly point ready for export. The efficiency in the overall materials handling is constrained by the use of improper equipment and/or worn out equipment which include unsuitable packaging materials like bags. As a result, materials handling is costly, time consuming and tend to affect the final quality of the products.

3.2 Poor Infrastructure

Infrastructure still remains among the most important challenges as far as agro-food industry in Africa is concerned. According to USAID (2009) inadequate infrastructure has long constrained Africa's economic growth and competitiveness. Previous studies have shown that basic physical and organizational structures i.e. services and facilities which are necessary for the efficient operations of agro-processing industries are not readily available. The African countries are lagging behind their developing country peers in almost all of the infrastructure coverage (Foster, 2008). This is a serious setback to the success of agro-processing industry in Africa since the presence and support of the infrastructure as produces are transited from rural to urban is unavoidable. Also, the seasonality of crops coupled with perishability means that the impact of poor infrastructure can be devastating to the farmers and the involved entrepreneurs. In general, countries in Sub Saharan Africa are critically lacking the cold storage facilities, a situation that leads to considerable losses of perishable produces during transportation. The state of infrastructure which is generally inadequate and coupled with poor support services tend to contribute significantly to the post harvest losses that farmers incur.

Further, lack or poor infrastructure tends to affect the capability of small scale farmers and entrepreneurs to access markets. Also it is evident that the poor distribution networks in many countries tend to lead to high mismatch between demand and supply. This situation when coupled with poor marketing infrastructure lead to missed market opportunities and contribute significantly to such problems as post harvest losses like crops rotting on farm. Table 1 below shows the comparison of the status of some selected infrastructure in Sub-Saharan Africa as compared with other countries. It is clearly depicted from the table that on overall the infrastructure in Africa needs to be improved if it has to contribute positively to the growth of agro-processing industry.

Normalized units	**Sub-Saharan Africa**	**Other countries**
Paved road density	31	134
Total road density	137	211
Mainline Telephone density	10	78
Mobile Telephone density	55	76
Internet density	2	3
Generation capacity	37	326
Electricity coverage	16	41
Improved water	60	72
Improved sanitation	34	51

Source: Yepes and others 2008.

Table1. Comparison of selected infrastructure in Sub-Saharan Africa and those in other countries

(Key: Road density is kilometre per square kilometre; telephone density is in lines per thousands population; generation capacity is in megawatts per million population; electricity, water and sanitation coverage are in percentage of population).

The state of marketing infrastructure and marketing service are also highly constrained. Infrastructure such as storage and pack houses for perishable products is lacking. In cases where they exist they are in a state that requires urgent refurbishment.

3.3 Stock maintenance & control constraints

As mentioned earlier, the agro-food industry in many countries in Sub Saharan Africa is mainly at a small to medium scale level. In anticipation of many uncertainties, the operators of these industries tend to take measures which may reduce the risk of shutdowns due to logistical related problems. For example, poor transportation is likely to lead to a delayed delivery of goods to the factory making it difficult for the agro-processing industry operators to plan and execute an efficient stock control plans. It is due to these logistics problems that agro-food industries opt to keep large stocks of materials such as packaging in anticipation of the future scarcities and uncertainty of the availability of the required stock. Such overstocking presents a problem as space is not always available to accommodate the extra goods hence leading to products deteriorations. Also, if more stock is kept at the plant it means that cash is being tied instead of being utilized for other productive activities. This tends to affect the overall performance of the agro-industry.

3.4 Packaging Materials

The packaging manufacturing and supply industry is not well developed in many countries in Sub Saharan Africa. Most of the packaging materials used in Sub Saharan countries are imported from other countries. This poses a logistical challenge to many small and medium scale enterprises as far as acquisition of right type and amount of packaging materials is concerned. For many agro-processing companies in SSA, the acquisition of the packaging materials at the right time and in the right quantity and quality is one of the main logistical challenges especially for the small scale operations. Logistically, purchasing the packaging materials load tends to pose the following challenges. For many small and medium scale agro-industries packaging materials such as containers and labels are purchased in bulk large quantities to compensate for the time of scarcity. In turn, the storage of these packaging materials also tends to pose another challenge to agro-industries as huge stocks tend to require huge amount of space. This problem of packaging is evidenced by the field experience from Tanzania (Box 1) whereby entrepreneurs explain their situation and some of the measures that they take to alleviate the situation.

Box 1. Challenges facing entrepreneurs in acquiring packaging materials.

Examples of cases showing the challenges and missed opportunities caused by logistics related problems that lead to unavailability of packaging materials among the small scale producers in Africa is explained in the two examples below which depict the experience of two entrepreneurs. Metrochem which is a small scale company based in Mwanza, Tanzania dealing with processing of tomato and chilli sauces and Eliesh Products which is a small scale company involved in wine production.
Metrochem: "The source of packaging materials for our tomato and chili sauces is Nairobi in Kenya. It is cheaper to source from Nairobi in Kenya even when transport cost is added as compared to sourcing from Dar es Salaam or Arusha. I wish there was a supplier from Mwanza" Lucas Kasulende, Managing Director, Metrochem Industries, Mwanza, Tanzania.

Eliesh products: "We recycle used Heineken bottles and used imported wine bottles for packing wine. Sourcing from local suppliers is not possible because they ask for large orders. I have orders to supply wine in Kenya, but I cannot supply because of lack of packaging materials" Lilian Charles Koko, Eliesh Products, Mara Tanzania.

Source: MMA(2009)

3.5 Underdeveloped cold chain

Africa produces huge amounts of fresh produces which makes it necessary to have well developed cold chain facilities. Unfortunately these facilities are lacking in SSA. This situation has brought about a huge challenge requiring effective logistic systems associated with well operating and maintained cold chains for achieving a safe delivery of goods to customers. Even in cases where the cold chain is in place, still the challenge is how to maintain the equipment which are in most cases old and few and also on how to link this service with other important services such as warehousing and storage facilities. In most cases such connectivity is lacking and this poses a danger of total loss of the perishable produces and contributes to the loss of lucrative business opportunities which if won, could have brought back a much needed income to the agro processors. While the lack of funds to be invested in upgrading the cold chain facilities is one of the main stumbling blocks, the issue of trained personnel is another constraint. Furthermore, the maintenance of the cold chain equipment is also constrained by lack of good maintenance plans to link needs for maintenance of the equipment in the field and the stock of spare parts that is kept at the plant.

3.6 Power supply

The availability of power supply has continued to be a major constraint in many countries in Africa hindering the development of agro processing industry for produces which are highly perishable. According to Foster and Breno-Garmedia (2009), power supply is another important challenge as far as logistics is concerned. This is not surprising given the fact that the available data shows that Africa generates only about 37 megawatts per million people as compared to the average of 326 megawatts per million people in other countries (Yepes et al., 2008). Unfortunately, with the current level of power generation it means that African countries will continue to suffer problems of power cuts for a considerable foreseeable future. Also, dependency on power generation from hydroelectric power plants mean that during the period of poor rainfall or drought power generation becomes affected as well. In addition to power generation, the power transmission and supply infrastructure need also a face lift as most of the current systems are old and functions intermittently leading to loss of power during transmission.

3.7 Information Technology (IT)

According to Azevedo et al (2007) logistics information and communication are important inputs for firms to have competitive advantage over their competitors. The IT services are very critical for developing countries in facing challenges associated with development of well functioning logistic systems. However, IT is one area which is faced with a lot of challenges. In the current developments in the world supply chains, it is critical for the actual information on the status of goods and services to be communicated in two way traffic between the origin and the intended final destination as well as with the key players along the whole chain. This has to be done in real time for it to be effective. Information Technology is also closely linked to the inventory of crop produces by ensuring that stocks are kept to such levels that there is no over stocking and firms don't run a risk of loosing customers due to unavailability of goods. While there have been some efforts in countries like Tanzania to establish crop markets with good facilities to serve farmers and entrepreneurs such as Kibaigwa Grain Market in Kongwa district in Dodoma region, such efforts need to go hand in hand with IT facilities to facilitate communication. However, while such efforts are welcome as a move in the right direction, such markets are yet to attain their full potential partly because IT is not fully in place to ensure that the market stakeholders such as buyers and famers communicate efficiently with the buyers in far cities such as in Dar es Salaam. Africa still lacks most of the IT hardware and in addition to that the new innovative technologies such as satellite technologies, which could enable key stakeholders in the value chain to remain in constant communication is generally lacking. Also technologies such as the electronic data interchange, artificial intelligence, bar coding and scanning are still not common in many parts of Sub Saharan African countries.

3.8 Transportation of agricultural products

Transportation is another main challenge as far as logistic is concerned in the countries in Sub Saharan Africa. According to UNESC (2008) food logistics are built around transport processes and include warehousing, stock management and related activities. However, despite its importance, the transport sector which has a critical role to play in the efficient logistics operations mainly with respects to distribution of agricultural products, processed products and other materials associated with agro-industries is in bad states in many countries. Also, the railway systems which have potential of relieving pressure from the road transportation system is also faced with many challenges. It is common to see old trucks being used to transport agricultural produces in Sub Saharan Africa. These trucks are uneconomical due to the high truck downtime that reduce services reliability and increases fuel inefficiencies. They also have high maintenance cost and environment pollution. The road networks from the farms where agricultural produces originate from as they are being transported to the markets in urban centres are also relatively poorly developed. This leads to a number of problems that farmers have to face including high damage to the crops that are being transported thus reducing the quality and contributing to the food losses that farmers and transporters incur. Furthermore, in many cases distances involved are long which tend to impact the quality of produces. Under such circumstances, appropriate transport infrastructure including proper roads becomes of high importance.

4. What needs to be done?

The role of the governments in enhancing the current status of logistics in Africa and especially in developing infrastructure is very critical to the development of agro-industries. The governments still have a key role to play here although there is a potential to involve the private sector through the public private partnership initiatives. It is evident that there is a need for more willingness and support to be put on the efforts to develop infrastructure improvement; this should go hand in hand with the improvement of the equally important logistics such as the use of ICT. Also, training of logistics personnel is important in the improvement of the current status of logistics in agro industry. On overall in order to enhance its contribution to a better performance of the industry the following actions are suggested:

(i) There is a need to improve the local infrastructure with emphasis on developing better connections to the markets. More emphasis and efforts needs to be put towards transportation (roads, rails, marine and air freight) in order to improve the storage, packaging and handling systems, retail facilities, information technology, and overall supply chains.

(ii) The improvement of transportation with aim of enhancing the performance of the marketing systems should include the improvement of the feeder roads. Improvement of transport should be given emphasis and priority by the government.

(iii) Improvement of packing and storage facilities is necessary so that they are well linked with other infrastructure storage facilities and practices in such a way that storage capacity of pack house and storage houses that are proportional to the capacity of transportation system are able to accommodate in good condition the goods being stored.

(iv) Increase logistical support towards improving infrastructure that may transform the crops to a more stable state better stores and better storage practices (handling) through such initiatives as improved market infrastructure?

(v) Improve the local logistics systems in addition to the local infrastructure: Material handling, warehousing and stores

(vi) Support agro-industries to develop a better stock control practices. This may be done by supporting such industries in getting access to suppliers of packaging materials as well as through improving the transport system including developing good feeder roads. A well communication system would also lead to a better stock control

(viii) It is important also to improve information technology by supporting access to both hardware and software. The governments have a role to play in making sure that agro-industries are supported to get access to the IT facilities.

5. Future FAO support on logistics matters

The Rural Infrastructure and Agro-Industries Division (AGS) advocates and supports the development of entrepreneurship in agricultural support services including support of supply chain management. The Division aims to assist farms and agribusinesses in developing managerial and technical skills for supporting production, post-harvest, infrastructural, marketing and financial operations related to developing and improving efficiency, effectiveness, competitiveness, and profitability of agricultural and food enterprises. The Division is also putting emphasis on supporting FAO members in improving logistics with the aim o enhancing the performance of agro-industries. Some of the activities that the division through the Agro-Industries Group is engaged on as far as logistics is concerned are discussed below.

5.1 Appraisal of the logistics management in agro-industries in Africa

An in-depth understanding of the knowledge, attitude and practices of agro-food processors in Africa on logistics is crucial in providing support to small and medium scale entrepreneurs. Therefore FAO intends to carry out an appraisal, collecting information on the existing practices, challenges and opportunities in Small and Medium Agribusiness Enterprises (SMAEs) as far as logistics management is concerned. This will help to determine the dimensions of logistic management problems and therefore be able to design appropriate interventions. The agro-food industry sectors to be covered would include food commodities mainly grains, fresh foods and cold stored products such as milk and meat. The study is expected to cover key stakeholders such as; Modern retailers, food services industry, large transport & distribution companies and agro-food processors. The gathered information would then be used in developing and implementing appropriate interventions on logistics. The main activities to be undertaken by a consultant during the scoping study would include:

(i) Review of the existing research literature including existing data and reports on logistics management

(ii) Field work which will involve stock taking of the current practices and identifying problems and challenges in logistics management within the agro-industries.

(iii) Exploration and appraisal of the performance of the private sector in logistic management in the field and identification of the best practices that may be used in agro-food industry.

(iv) Provision of concrete recommendations on how to improve logistics management in agro-food industry sector especially in the developing countries in Afrca.

5.2 Preparation of publications to support logistics

FAO recognizes that many managers and operators of agro-food industries are still unaware of the relevant concepts and the potential benefits of efficient logistical systems. Moreover, whereas the technical literature on logistics is quite extensive, materials dealing with the specific needs of agro-industries, especially at small and medium scale levels, are still few. One of the areas that FAO is working on is preparation of a practical publication on logistics that is aimed at presenting the essential concepts of logistical management and highlighting issues of relevance within the context of modern agro-food systems. The aim of this practical publication is to present the essential concepts of logistical management and to highlight issues of relevance within the context of modern agri-food systems in order to contribute to managerial improvement processes in the agro-industrial sector, particularly for the small and medium scale enterprises in developing countries. This work has already been initiated at AGS and on its completion the publication would contribute to managerial improvement processes in the agro industry sector, particularly for small and medium scale enterprises in developing countries. The publication will also complement the information provided by FAO in such discipline as value addition and agribusiness management as an introductory reference on agro-industrial logistics concepts and applications. This introductory text on agro-industrial logistics concepts and applications will target managers of small and medium scale agro processing operations in developing countries.

6. Conclusion

The contribution of agriculture to national economies would be significantly enhanced if proper logistic systems are put in place. Improved logistical systems will help to create a smooth movement of crops, leading to timely delivery of the produces to the market and in a good state. African countries need to improve the logistic services including all the administrative matters associated with it, so as to create good working environment for the supply chain for agricultural produces and products. As the Sub Saharan Africa countries embark on economical programs they need to ensure that logistical support to agricultural industries is integrated in those programs. Efforts need to be made to ensure that all important components of logistics system are in place. Strategies needs to be in place to develop and update the logistics system to in Africa. Such initiatives as involving the private sector through the public-private partnerships need to be encouraged.

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Counterfeiting in Italian high-end wine business: outcomes from a survey based research

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Abstract

Purpose: To highlight current perception level of counterfeiting phenomenon in the high-end wine industry and point out current knowledge of anti-counterfeiting methods/ methodologies/ technologies among producers.

Design/ Methodology/ Approach: the research work analyses the outcomes of an on-going survey submitted to more than 200 Italian companies operating globally in high-end wine business.

Findings: at the current stage of the research just a few companies completed the survey, thus a synthetic overview of the results could be easily reverted.

Research Limitations/ Implications: The findings of such a research work are limited to what available to the authors in terms of companies and business dynamics knowledge. Moreover the outcomes are directly linked to the methodology used in the survey and to its form. These implies that different sources of information, background or territorial peculiarities as well as another form of investigation could lead to different conclusions.

Practical Implications: The research outcomes will help researchers and practitioners to gain a deep understanding of the perception of counterfeiting problem among high-end wine producers versus the real size of the problem.

Originality/ Value: The value and originality of this paper resides in its ability to formalize through a scientific methodology the difference between perception and reality of a problem that could have significant consequences from both economical and health stand points.

Keywords: *Wine business, Counterfeiting, Survey, Perception, Made in Italy*

1. Introduction

Counterfeiting intended as a precise and self-standing issue in academic investigation practices has earned increasing importance from 80's; nowadays such a research matter gained impressive interest starting from years 2000 as shown in Fig. 1.

Importance of counterfeiting for Food & Beverage (F&B) industry resides mainly in the interest for fighting health-hazards that it may cause to consumers even if, in the last years, business-related topics have moved researchers in understanding issue's dynamics. F&B is a huge industry in terms of both generated turnover and number of people employed: from a recent report global market dimension has been worth more than 3.8 $ trillion being a stable working place for more than 22 million employees (Deloitte, 2010).
Europe can be considered the greatest market (29,8% of the total), even if the overall growth rate (+3% CAGR) has basically due to globalization and emerging countries contribution, and this can be considered the reason why the largest part of counterfeit F&B goods have been marketed within the EU boundaries. According to the Counterfeiting Intelligence Bureau (2006) the economic damage that the phenomenon causes to the industry could be worth 370 $ billion, the 9,5-10% of the overall yearly industry turnover; out of this, more than 42% (in value) of the counterfeit products are produced in Far East countries and marketed in the European Countries, while the 13% produced in Europe remain in the EU market, leading to representing EU as the greatest market form counterfeit F&B products with more than 55% of the total (Nicoletti et al., 2007).

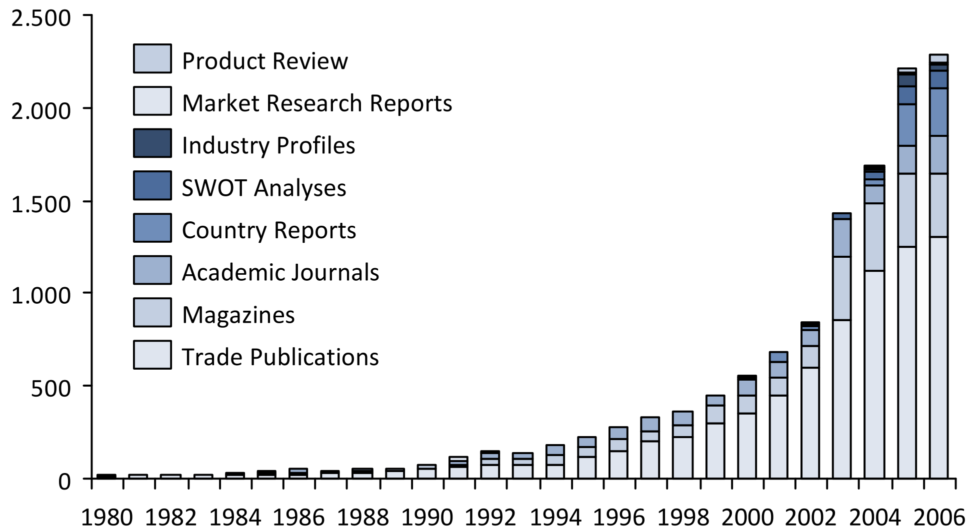

Fig. 1 - Counterfeiting-related publications in academic and practitioners journals, 1980-2006. Source EBSCO host Business Source Premier

According to FederAlimentare (2011), the Italian F&B industry Association, in a EU F&B market worth more than 1€ trillion, the Italian market (124 € billion in 2010, +3,3% on 2009) - the third in terms of generated revenues– suffers a loss of more than 60 € billion due to both pure counterfeiting (6 € billion) and *Italian Sounding* phenomenon (54 € billion). This means that counterfeiting of Italian products represents almost one sixth of the global F&B phenomenon value.

In this environment, wine business represents one of the most damaged industry for both Italian (17% of the overall F&B production) and EU (28% of the overall wine production) economies (Osservatorio MPS for MPS Wine Index). According to FederAlimentare Italian wine business, that can be worth 13,5 € billion (3,7 € billion export), suffer of a 2 € billion counterfeiting loss in revenues, resulting in about the 14,8% of the total and more than 50% of the total export value: out of this, more than 830 € million are generated within United States (41%) while Asian markets are estimated as able to receive more than 25% of the total counterfeit Italian wine by 2013 (Coldiretti, 2009).
Despite an average wholesale price per bottle of 1,85 €, about 60% represents the share of "Guarantee of Origin" wine segment marketed abroad with an extra price, making the mid-high end segment the perfect target for counterfeiting practices (Food and Beverage, 2010).

In this scenario, the main aim of the research work behind this paper is to understand and present the current level of perception about counterfeiting phenomenon among high-end wine producers in Italy, the second country for global wine export and production. Moreover we aimed at analysing - among Italian producers - the diffusion and knowledge of techniques/ technologies that could alleviate such a problem or at least reduce counterfeiting opportunities.
This way, we intended to provide a starting point for both researcher community/ practitioners to develop further research projects toward wine products authenticity warranty and authorities/ government bodies to promote awareness campaigns and actions in order to protect one of the most widely recognized Made in Italy pillar.

2. Research Methodology and Boundaries

In this section we want to provide a brief summary of the methodology herein adopted.
The research work presented belongs to empirical research branch; data gathering is based on a survey design and submission to a clearly defined sample of subjects, i.e. Italian-based mid-high end wine producers.
Outcomes, that at the moment of writing could be considered really preliminary and partial, have been evaluated thanks to basic synthesis and analysis instruments/ tools and techniques. At the end of the responses collection phase, overall results will be published.

Before proceeding to present the work we want briefly define boundaries the research moved within.
Counterfeiting treated herein could be defined as "trade in goods that bear without authorization a reference to a brand, manufacturer, organization that warrants for the quality, standard, conformity of the good that rightfully uses this reference" (Staake et al. 2009). In addition, it:

- covers unauthorized use of brand names characteristic colors and shapes;
- includes illicit use of control stamps and marks of conformity; and
- excludes illicit activities such as bootlegging or trade in stolen products.

Finally, counterfeiting as intended in the present work, deals with deceptive physical goods, thus goods marketed with the fraudulent aim to be misled at the consumer's eyes.

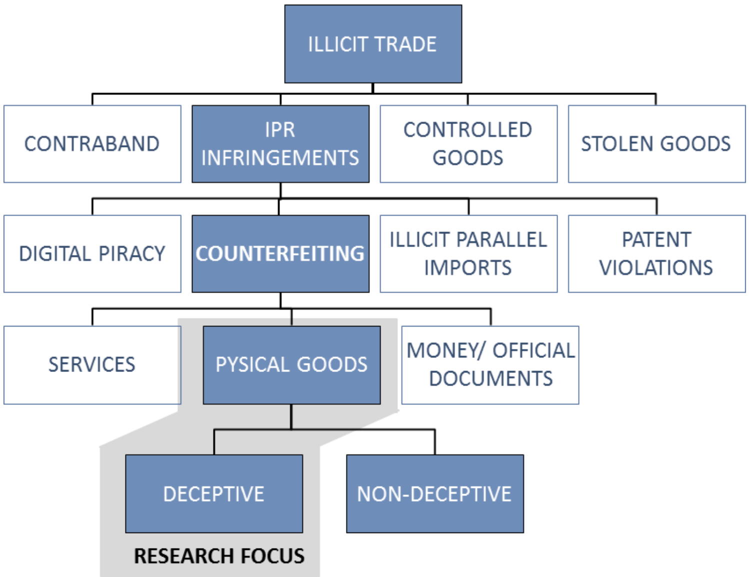

Fig. 2 - Definition of counterfeit product used in the present research

As widely known, counterfeiting could lead to two different kinds of consequences:

- *Health Hazard,* including cased of decreased nutritional value, antibiotic resistant bacteria, allergic reactions, cardiovascular complications, cancer-causing food consumption, death, … (Emberlin et al, 1999; Mace, 2008; Jackson LS., 2009); and
- *Business-related,* such as loss in potential revenues/ profit/ MS, loss in Brand Value, investments decreasing, waterfall internal consequences (workplaces reduction, …), waterfall satellite companies consequences, … (Chaudhry PE., 2009; Avery, 2008; Gessler, C. 2009; Bai J.B. et al, 2007).

In the present research work we focused mainly on business related effects of counterfeiting mainly to understand the perception of loss in potential revenues or profit and of decrease in Brand Value, often intended not as the specific label value but as the geographic origin brand (e.g. Brunello di Montalcino, Barolo, …).

This way, the survey has been composed by four parts. In the first part, general information regarding the company has been inquired, while the second part deals with the companies sensitivity to the counterfeiting problem. In this part, we have posed questions about the influence of counterfeiting in both the overall wine business and in own companies. The third part deals with processes and tools adopted in the companies which regards the product quality. Finally, the last section deals with the knowledge and the adoption of methods and tools to prevent the counterfeiting phenomenon in the company. This way, the last part of the questionnaire ask if the companies know and/or adopt methods regarding the product traceability (i.e. barcode, QR code, RFId, etc..) and the product authenticity (i.e. Mass spectrometry, Infrared Spectroscopy etc..).

3. Survey population

The survey design process has been tailored on characteristics generally owned by companies we wanted to analyze; in particular, the survey targeted small-medium enterprises (SMEs) with annual revenues lower than 20 € million, a good percentage of export (more than 20%) on total turnover, an appellation of origin consortium with a strict disciplinary, and an average price per bottle that could position such companies in the mid-high end segment (not luxury or auction wines).

Thanks to the support of some consortia (e.g. Consorzio Chianti Classico, Consorzio del Vino Brunello di Montalcino, Consorzio Vini di Bolgheri, Consorzio Tutela Barolo - Barbaresco - Alba Langhe e Roero, Consorzio dell'Asti D.O.C.G.) we submitted the survey to more than 200 companies along Italy, without a particular geographic clustering as shown in Fig. 3, but with extra Italy distribution channels.

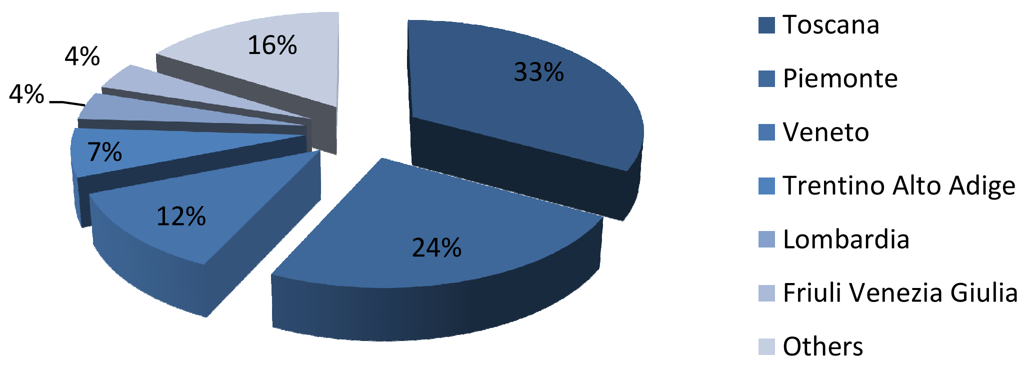

Fig. 3 - Geographic distribution of the 200+ wine producers companies

Getting a closer look at those companies whose financial information are publicly available (some of them are classified as cooperative entities and, thus, not obliged to make public their financial statements according to Italian law) we can provide some interest insights:

- Average number of employees: 27 (ranging from 0 for family running companies to 122)
- Average revenues (2010): 6,54 € million (ranging from 0,25 to 23,45 € million)
- Average EBITDA (2010): 0,48 € million, 7,2% on revenues

4. Profile of Survey Respondents

As wrote above, the survey is composed by four parts. In the first part, general information regarding the companies have been requested. As shown in Fig. 4, the sample of the analyzed companies is composed by 20 companies, with the majority of them localized in the Piemonte and Tuscany regions. Even if the sample is different from the population described in Fig. 3., authors opinion is that most of the conclusion that will be described in this paper can be extended to all the proposed population.

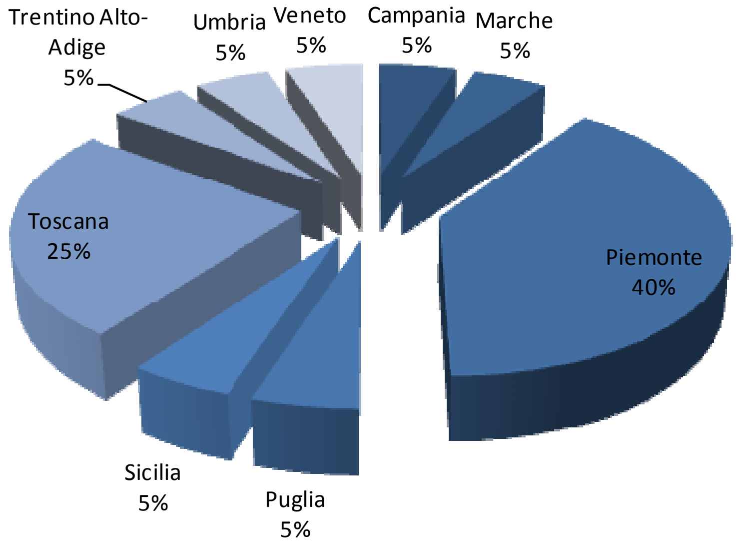

Fig. 4 - Geographical distribution of the surveyed companies

Regarding the companies dimension, Fig. 5 shows that the majority of the companies has a number of employees lower than 15 units, while the majority of the company has a turnover ranging between 1 and 7 € Million.

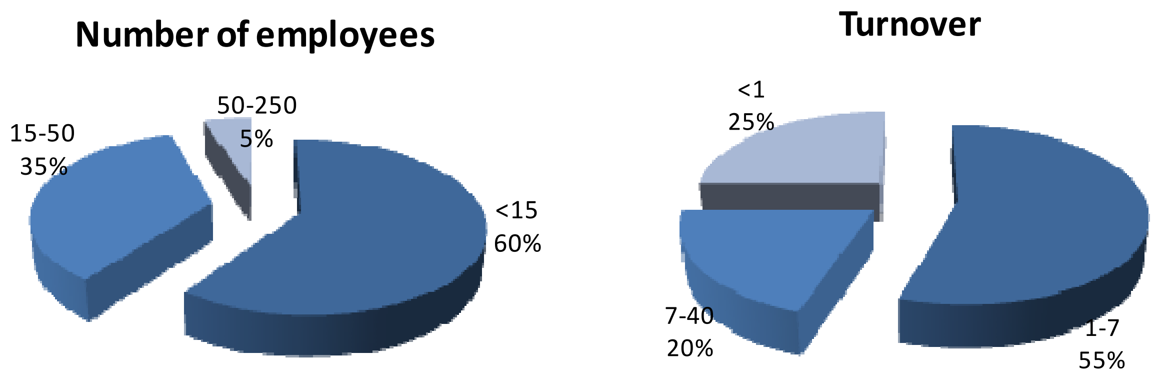

Fig. 5 - Respondents clustered by numer of employees and turnover bunch

Starting from such companies clusters, the survey focused on the classification of the product marketed by the those companies, in order to understand whether could be a relationship between the type of the produced product and the knowledge and/or adoption of methods and tools to prevent the counterfeiting phenomenon.

Our respondents cluster is composed by companies that produce for the 80% table wine priced less than 15 euro per bottle for the 40%, and between 15 and 30 euro per bottle for another 32%. Lower percentage position wines priced between 30 and 50 euro (16%) ore over 70 euro per bottle (12%). Further information can be find in Fig. 6.

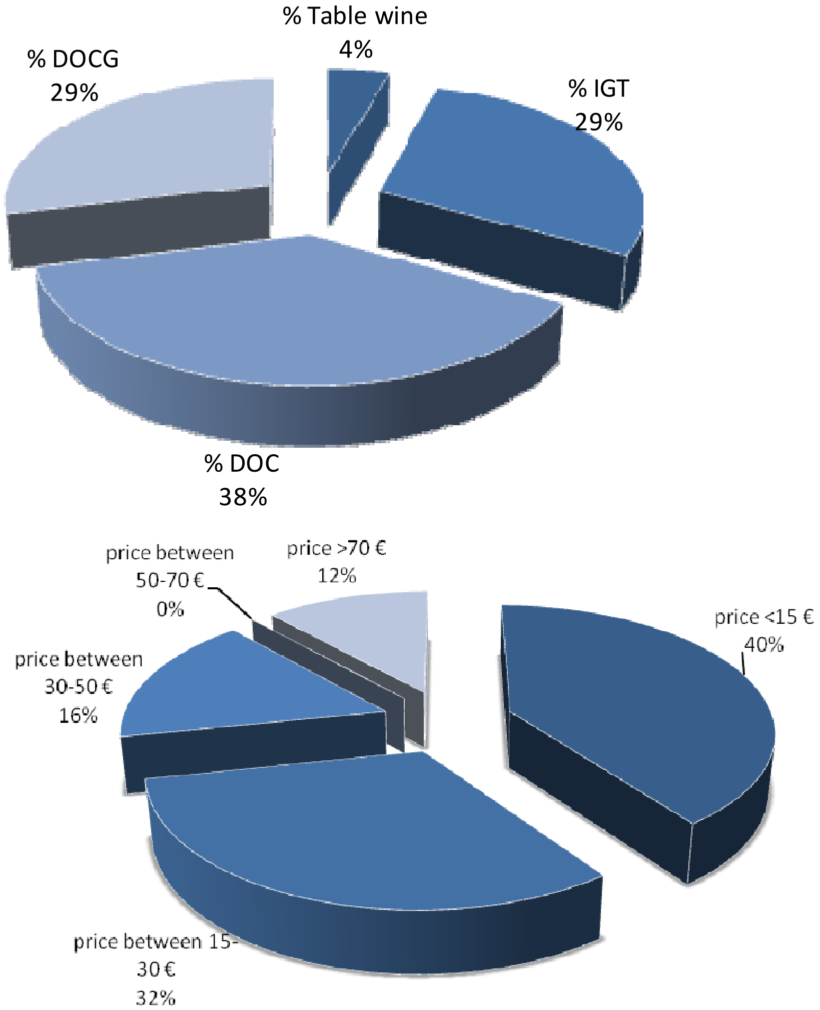

Fig. 6 – Respondents companies clustered by bottles price segments

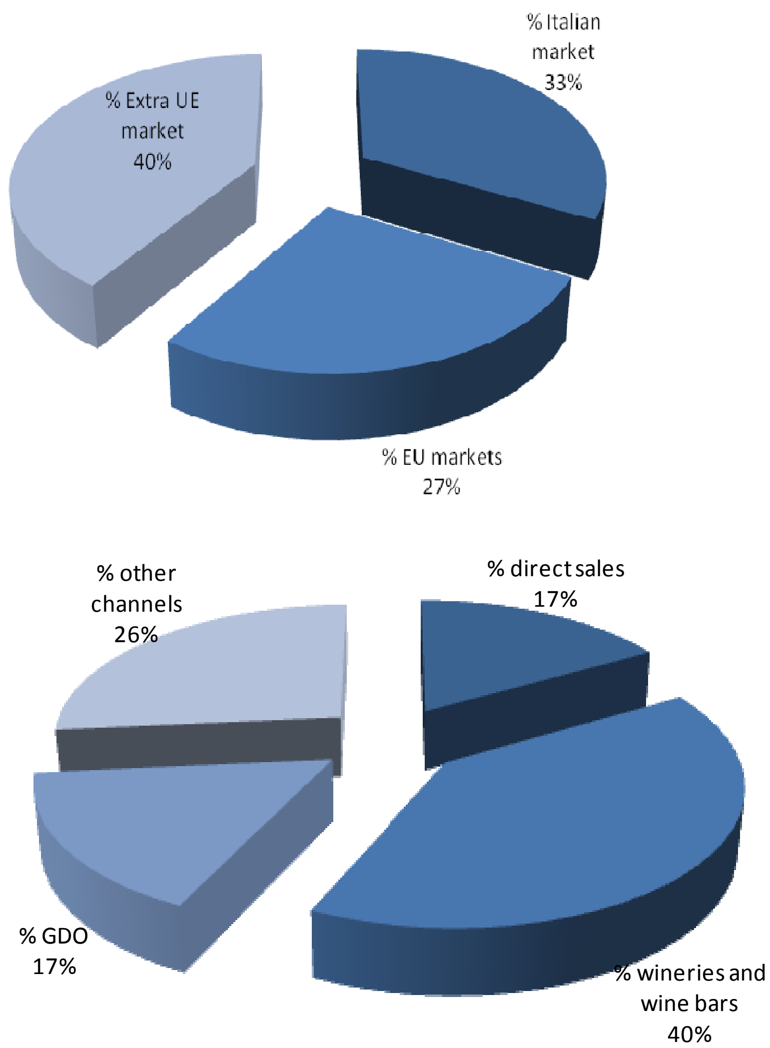

Fig. 7 - Overall market distribution for the respondents companies

Going further in the analysis of the survey results, surveyed companies sell their products for the 33% in the Italian market, while for the 27% in the EU markets, and for the residual 40% in the non UE markets (mainly U.S., Asian and Australian Markets). Most of the product (40%) is distributed through wineries and wine bar, while other distribution channels are GDO and direct sales worth each one for the 17% of the total volume distributed. The last 26% of the product is sold through other channels.

5. Main Survey Outcomes Analysis

Going deeper in the analysis of the results, it is interesting to evaluate the perception of the companies regarding the influence of counterfeiting phenomenon in the market and within the company itself.

Fig. 8 shows a very interesting piece of information, which in part can justify the low percentage of methods and tools adopted to prevent the counterfeiting problem by the company. While the perception of the phenomenon of counterfeiting in the market is generally correct (the real value is near to the 15% of the turnover), more than the 60% of the surveyed companies points out that the incidence of the counterfeiting phenomenon in their company impacts for less than the 5% of the turnover. This fact shows that most of the companies underestimate the phenomenon inside the company, and they think that even if the problem exist, this does not affect their companies.

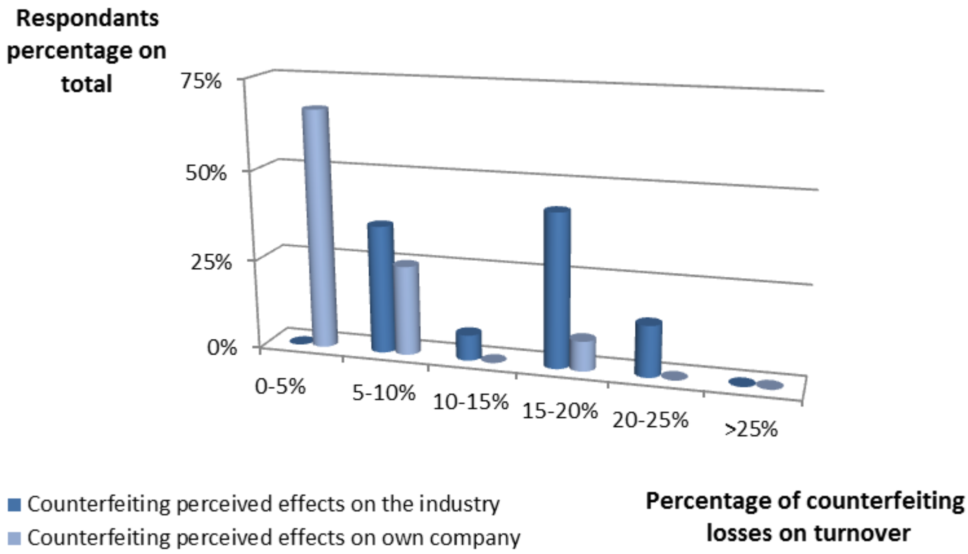

Fig. 8 – Counterfeiting perception among producers on own companies vs. overall industry

Once understood the counterfeiting phenomenon perception level among producers, we wanted to going in depth to analyze why producers were so sure that their own wine are not affected by the problem. Our main hypotheses was linked to a certain kind of control both on the product and on the logistics/ supply chain network that could in some way make producers convinced that their own product was free from counterfeiting risks.
In the Fig. 9, it's crystal clear that the great majority of producers do not perform controls on wine externally. In fact, only the 40% of them believe that external controls could reduce product counterfeiting effects. Moreover, the 20% of producers that perform some kind of wines control seem to be pushed by the consortium it belongs to; in some way we can claim that general thought among producers could be synthetized in describing counterfeiting as an important factor affecting the business but for what it may concern to their own productions it is not relevant, to the point that only 20% of the respondents is available to pay an external private body to carry out controls on their own products.

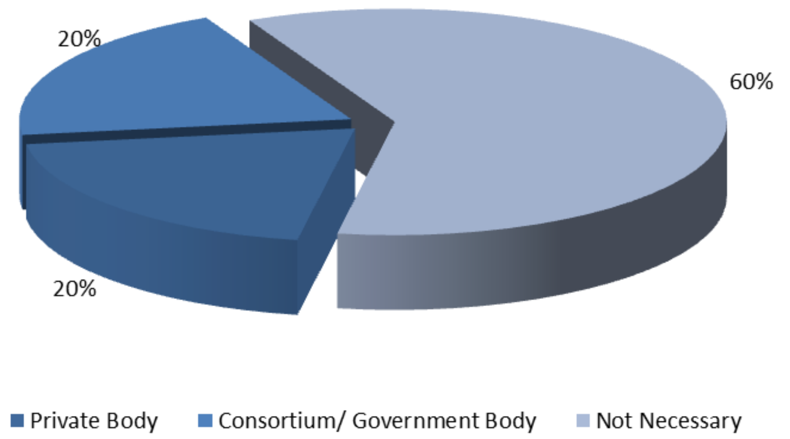

Fig. 9 – External anti-counterfeiting controls performed by producers, breakdown by kind of involved bodies

The reasons underlying this behavior resides probably in a lack in understanding of the "lost earning" concept. Most of the producers seem not to see the counterfeiting effects on their own productions until they are not capable of selling the normal share of production that are used to. In addition to that, they are deeply convinced that the major needs of external controls are needed in the wine-making process, as shown in Fig. 10 and in Fig. 11 while, instead, most of the counterfeiting opportunities arise in the bottling and distribution processes.

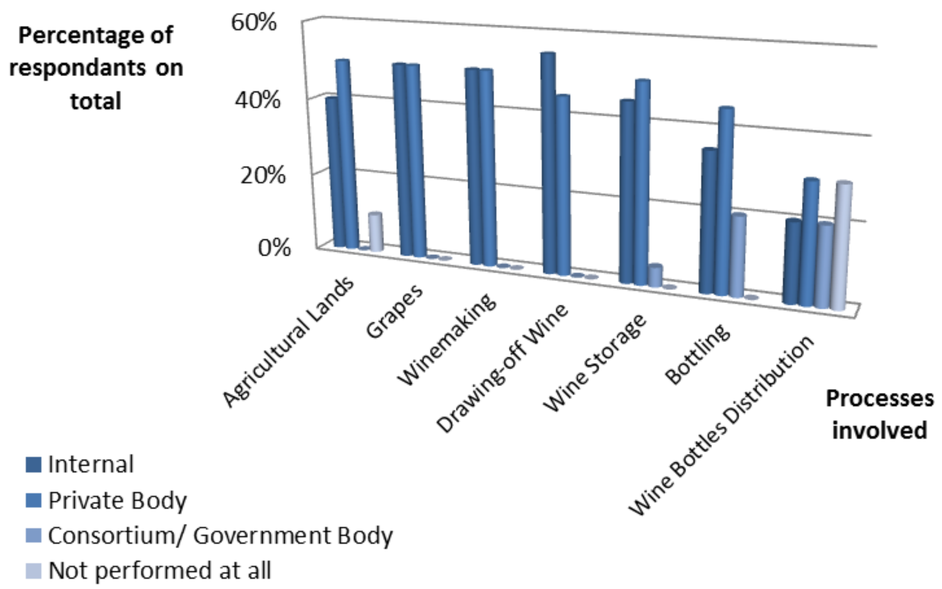

Fig. 10 – Anti-counterfeiting controls performed by process, breakdown by bodies involved

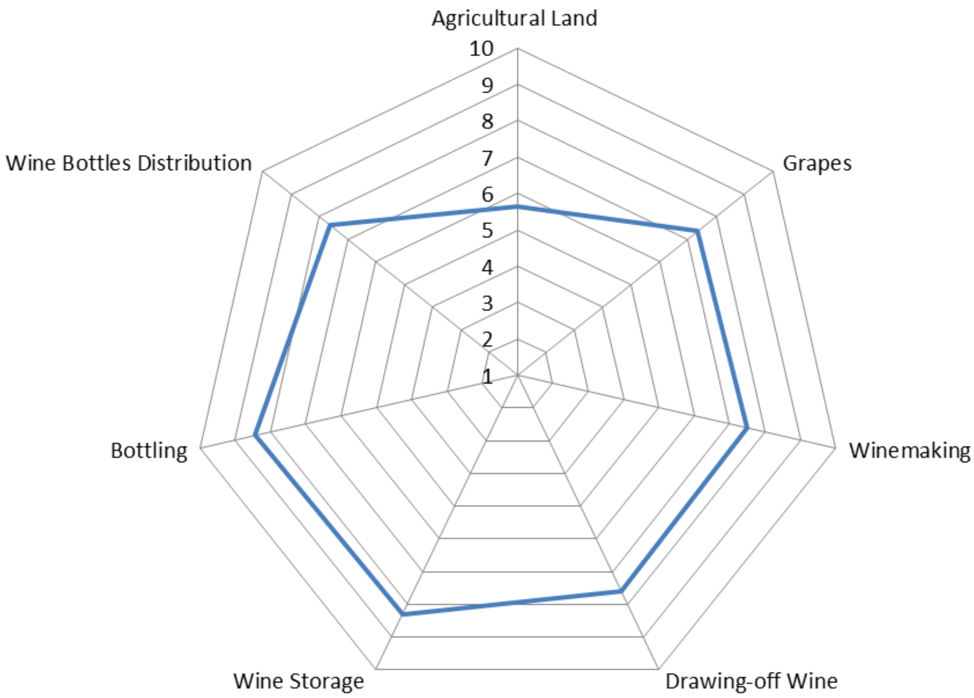

Fig. 11 – Average criticality analysis per process

This outcomes make us point out some interesting conclusions:

(1) producers are generally aware of the overall phenomenon dimension but they tend to underestimate counterfeiting effect in their own reality because they are generally linked to measure such consequences on the share of production they are usually able to sell, thus not considering at all the option to sell a greater percentage vs. normal (just rarely it reaches the ninety-something percent) or changing the sales channel mix proportions;
(2) they believe that counterfeiting is mainly driven by direct competitors intended as producers that illicitly put into the market a externally equivalent product with fake content inside without respect for the fact that the large majority of counterfeit wine comes to markets from abroad (Beverfood, 2011): in fact they perceived as most critical processes those where content control is generally demanded to producers themselves; and
(3) they tend to underestimate the consequences of brand loss in value, intended as the loss experienced by an appellation of origin due to counterfeiting, that directly could affect their own activities.

Going further in the analysis appears clear how important could be find anti-counterfeiting solutions that at the same time could fight counterfeiting of both content and bottle. For this reason we tried to measure which technological instruments are the most known and used with an anti-counterfeiting scope and in doing this we clearly divide methods in those referred to bottles (packaging) and to content.

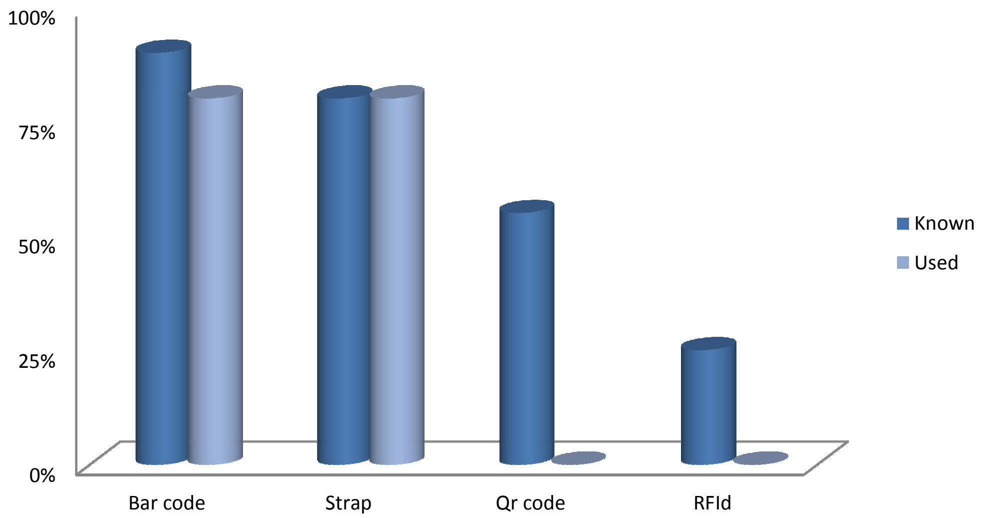

Fig. 12 – Mostly used track and tracing technologies for bottles, percentage of known vs. used by respondents

As shown in Fig. 12, there is a well widespread knowledge of a variety of technology means that can be used even in anti-counterfeiting way but, from overall comments, we can infer that such methods are generally used because required by external bodies; in particular, we could deepen that barcodes are required for Distribution or Logistics systems/ application (e.g. Retail), while straps are imposed by consortia. None of the respondents uses deliberately other paid not imposed technological instruments to reduce risks of package counterfeiting because of the not-significant risk level perceived for own companies.
Also taking into account technologies that could help in fight counterfeiting of wine intended as the liquid contained in the bottle itself, surveyed companies demonstrated a good knowledge but a scarce tendency to use them especially when not driven by regulation or consortia disciplinary strictness (Fig. 13).

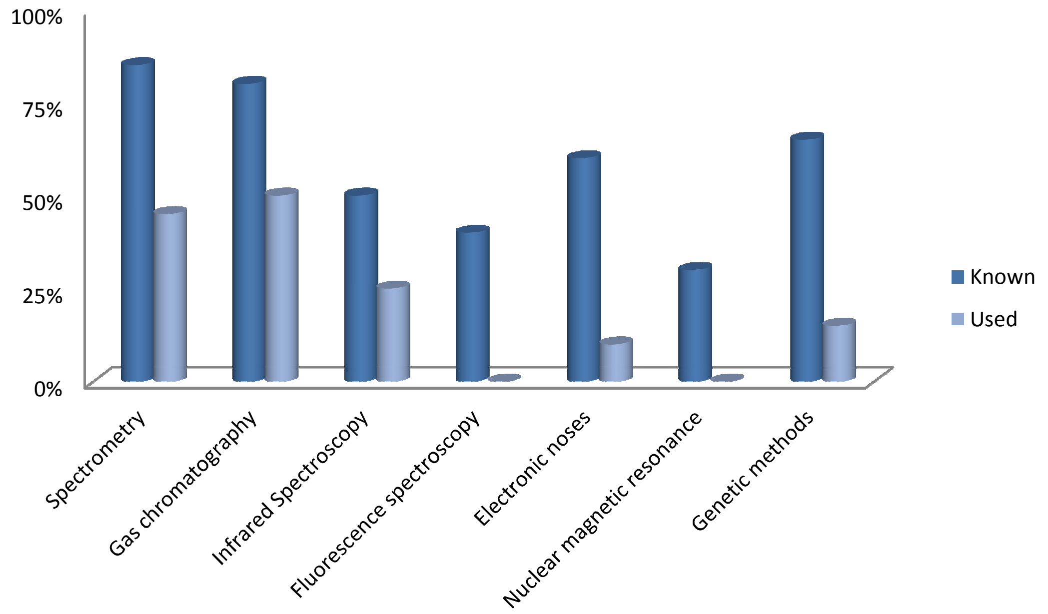

Fig. 13 - Mostly used content mapping technologies, percentage of known vs. used by respondents

The last dimension we wanted to investigate was related to the availability to invest in technologies able to prevent or fight counterfeiting. As shown in Fig. 14, just a few of the respondents is available to invest something: only the 40% more than 1% of their total annual revenues, while only the 10% more than 5% on total revenues.

This shows again how the overall dimension of the phenomenon is generally correctly estimated but totally underestimated when referred to own companies, leading to point out how poor communication on counterfeiting tends to reduce wine producers' commitment in fight this issue especially when benchmarked to other industries where even with a lower impact on the overall business manufacturers are more available to invest to fight it (e.g. Fashion & Luxury Goods where counterfeiting does not reach 10% on overall turnover, while companies are available to invest more than 10% to fight it and taking advantage on competitors at customers' eyes).

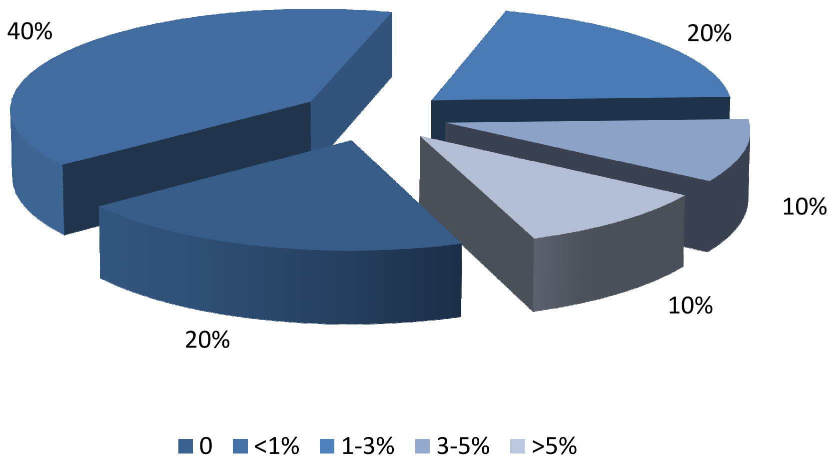

Fig. 14 – Producers' availability in investing in anti-counterfeiting, breakdown by percentage on revenues

6. Conclusions

In this paper we have presented a brief analysis of partial outcomes of a survey-based research on the topics of mid- high end wines counterfeiting phenomenon in the Italian market, the second for production and export in the global scenario.
Main aims of such a research is understanding the current level of perception about the counterfeiting phenomenon among producers and actual knowledge and use of technologies/ instruments for preventing and/ or limiting effects that such illegal practice is proved to cause to the industry.

In doing this we have selected a sample of more of 200 Italy based companies operating in wine production generally SMEs (i.e. with total annual revenues lower than 20 € million), with a significant percentage of revenues coming from Extra Italy countries (counterfeiting of Italian F&B products arise above all abroad), an appellation of origin with a strict disciplinary and an average price per bottle that could position them in the mid-high end segment while avoiding luxury or auction wines producers.

First responses collection showed interesting outcomes basically groupable in three insights:

1. Producers are quite well informed about the overall phenomenon and its impact on Italian business; nevertheless they tend to underestimate the phenomenon in their own companies due to (i) general belief that fraudulent acts are , in most cases, put in place by their direct competitors, thus other producers of their own consortium putting into the market a larger quantity of products than available (or permitted),

generally contaminated; (ii) loss in the value of the brand, intended as appellation of origin brand, cannot affect single label business performance, while most of counterfeiting cases report not a specific label imitation while an abuse in the appellation of origin brand; and (iii) producers tend to evaluate negative effects of counterfeiting based on the difference in sales with respect of the share of generally sold, completely avoiding the lost earning notion.

2. Interviewed companies are deeply convinced that internal controls that they perform are the perfect warranty that their own product is authentic and not counterfeit, not accepting at all the cases of wrong product mixes or not voluntary contamination; at the same time they declare that external bodies controls are not acceptable for activities they traditionally perform or want to continue to perform, but at the same time they could be useful for others unfair producers in order to guarantee an high level of disciplinary or law respect.
3. Technological instruments for tracking and tracing bottles as well as content mapping/ DNA tracking systems that could be useful in anti-counterfeiting are generally quite well known, but most of the interviewed declare to use them only to be compliant with laws and consortia disciplinary as well as because of bargaining power of great clients (e.g. Retailing Chains); only a few of the respondents are, in fact, available to invest significant share of revenues in fighting the phenomenon.

However, even if results have to be confirmed by a significantly greater number of respondents, the outcomes trend appears quite clear and homogeneous to the point to make us enough confident to draw some conclusions about future needs and steps to be covered such as:

- evaluating lost in brand value perception from consortia point of view that, at the current stage, they seem to be the major "value keepers" of appellation of origin brands; this could stimulate to evaluate the introduction of additional anti-counterfeiting measures;
- providing a technology-based plus business process based system to fighting high end wines counterfeiting; and
- promoting an increase in sensitiveness about the problem through consortia communication actions.

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Effect of transport vibrations on food quality traits

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Abstract
The main researches conducted on vibration levels due to transport and their effects on the quality of food are reviewed together with the related influencing factors. The methodologies set up from the end of the 1960s to recent years to assess and simulate the mechanical vibrations are also described. The works present in literature, mainly dedicated to fresh fruits and vegetables, showed that damages are related to several parameters such as the product characteristics (natural frequencies), the packaging and position of the container along the column, the type (suspensions and number of axles) and speed of truck and the road surface conditions. In general, high levels of the power spectral density values, obtained from the analysis in the frequency domain of the accelerations measured onto the floor of the truck, are observed in the range of the low frequencies; the peaks are often due to the discontinuity of the road surface. In a typical packaging for fruit shipping (column of crates), these vibrations can be amplified several times from the bottom to the top of the column where the product, according to its resonant characteristic, can be subjected to continuous rebounds onto the packaging.

Keywords: *mechanical vibrations, transport, truck, food quality traits.*

1. Introduction

During transport, food damages can be due to vibrations and shocks transmitted by the vehicle floor to the product through the packaging. According to the intensity and the duration of such mechanical stresses, different kind of injury can occur. In order to guarantee the high quality of products demanded by consumers, the experiences conducted during the last fifty years on truck transport, showed that several factors should be taken into consideration. In particular, apart from the characteristics of the vehicle and the road surface, the study of the ability of the shipping column to soften the accelerations transmitted from the vehicle floor and consequently the mechanical properties of the packaging and the product should be considered.
The present paper intends to review the main researches conducted on the effect of transport on the food quality traits by focusing on the methodologies set up for the vibration measurements and simulations and on the factors affecting their transmission to the product.

2. Methodologies set up to assess the effect of transport vibration of food quality traits

From the end of the 1960s to recent years several methodologies were set up to evaluate the damage on food due to truck transport and different systems to simulate transport were used.

In the researches conducted by O'Brien and its collaborators during the 1960s, in-transit mechanical vibrations of different types of trucks were determined by placing piezo-electric accelerometers in different positions inside bins and wooden boxes previously filled with the agricultural product, especially fruits and vegetables. The accelerometers were connected to amplifiers and to multi-channel chart recorders. The recorded accelerations were successively simulated by means of a simple mechanical laboratory vibrator oscillating on coil springs powered by an electric motor able to cover the amplitudes and frequencies measured on the vehicles. These sinusoidal vibrations were obtained by an actuating system characterized by counterweights able to rotate about the centre of the table gravity (O'Brien et al., 1963; 1965; 1969; Chesson and O'Brien, 1971).

The studies carried out in the 1980s were characterized by the use of electro-hydraulic vibration systems to simulate in-transit vibration levels. These systems consisted of a hydraulic pump, a platform mounted on a hydraulic cylinder and a function generator connected to an amplifier. By means of these devices, sinusoidal or random vibrations obtained from the frequency analysis (Fast Fourier Transform, FFT) of the accelerations measured on the vehicles floor (Peleg e Hinga, 1986; Fischer et al., 1992), or random spectra according to the standardized procedures of the American Society of Testing and Materials, ASTM Method D-3222 (Mechanical-Shock Fragility of Products using shock Machines, ASTM, 1979) and Method D-999 (Vibration Testing of Shipping Containers, ASTM, 1979 (Turczyn et al., 1986; Singh and Xu, 1993) were reproduced. Power Spectral Density (PSD) values versus the frequency obtained from the FFT algorithm were also reproduced by means of the vibrating actuators (Timm et al., 1996).

Instrumented spheres (IS), developed by USDA/ARS and Michigan State University (Tennes, 1988), were also used to record shocks during intrastate transportation of fruits (Schulte Pason et al., 1990). These devices, characterized by a tri-axial piezo-electric accelerometer placed inside a shell together with all associates hardware and battery, are still used to assess the handling quality during harvest and post-harvest processes of different of agricultural products such as fruit, vegetables and eggs.

Finally, electro-dynamic shakers, driven by a power amplifier and controlled by a control system, were used to generate PSD profiles, sinusoidal vibrations and shocks on typical packaging columns in order to assess both the mechanical behaviour of the entire structure (packaging and products) and the effects on the product quality traits (Barchi et al., 2002; Berardinelli et al., 2005*)* (Fig. 1).

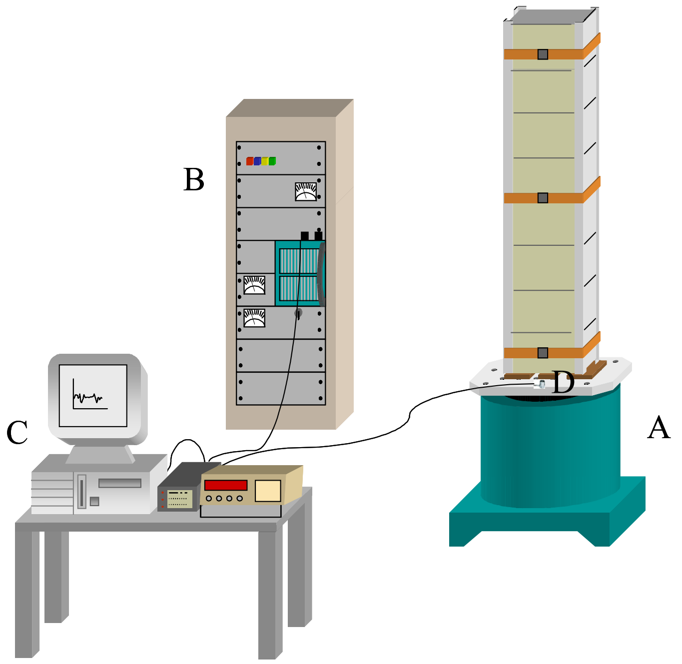

Fig. 1. Typical layout of the electro-dynamic shaker. A: shaker; B: power amplifier; C: control system; D: piezo-electric accelerometer mounted on the vibrating table connected to the control system.

3. Factor affecting the transmission of the mechanical vibrations during transport

The mechanical vibrations transmitted to the product are affected by several factors related to the transport vehicles, to the road surface, and to the physical-mechanical characteristics of the packaging and to the transported product.
Main factors related to the truck are its suspension system (air-ride or leaf spring suspensions) (Chesson and O'Brien 1971; Pierce et al., 1992), the position along the floor (Berardinelli, 2003, Fig. 2), and the road surface (Peleg e Hinga, 1986).

Physical-mechanical properties of the packaging can also affect the vibration levels measured on the product. Some types of packaging, such as bulk bins, was proven to remarkably amplify them. A significant amplification can be also observed passing from the bottom to the top of the shipping column. For fruits and vegetables, product damages can occur when a combination of amplitudes and frequencies is enough to reach its resonant conditions (the product move freely); these conditions are frequently measured in the top layers just in a frequency range where the vibrations measured on the vehicle floor show a peak (O'Brien et al., 1965; O'Brien & Guillou, 1969; Chesson & O'Brien, 1971). Figure 3 shows an example (Berardinelli, 2003) of the amplification of the acceleration from the bottom to the top of cardboard boxes in the range of low frequencies (from 5 to 25 Hz). The vibrations at this frequencies range are usually due to the discontinuities of the road surface.

A model to predict damages of horticultural produces according to the road profile, the characteristics of the vehicle and the mechanical properties of the packaging and product was developed by Jones et al., 1991. In such model, the energy absorbed by the product was calculated from a force-characteristics description of the vehicle and loads elements.

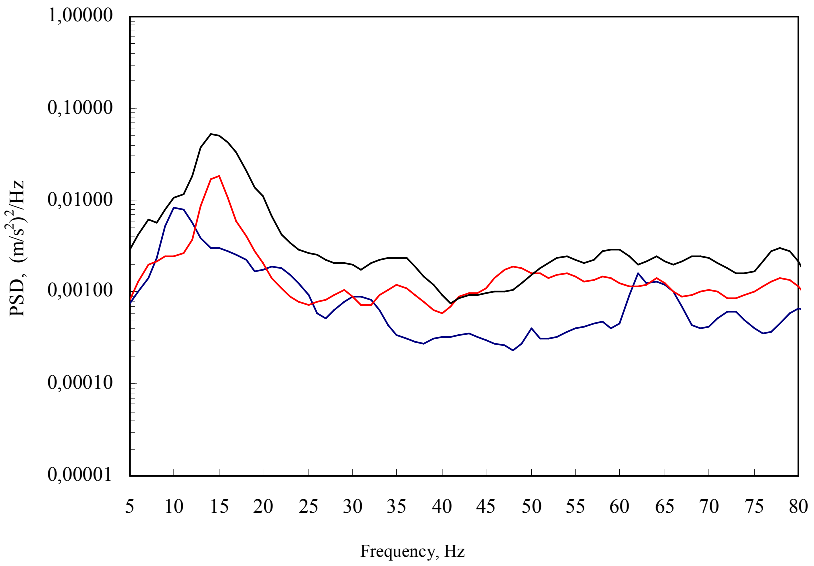

Fig. 2. Power spectral density (PSD) measured in three positions along the vehicle (truck semi-trailer) floor: ____ Front, ____ Middle, ____ Rear.

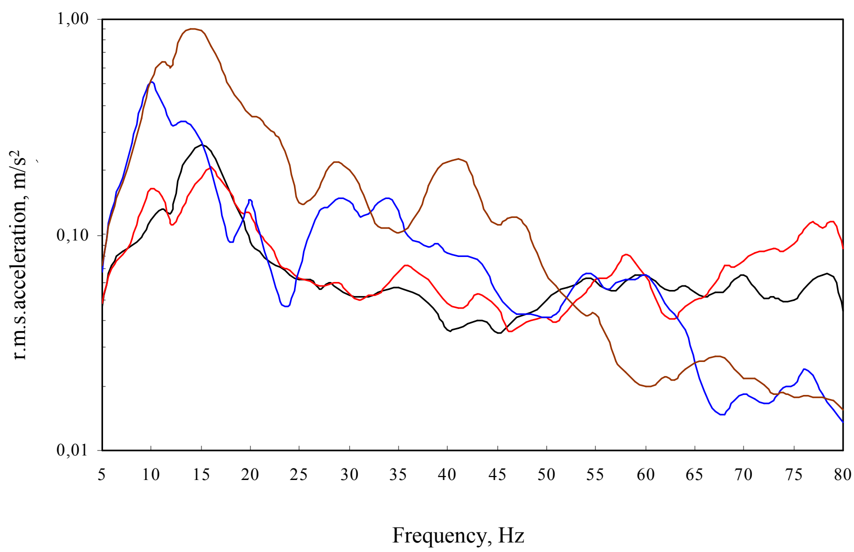

Fig. 3. Root mean square acceleration (r.m.s.) measured in three levels of the column (cardboard boxes) during a simulation of the PSD profile (rear position) in Fig. 2.: ____ shaker, ____first box, ____fourth box, ____ eighth box.

4. Researches conducted on food damage during transport

Table 1 summarize the main researches carried out on the effect of vibrations due to transport on food quality traits since the 1960s to date. As emerged from the table, the great part of the literature is dedicated to fresh fruits and vegetables that are demonstrated to be highly susceptible to in-transit vibration injury. The cited experiences pointed out that damages occur because the transmitted energy reach the product resonant frequencies causing its rotation and rubbing with the packaging. The effects of transport vibrations and shocks occurring during farming operations were also investigated on peaches (Fig. 4.). Parallel researches were carried out in order to understand the vibrating characteristics of different types of fruit (O'Brien et al., 1965; Chen and De Baerdemaeker, 1993) and packaging (Gentry et al., 1965). From the works conducted on eggs emerged that in-transit vibrations can negatively affect the internal quality of eggs in terms of albumen density and resistance to rupture of the vitelline membrane surrounding the yolk (Berardinelli et al., 2003a; 2003b).

Agricultural product	References
Apples	Maindonald and Finch, 1986
	Schulte Pason et al., 1990
	Singh and Xu, 1993
	Timm et al., 1996
	Van Zeebroeck et al., 2007
Citrus	Peleg and Hinga, 1986
Eggs	Berardinelli et al., 2003a; 2003b
	Panda et al., 1973
Grapes and strawberries	Fischer et al., 1992
Kinnow fruits	Raghaw and Gupta, 2003
Loquats	Barchi et al., 2002
Mangos	Chan and Chung-Kee, 2009
Peaches	Ragni et al., 2001
Pears	Berardinelli et al., 2005
	Zhou et al., 2007
Potatoes	Grant et al., 1986
Tomatoes	Singh and Singh, 1992
Watermelons	Shahbazi et al., 2010

Table 1. Main researches carried out on the effect of transport vibrations of food quality traits.

Fig. 4. Simulation of intra-farming transports of peaches by means on an electro-dynamic shaker (Ragni et al., 2001).

5. Conclusions

From the experiences reviewed in the present paper emerged that several factors can affect the quality of the agricultural products during transport. These factors are mainly related to the characteristic of the vehicle (truck tires, suspension system) and the road surface, and to the mechanical properties of both the packaging and the product. For typical fruit shipping columns, highest acceleration levels are measured at their top layers; these accelerations, according to the fruit resonant characteristics can be responsible of a great percentage of severe bruising in terms of discoloured areas, and broken cell walls. Even if several, the researches conducted on the effects of transport vibrations on the food quality traits are mainly focused of the fresh fruits, vegetables and eggs. Interesting researches could be addressed to the analysis of liquid products such as wine or olive oil in order to study if the combination of different stress factors such as vibration and temperature can affect their organoleptic characteristics.

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Pre-fermentative replacement of sulphur dioxide by lysozyme and oenological tannins: Effect on the formation and evolution of volatile compounds during the bottle storage of white wines

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Abstract
In this work, the effects on volatile profile of the pre-fermentative substitution of SO_2 with lysozyme and oenological tannins were studied in white wines. At the same time, in order to understand the changes of volatile compounds in SO_2-free wines, the evolution of volatiles was evaluated over one year of storage in bottles.
For this purpose, a number of laboratory scale fermentations of *Sauvignon Blanc* musts were carried out and the effects of three variables (SO_2, lysozyme and oenological tannins) were investigated by means of GC-MS analysis.
Results showed that the replacement of SO_2 with lysozyme and oenological tannins influenced the volatile composition of wines at the end of the alcoholic fermentation. Wines fermented with SO_2 showed higher total alcohol amounts, while the presence of oenological tannins augmented the level of esters.
The presence of SO_2 influenced as well the alcohols and esters profiles of wines during bottle storage. Also, the presence of oenological tannins displayed a positive role in maintaining the amounts of esters over certain levels in wine stored for 1 year, likely due to their oxygen scavenging ability. By contrast, acids were less affected by the investigated adjuvants both at the end of the alcoholic fermentation and during the storage time.

Keywords: *lysozyme; SO_2; oenological tannins; volatile compounds; ageing in bottles; wine*

1. Introduction

Several studies have been undertaken in food science with the declared goal of developing innovative ways to ensure safer and healthier food.
In oenology, the current attention is focused on the use of sulphur dioxide commonly employed as a preservative in winemaking because of its well established technological properties. In fact, it acts as an antioxidant to protect wine phenols from oxidation and inhibits must endogenous oxidases, in this way controlling the onset of undesirable fermentations (such as acetic or malolactic fermentation) (Ribéreau-Gayon et al., 2000). However, excess SO_2 has been reported to have toxic effects on human health, resulting in headaches, nausea and asthmatic reactions in sensitive individuals (Gao et al., 2002; Vally & Thompson, 2001; Romano & Suzzi, 1993). It is also important to reduce the amount of SO_2 in wine since this compound is found in many food products as a food additive and the amount consumed is accumulative in the organism.
During the last few years, the use of lysozyme has been proposed to control malolactic fermentation in winemaking supporting or even replacing sulphur dioxide (Chinnici et al., 1996; Bartowsky, Costello et al., 2004; Sonni et al., 2009). Lysozyme, which is already used as an antimicrobial agent in the food industry (Cunningham et al., 1991; Ghitti et al., 1983), has no adverse effect on the growth of yeast and can be used during alcoholic fermentation to prevent the growth of spoilage lactic acid bacteria and to reduce the occurrence of stuck/sluggish alcoholic fermentations (Gao et al. 2002). Furthermore, this substance seems not to influence the sensorial properties of wines and not to enhance the browning of white wines during their storage (Bartowsky et al., 2004).
In oenology, the use of tannins is a common practice. These substances are plant derived extracts from several botanical species. Depending on the origin, tannins can be classified into two groups, namely (i) hydrolysable tannins (gallotannins and ellagitannins, derived from oak or other plant species); (ii) condensed tannins (derived mainly from grapes) (Sanz et al., 2008; Haslam, 2007). Traditionally used to facilitate the clarification of musts and wines, they can also contribute to wine structure, stabilise the colouring material in red wines, and improve the sensory impact of the final product (Bellachioma et al., 2008; Parker et al., 2007). Furthermore, as previously reported by our group, the pre-fermentative addition of gallotannins associated with lysozyme can help to prevent the oxidative phenomena of musts and wines that are likely a consequence of a dual mechanism involving enzymes inhibition and radical scavenging activity (Sonni et al., 2009). Information, however, concerning the time-evolution of the aromatic profile for SO_2-free wines obtained using lysozyme and oenological tannins is still lacking.
In two previous studies, we investigated the composition of volatiles and the amino acid consumption in white musts fermented with and without SO_2 addition, using two low-SO_2-producing selected yeast strains (strains 333 and 1042) (Cejudo-Bastante et al., 2010; Sonni et al., 2009).
In the present investigation, the same strain 333 was used to deepen our understanding of the effects of SO_2, lysozyme and oenological tannins on volatile composition in white wines. Furthermore, to understand the changes in the aromatic profile of white SO_2-free wines, the evolution of the volatile compounds over a 1 year period of ageing in bottles was also evaluated. To this end, a series of 21 laboratory-scale fermentations were carried out and the volatile profiles were analysed by gas chromatography-mass spectrometry (GS-MS) at the end of the alcoholic fermentation, after 3 months and after 1 year of bottle storage.

2. Material and methods

2.1 Alcoholic fermentations

Lysozyme chloride was supplied by Fordras S.A. (Lugano, Switzerland), while liquid gallic tannin (Excellent Gold White) was purchased from Oliver Ogar Italia (Verona, Italy). Sulphur dioxide has been used as the potassium salt (Carlo Erba, Italy).

Forty two litres of fresh must from cv. *Sauvignon Blanc* grapes, harvested at the Azienda Agricola Terre Naldi (Tebano, Emilia Romagna, Italy), were filtered through a 0.45 µm seiz-Supra EK filter from Seitz (Bad Kreuznach, Germany) and fermented in a 2 l laboratory glass fermentors, previously saturated with N_2. A glass trap (filled with 4 N H_2SO_4) prevented microbial contamination and oxygen entrance. A low SO_2 producing selected strain of *Saccharomyces cerevisiae* (strains 333 from University of Bologna - ESAVE collection), was used to carry out fermentations and was inoculated at an initial cell concentration of 1.5 × 10^6 CFU ml^{-1}. Seven trials (C, L, LT, S, ST, SL, and SLT) were evaluated with the aim of studying the effect of the following variables: (1) lysozyme, (2) SO_2, (3) gallotannins, as described in Table 1. The fermentations were performed in triplicate. The must were stirred daily to ensure a homogenous fermentation. The fermentations were monitored by daily weighing the fermentors, and samples were taken at the end of fermentation, when the loss of weight stopped.

The final wines were bottled, under a nitrogen flux, in 125 ml bottles, and stored in the dark, at cellar temperature for 1 year. Analysis of the volatile composition of the wines at the end of the alcoholic fermentation, after 3 months and 1 year of storage were performed in duplicate.

2.2 Oenological parameters

Determination of density, total and volatile acidity, dry extract and total SO_2 were made according to OIV methods (OIV, 2009). The pH was determined using a pH-meter (Mettler Toledo, Spain). The alcoholic strength of wines was determined by using a oenochemical distilling unit (Gibertini, Italy). All the analyses were made in duplicate. Organic acids were determined in HPLC using a modification of the methodology previously described by Castellari et al. (2000), which permits an improved identification of succinic, shikimic and pyruvic acids. Briefly, an isocratic elution at 45°C by using H_3PO_4 0.2 M (adjusted at pH 2.8 with KOH 1 M) was carried out. The HPLC analysis was performed using a Jasco apparatus (Tokyo, Japan) equipped with a binary pump (PU 2089), a 20 µl loop, a Rheodyne valve (Cotati, CA, USA), a photodiode detector (PU MD 910), and a column oven. The column was a Bio-Rad Aminex HPX 87H (300 mm × 7.8 mm) (Hercules, CA, USA). Quantification was performed at 210 nm using an external standard calibration curve.

2.3 Aroma analysis

Standard compounds were supplied by Aldrich (Milano, Italy), Sigma Chemicals (St. Louis, Missouri, USA), Fluka Chimie AG (Buchs, Switzerland). Hydromatrix resin for the liquid extraction was from Varian Inc. (Palo Alto, California, USA) and dichloromethane (Suprasolv) was purchased from Merck (Darmstadt, Germany).

Higher alcohols (acetaldehyde, ethylacetate, *n*-propanol, *i*-butanol, isoamyl alcohol) were analyzed according to the method outlined by Brunelle (1968). A gas-chromatograph 8000

series (Fisons, Milan, Italy) equipped with a flame ionisation detector and a packed column 23 % Carbowax 1500 (w/w) on Chromosorb W (60-80 mesh) were used. The working conditions were: GC grade nitrogen as carrier gas at flow rate (constant flow) of 3.0 ml min^{-1}, column temperature of 70°C (isothermal), detector and inlet temperature was 150°C. Sample volume injected was 2 µl.
For the analysis of all the other volatiles, the sample preparation procedure proposed by Gerbi et al.(1992) was used. The analysis of the extracts was carried out in a GC-MS Thermo Finnigan Trace GC ultra gas chromatograph (San Jose, CA, USA), equipped with a Thermo Finnigan Trace DSQ mass selective detector and a fused silica capillary column Stabilwax-DA (Restek, Bellefonte, PA; 30 m, 0.25 mm i.d., and 0.25 µm film thickness), under the following working conditions: GC grade helium as carrier gas at a flow rate (constant flow) of 1.0 ml min^{-1}; column temperature program, 40°C heated at 3°C min^{-1} to 100°C and then heated at 5°C min^{-1} to 240°C (held for 10 min). The injection temperature was 250°C. Samples (1 µl) were injected in the splitless mode. Detection was carried out by positive ion electron ionization (EI) mass spectrometry in the full scan mode, using an ionization energy of 70 eV and a transfer line temperature of 280°C. The mass acquisition range was m/z 30-400 and the scanning rate 1 scan s^{-1}. Chromatographic peaks were identified by comparing their mass spectra with those of standards and/or those reported in the literature and in commercial libraries NIST 2.0 and Wiley 7. Quantification was carried out from total ion current peak areas according to the internal standard method (100 µl of a 514 mg l^{-1} solution of 2-octanol were added to 20 ml of each sample); the response factor of standard volatile compounds to the internal standard was experimentally obtained and applied to correct the peak area of each analyte. For compounds lacking reference standards, the response factors of standards with similar chemical structures were used.

2.4 Statistical analysis

For each final wine, significant differences in mean concentrations of volatile compounds were tested by means of ANOVA analysis followed by a post hoc comparison (Tuckey's test at $p > 0.01$). To evaluate the influence of each tested factor (lysozyme, SO_2 and gallotannins), the data were subjected to multiple regression analysis after a graphical exploration to exclude outliers. All analyses were conducted using "Statistica 6" package (StatSoft Italia Srl, Italy).

3. Results and discussion

3.1 General parameters of final wines

The analysis of the oenological parameters at the end of the alcoholic fermentation showed similar values of pH (between 2.91 and 3.01), alcoholic strength (between 11.3% and 12.2 % v/v) and total acidity (between 7.2 and 8.2 g tartaric acid l^{-1}), in ranges that are considered normal for this product. The values for volatile acidity (between 0.4 and 0.5 g acetic acid l^{-1}) together with the amounts of lactic acid (spanning between 0.175 and 0.369 g l^{-1}) confirmed the lack of both malolactic and acetic fermentation. Total SO_2 in all C, L and LT samples (between 0.3 and 1.6 mg l^{-1}), confirmed that the strain 333 can be considered a low SO_2 producer. It has already been shown that the pre-fermentative use of sulphur dioxide can result in an accumulation of acetaldehyde in the final wines (Swiegers et al., 2005; Romano & Suzzi, 1993). In our SO_2 added wines, acetaldehyde amounts (between 33.2 and 47.5 mg l-

[1]) at the end of the alcoholic fermentation were around 3-4 times higher when compared to samples obtained without SO_2 addition (between 12.9 and 13.2 mg l^{-1}) and this fact could well contribute to the sensory attributes of the wines.

3.2 Volatile composition of final wines and its evolution during bottle storage

The volatile compounds identified in wines are reported in Table 2. A total of 67 compounds were identified, 37 of which were confirmed by comparing their RT and mass spectra with authentic standards. For the remaining volatiles, identification was accomplished by matching their mass spectra with Nist 2.0 and Wiley 7 libraries and further confirmed by the comparison to linear retention indexes (RIs) previously published (Chinnici et al., 2009; Natali et al., 2006). Tables 3, 4 and 5 show the evolution of the compounds which mainly contribute to the final aroma of wines and/or gave significant results after statistical treatment.

On the right hand side, the tables show the significant ($p > 0.01$) standardised beta coefficients from the multiple regression analysis, carried out with the aim of highlighting correlations between each factor (SO_2, lysozyme and gallotannins) and the production or evolution of volatiles. The higher the regression coefficient (beta), the stronger the impact of the factor on that specific compound. Furthermore, the sign of the beta values indicate the direct (positive sign) or reversed (negative sign) correlation of factors on each single compound.

3.2.1 Alcohols

Alcohols may have intense odours that can play a role in wine aromas. At concentrations less than 300 mg l^{-1} (as a sum), they contribute to the wines aromatic complexity, while at higher levels their penetrating odours can mask the wine's aromatic finesse (Rapp & Versini, 1996). The concentration of total alcohols in our samples did not exceed this threshold at anytime, so these compounds would have contributed in a positive way to the wine aroma (Table 3). Table 3 shows the amount of the principal alcohols found in wines at the end of the alcoholic fermentation, after 3 months and 1 year of bottle storage. At the end of fermentation, C and L samples tended to show the lowest amount of alcohols as a sum. According with our previous study (Sonni et al., 2009), SO_2 showed a positive influence on alcohols production as confirmed by the regression coefficient of SO_2 factor on such class of compounds. Among single volatiles, sulphur dioxide had a positive influence on 2-methyl-2-butanol and 3-ethylthio-1-propanol production, while a negative influence for 3-ethoxy-1-propanol was apparent.

It has been reported that during fermentation sulphites may promote the synthesis of some alcohols by influencing the Ehrlich pathway (Nykanen, 1986; Hernandez-Orte et al., 2006; Garde-Cerdan & Ancin-Azpilicueta, 2007). However, it is worth noting that in a previous study conducted on two *S. cerevisiae* strains (Cejudo-Bastante et al., 2010), we found that SO_2 consistently favoured the consumption of ammonium nitrogen, even though amino acid metabolism was strain dependent and no common behaviour was highlighted between the two strains with respect to SO_2 influence. In that work, contrary to strain 1042, strain 333 did not increase the total consumption of amino nitrogen when in the presence of sulphites. This latter evidence may justify the data obtained in the present work, where for some alcohols involved in the Ehrlich pathway, such as isoamyl alcohols, 3-methylthio-1-propanol and phenylethyl alcohol, synthesized from leucine, isoleucine, and phenylalanine, respectively, no clear influence of sulphites was found.

Interestingly, the production of 3-ethoxy-1-propanol increased when SO_2 was absent, a result which is consistent with previous works on wines fermented without the use of SO_2 (Sonni et al., 2009; Herraiz et al., 1989; Margheri & Versini, 1986).

Irwin (1992) postulated that the formation of this alcohol may derive from the Ehrlich degradation of *O*-ethylhomoserine, which is a by-product of the methionine biosynthetic pathway. It appears, hence, that sulphites may interfere in the enzymic pool involved in the synthesis of 3-ethoxy-1-propanol starting from the former unusual aminoacid.

After 3 months of storage, a positive influence of SO_2 on the evolution of total alcohols was found and these data are in accordance with the results found by Garde-Cerdan and Ancin-Azpilicueta (2007). However, after 1 year of ageing, no significant influence of the tested factors on the total alcohols amount was found. Among single compounds, an increase in the concentrations of some alcohols, such as isoamyl alcohols, benzyl alcohol and phenylethyl alcohol, during the bottle storage was highlighted. Concerning the latter one, SO_2 showed a direct significant influence on its content, and its concentration widely exceeded the threshold level (10 mg L^{-1}) hence, contributing to a floral, rose aroma (Swieger et al., 2005). For 3-ethoxy-1-propanol, the initial differences in concentration among samples persisted during the entire storage period. Tannins did not show any influence on the evolution of this class of compounds, except for the 3-ethoxy-1-propanol values after 1 year of bottle storage.

3.2.2 Esters

In Table 4 the concentrations of esters at the end of the alcoholic fermentation and their evolution over 1 year of bottle storage are shown.

Total esters amounts quantified at the end of the alcoholic fermentation were significantly different among the samples.

Tannins seemed to result in the most positive influencing factor on esters production at the end of the alcoholic fermentation, particularly for isoamyl acetate, ethyl octanoate, ethyl-4-hydroxybutanoate, phenylethyl acetate and ethyl hydrogen succinate. As suggested in other papers, this result may be due to the ability of tannins added before fermentation to affect the presence of oxygen in musts and wines, as a consequence of a double mechanism of enzyme inhibition and radical-scavenging activity (Sonni et al., 2009; Bosso et al., 2001; Bellachioma et al., 2008). Tannins can quickly drop the oxygen availability, contributing to preserve the esters amounts of wines over certain levels, avoiding the loss of fresh, fruity attributes.

Concerning medium-chain fatty acids ethyl esters (MCFA ethyl ester), in contrast with other studies in literature, reporting an increase in production in wines fermented with SO_2 (Moio et al., 2004; Herraiz et al., 1989; Bardi et al., 1998; Nykanen, 1986), our results did not show any influence of sulphites on these esters. For our wines, according to Shinoara and Watanabe (1981), the added SO_2 amount (60 mg l^{-1}) was probably unable to significantly reduce the availability of free oxygen during the alcoholic fermentation, that could have arrested the lipid biosynthesis and promote the MCFA ethyl esters formation by yeasts (Moio et al., 2004; Bardi et al., 1986).

The evolution of esters during the storage period was characterised by a wide increase, spanning from less than 50 mg l^{-1} of total esters concentration at the end of the alcoholic fermentation to about 200-300 mg l^{-1} after 1 year of ageing (Table 4). However this trend was almost completely due to the large augmentation of ethyl lactate and, especially, ethyl hydrogen succinate. For this reason, Table 4, shows the total esters amounts from which the concentration of the latter ester was subtracted. Multiple regression analysis shows that, at 3 months of bottle storage, SO_2 resulted in the most positive influencing parameter on the total esters amount and on almost all of the ester compounds quantified, whereas after 1 year, tannins resulted in the most positive influence, as was the case at the end of the alcoholic fermentation.

It is well known that during storage ethyl esters may undergo hydrolysis slower than acetates, because the amount they reach at the end of the alcoholic fermentation is closer to their equilibrium concentrations. This reaction is the most important factor resulting in the loss of the fruity character of young white wines (Pérez-Coello et al., 1999).

Acetates decreased during storage time, probably due to their fast hydrolysis rates, as suggested previously. Among single compounds, isoamyl acetate decreased during the bottle storage, reaching a very low amount after 1 year (0.20-0.30 mg l^{-1}). For phenylethyl acetate, an initial increase after 3 months was followed by a decrease after 1 year of bottle storage, coming back to nearly the same values shown at the end of alcoholic fermentation. By contrast, hexyl acetate was found to be influenced by the presence of SO_2, and increased during all the storage period, especially in SO_2 added samples. In particular, in these samples the concentration of hexyl acetate reached the perception threshold level (0.69 mg l^{-1}), contributing with a green, herbaceous aroma to the wines sensory profile (Sumby et al., 2010).

Concerning the ethyl ester compounds, ethyl lactate and diethyl succinate showed the same trend of evolution, increasing during the storage time up to 1 year for all the wines, because of chemical esterification reactions occurring after fermentation (Pérez-Coello et al., 1999). Furthermore, ethyl lactate evolution was significantly influenced by lysozyme (Table 4): the L trial after 3 months and 1 year of storage showed the highest concentrations of this ester, as confirmed by the positive regression coefficient value for lysozyme over the entire storage period (Table 4). On the other hand, a negative regression coefficient for SO_2 and tannins factors was found. Concerning the other trials in which lysozyme was added associated with tannins (LT trial) and with SO_2 (SL trial), they did not follow the same trend of evolution of L wines.

3.2.3 Acids

Fatty acids contribute to either the fresh flavour of wine if they are present in the correct amounts, or to an unpleasant flavour if they are in excess, and they also help to modify the perception of other taste sensations (Rybéreau-Gayon et al., 2007; Pozo-Bayon et al., 2005). The total fatty acid concentrations at the end of the fermentation and during the storage time were found to be around 10-25 mg l^{-1}, a value that did not impair wine aroma (Garde-Cerdan & Ancin-Azpilicueta, 2007). As in the case of MCFA ethyl esters, these values of concentration were not significantly affected by the presence or the absence of SO_2 (Table 5). The amounts of acids, such as octanoic acid and decanoic acid, followed the trend of the corresponding ethyl esters due to their common biosynthetic pathway, which leads to the production of long chain unsaturated fatty acids (Soumalainen & Lehtonen, 1979).

Concerning the storage period, the amount of acids were characterised by an increase after 3 months of bottle storage in every trial, followed by a decrease after 1 year of storage. This trend has already been reported by other authors for MCFA, even though the reason for this phenomenon remains unclear (Garde-Cerdan et al., 2008).

4. Conclusions

The different oenological protocols did influence the volatile composition of final wines, which resulted in distinct aromatic profiles as determined by GC/MS analysis. During storage, SO_2 was found to be the most influencing factor on the evolution of alcohols and esters. Also, the presence of tannins displayed a positive role in maintaining the amounts of esters over certain levels in wine stored for 1 year, likely due to their role in scavenging oxygen. By contrast, acids were virtually unaffected by the investigated variables. Due to the increasing consumer interest in wines with low SO_2 levels, this work contributes to deepen the knowledge on alternative winemaking protocols that could guarantee high quality products.

Tables and Figures

Trials / Factor	Strain (333)						
	C	**L**	**LT**	**S**	**ST**	**SL**	**SLT**
Lysozyme (g L^{-1})	-	0.25	0.25	-	-	0.25	0.25
$K_2S_2O_5$ (mg L^{-1})	-	-	-	120	120	120	120
Tannin (g L^{-1})	-	-	0.15	-	0.15	-	0.15

Table 1. Scheme of fermentation trials. (Legend for samples: C: Control, L: Lysozyme addition, LT: Lysozyme and gallotannins addition, S: Sulphur dioxide addition, ST: Sulphur dioxide and gallotannins addition, SL: Sulphur dioxide and lysozyme addition; SLT: Sulphur dioxide, lysozyme and gallotannins addition.)

number	compound	RI[a]	ident[b]
1	2-methyl-2-butanol	1048	MS
2	1-propanol	1069	S, MS
3	isobutyl alcohol	1098	S, MS
4	isoamyl acetate	1123	S, MS
5	1-butanol	1142	S, MS
6	isoamyl alcohol	1208	S, MS
7	ethyl hexanoate	1240	S, MS
8	hexyl acetate	1279	S, MS
9	3-hydroxy-2-butanone	1286	S, MS
10	1-hydroxy-2-propanone	1301	MS
11	2-hexanol	1319	MS
12	4-methyl-1-pentanol	1332	MS
13	3-methyl-1-pentanol	1339	S, MS
14	2-methyl-3-pentanol	1348	MS
15	ethyl lactate	1354	S, MS
16	1-hexanol	1366	S, MS
17	4-hydroxy-4-methyl-2-pentanone	1371	S, MS
18	*trans*-3-hexen-1-ol (μg L^{-1})	1379	MS
19	3-ethoxy-1-propanol	1385	S, MS
20	*cis*-3-hexen-1-ol	1401	MS
21	2-nonanone	1407	MS
22	ethyl octanoate	1414	S, MS
23	acetic acid	1463	S, MS
24	ethyl-3-hydroxybutyrate	1521	S, MS
25	benzaldehyde	1524	S, MS
26	dihydro-2-methyl-3(2H)-thiophenone	1531	MS
27	2(methylthio)ethanol	1539	MS
28	propionic acid	1547	S, MS
29	1-octanol	1559	S, MS
30	isobutyric acid	1577	MS
31	γ-butyrolactone	1611	S, MS
32	butanoic acid	1627	S, MS
33	N-ethyl acetamide	1652	MS
36	diethyl succinate	1673	S, MS
34	ethyl decanoate (μg L^{-1})	1678	S, MS
35	pentanoic acid	1748	S, MS
37	3(methythio)-1-propanol	1750	MS
38	1,3-diacetoxypropane	1770	MS
39	methyl-4-hydroxybutanoate	1802	MS
40	3(ethylthio)-1-propanol (μg L^{-1})	1813	MS
41	2-(2-butoxyethoxy)ethanol	1828	S, MS
42	2,4-dimethylbenzaldehyde	1839	MS
43	ethyl-4-hydroxybutanoate	1845	MS
44	phenylethyl acetate	1850	S, MS
45	isopropyl dodecanoate	1876	MS
46	hexanoic acid	1870	S, MS
47	ethyl dodecanoate	1888	S, MS
48	benzyl alcohol	1899	S, MS
49	1,4-diacetoxybutane	1924	MS
50	phenylethyl alcohol	1959	S, MS
51	2,6-dimethyl-3,7-octadiene-2,6-diol	1991	MS
52	S-(3-hydroxypropyl) thioacetate (μg L^{-1})	2029	MS
53	pantolactone	2051	S, MS
54	diethyl hydroxybutanedioate	2094	MS
55	octanoic acid	2116	S, MS
56	N-acetylglycine ethyl ester	2198	MS
57	ethyl 5-oxotetrahydro-2-furancarboxylate	2268	MS
58	decanoic acid	2283	S, MS
59	dihydro-5-(hydroxyethyl)-2-furanone	2403	MS
60	ethyl hydrogen succinate	2413	S, MS
61	dodecanoic acid	2449	MS
62	1-octadecanol	2634	MS
63	1-(4-hydroxy-3-methoxyphenyl)ethanone	2667	S, MS
64	tetradecanoic acid	2722	MS
65	hexadecanoic acid	2827	S, MS
66	4-hydroxybenzaldehyde	2864	MS
67	4-hydroxy-benzeneethanol	2925	S, MS

Table 2 . Minimum and maximum amounts of volatile compounds (mgL^{-1} identified in wines at the end of the alcoholic fermentation and during 1 year of bottle storage.

[a]Linear retention index. [b]Method of identification: S, by comparison of mass spectrum and retention time with those of standard compounds; MS, by comparison of mass spectrum with those included in the NIST 2.0 and Wiley 7 libraries.

	Wines							Regression coefficient*					
	C	L	LT	S	ST	SL	SLT	L	S	T	LysoxSO$_2$	LysoxTan	SO$_2$xTan
End of fermentation													
Total alcohols	150 ± 35.7 [a]	161 ± 6.14 [a]	211 ± 17.5 [ab]	204 ± 24.7 [ab]	198 ± 15.50 [ab]	241 ± 8.2 [b]	243 ± 5.53 [b]	-	0.731	-	-	-	-
Isoamhyl alcohols	39.1 ± 17.2	29.6 ± 1.13	36.6 ± 3.93	45.1 ± 2.95	39.1 ± 2.20	42.1 ± 0.88	42.9 ± 0.75	-	-	-	-	-	-
2-Methyl-2-butanol	0.04 ± 0.01 [a]	0.05 ± 0.00 [a]	0.37 ± 0.00 [b]	0.58 ± 0.03 [c]	0.17 ± 0.03 [a]	0.12 ± 0.03 [a]	0.75 ± 0.10 [d]	-	1.027	-1.351	-0.815	1.793	0.537
3-Ethoxy-1-propanol	0.36 ± 0.07 [c]	0.20 ± 0.02 [b]	0.45 ± 0.02 [c]	0.06 ± 0.02 [a]	0.10 ± 0.02 [ab]	0.21 ± 0.05 [b]	0.11 ± 0.01 [ab]	-0.577	-1.081	1.469	1.047	-0.497	-1.189
3-(Methythio)-1-propanol	0.59 ± 0.07	0.56 ± 0.04	0.60 ± 0.05	0.93 ± 0.22	0.79 ± 0.24	0.70 ± 0.17	0.92 ± 0.13	-	-	-	-	-	-
3-(Ethylthio)-1-propanol (µg/L)	n.d.[a]	n.d.[a]	n.d.[a]	5.43 ± 1.13 [b]	6.45 ± 2.14 [b]	7.44 ± 1.10 [b]	5.93 ± 1.19 [b]	-	0.814	-	-	-	-
Benzyl alcohol	0.09 ± 0.01 [ab]	0.09 ± 0.02 [ab]	0.14 ± 0.01 [b]	0.10 ± 0.03 [ab]	0.08 ± 0.02 [a]	0.09 ± 0.01 [a]	0.11 ± 0.02 [ab]	-	-	-	-	-	-
Phenylethyl alcohol	32.3 ± 5.74	25.9 ± 1.17	27.7 ± 1.21	27.9 ± 8.13	40.0 ± 0.10	27.5 ± 7.39	33.7 ± 2.63	-	-	-	-	-	-
3 months of storage													
Total alcohols	124 ± 12.0 [a]	132 ± 1.42 [a]	163 ± 19.1 [a]	158 ± 13.5 [a]	176 ± 37.7 [ab]	164 ± 21.8 [a]	258 ± 41.6 [b]	0.488	0.701	-	-	-	-
Isoamylalcohol	43.1 ± 2.93 [a]	50.6 ± 7.34 [a]	67.9 ± 10.7 [a]	55.1 ± 4.52 [a]	57.4 ± 16.4 [a]	51.2 ± 6.77 [a]	37.2 ± 7.23 [a]	-	-	-	-	-	-0.659
2-Methyl-2-butanol	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	-	-	-	-	-	-
3-Ehoxy-1-propanol	0.38 ± 0.23 [b]	0.13 ± 0.02 [ab]	0.37 ± 0.04 [ab]	0.06 ± 0.03 [a]	0.09 ± 0.02 [ab]	0.13 ± 0.01 [ab]	0.08 ± 0.01 [ab]	-	-1.019	-	0.557	-	-
3-(Methythio)-1-propanol	0.56 ± 0.13 [ab]	0.35 ± 0.06 [a]	0.29 ± 0.16 [a]	0.98 ± 0.11 [c]	0.96 ± 0.05 [c]	0.82 ± 0.01 [bc]	1.14 ± 0.04 [c]	-	0.993	-	-	0.266	0.292
3-(Ethylthio)-1-propanol (µg/L)	10.2 ± 4.58	10.7 ± 4.01	11.9 ± 1.16	13.0 ± 7.45	6.12 ± 2.24	4.58 ± 0.66	3.47 ± 1.58	0.735	0.648	-	-	-	-
Benzyl alcohol	0.43 ± 0.13 [a]	0.37 ± 0.04 [a]	0.49 ± 0.04 [a]	0.37 ± 0.06 [a]	0.46 ± 0.02 [a]	0.49 ± 0.04 [a]	0.78 ± 0.05 [b]	0.452	0.406	-	-	-	-
Phenylethyl alcohol	28.0 ± 0.41 [a]	32.5 ± 2.49 [a]	37.9 ± 8.16 [ab]	38.1 ± 2.56 [ab]	42.5 ± 11.1 [ab]	39.7 ± 3.95 [ab]	58.3 ± 4.83 [b]	0.497	0.751	-	-	-	-
1 year of storage													
Total alcohols	126 ± 22.0 [a]	158 ± 29.2 [ab]	159 ± 11.3 [ab]	176 ± 13.8 [ab]	159 ± 26.0 [ab]	197 ± 9.25 [b]	173 ± 15.1 [ab]	-	-	-	-	-	-
Isoamylalcohol	42.9 ± 8.66	52.8 ± 11.4	64.2 ± 0.92	58.0 ± 4.51	52.9 ± 13.4	56.9 ± 2.71	63.0 ± 20.9	-	-	-	-	-	-
2-Methyl-2-butanol	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	-	-	-	-	-	-
3-Ethoxy-1-propanol	0.23 ± 0.00 [b]	0.14 ± 0.03 [ab]	0.37 ± 0.05 [c]	0.05 ± 0.01 [a]	0.08 ± 0.03 [a]	0.12 ± 0.01 [a]	0.09 ± 0.02 [a]	-	-1.084	0.608	0.364	-	-0.612
3-(Methythio)-1-propanol	0.50 ± 0.11 [a]	0.60 ± 0.02 [a]	0.56 ± 0.09 [a]	1.01 ± 0.12 [b]	0.85 ± 0.16 [ab]	0.80 ± 0.04 [ab]	0.80 ± 0.14 [ab]	-	0.971	-	-	-	-
3-(Ethylthio)-1-propanol (µg/L)	n.d.[a]	n.d.[a]	n.d.[a]	4.04 ± 0.44 [bc]	5.27 ± 0.42 [c]	7.10 ± 0.34 [d]	2.72 ± 0.92 [b]	-0.234	0.623	-	0.282	-0.516	-0.403
Benzyl alcohol	0.72 ± 0.29	1.04 ± 0.22	1.15 ± 0.18	1.04 ± 0.01	0.75 ± 0.18	0.58 ± 0.03	0.97 ± 0.26	-	-	-	-0.770	0.668	-
Phenylethyl alcohol	38.4 ± 4.99	40.9 ± 11.6	32.9 ± 2.30	47.6 ± 5.80	52.1 ± 6.15	49.8 ± 2.37	54.3 ± 13.9	-	0.779	-	-	-	-

Table 3. Concentrations of the major alcohols (mg L^{-1} ± STD) in wines at the end of the alcoholic fermentation and after 3 and 1 year of storage. Influence of the tested factors on their production, as assessed by multiple regression analysis, are also shown (p <0.01). In the same row, different letters denote significant differences at $p < 0.01$

*Only standardised regression coefficients (beta values) with $p < 0.01$, are reported.

	Wines							Regression coefficient*					
	C	L	LT	S	ST	SL	SLT	L	S	T	Lyso×SO_2	Lyso×Tan	SO_2×Tan
End of fermentation													
Total esters (excluding *ethyl hydrogen succinate)*	11.7 ± 3.25	13.6 ± 0.30	12.7 ± 0.35	9.14 ± 0.73	11.9 ± 1.21	11.8 ± 2.02	12.4 ± 0.84	-	-	-	-	-	-
Isoamyl acetate	0.49 ± 0.02 [a]	0.81 ± 0.02 [b]	0.95 ± 0.14 [bc]	0.89 ± 0.12 [bc]	1.06 ± 0.07 [bc]	1.12 ± 0.01 [c]	0.86 ± 0.11 [bc]	0.782	0.971	1.399	-	-0.970	-0.885
Ethyl hexanoate	0.71 ± 0.32	0.67 ± 0.17	1.02 ± 0.16	0.74 ± 0.18	1.03 ± 0.19	1.07 ± 0.05	1.18 ± 0.12	-	-	-	-	-	-
Hexyl acetate	0.17 ± 0.16	0.09 ± 0.01	0.14 ± 0.03	0.10 ± 0.02	0.16 ± 0.04	0.22 ± 0.02	0.19 ± 0.03	-	-	-	-	-	-
Ethyl lactate	3.73 ± 0.50 [a]	7.28 ± 1.31 [b]	2.94 ± 0.19 [a]	1.84 ± 0.10 [a]	2.51 ± 0.19 [a]	2.80 ± 0.06 [a]	2.41 ± 0.08 [a]	1.007	-0.535	-0.930	-0.671	-	1.022
Ethyl octanoate	0.12 ± 0.03	0.12 ± 0.03	0.20 ± 0.02	0.14 ± 0.03	0.24 ± 0.13	0.09 ± 0.09	0.22 ± 0.05	-	-	1.300	-	-1.056	-
Ethyl decanoate (μg/L)	165 ± 96.0 [a]	283 ± 64.2 [a]	256 ± 4.55 [ab]	155 ± 22.3 [a]	164 ± 38.6 [a]	172 ± 12.4 [a]	170 ± 8.99 [b]	-	-	-	-	-	-
Diethyl succinate	0.03 ± 0.01	0.02 ± 0.01	0.03 ± 0.00	0.01 ± 0.00	0.03 ± 0.02	0.03 ± 0.00	0.02 ± 0.00	-	-	-	-	-	-
Ethyl-4-hydroxybutanoate	2.05 ± 1.53	1.02 ± 0.30	3.04 ± 0.52	1.63 ± 0.27	3.28 ± 0.13	2.61 ± 0.88	3.19 ± 0.42	-	-	1.534	-		-
Phenylethyl acetate	0.29 ± 0.14	0.26 ± 0.01	0.34 ± 0.02	0.35 ± 0.08	0.61 ± 0.44	0.36 ± 0.13	0.47 ± 0.05	-	-	1.321	-	-1.203	-
Ethyl hydrogen succinate	23.3 ± 0.47 [b]	15.2 ± 0.09 [ab]	24.7 ± 1.63 [b]	10.3 ± 3.01 [a]	19.9 ± 5.01 [ab]	26.0 ± 3.97 [b]	21.6 ± 5.32 [ab]	-	-1.090	1.980	1.823	-1.081	-1.068
3 months of storage													
Total esters (excluding *ethyl hydrogen succinate)*	12.7 ± 1.93 [a]	19.7 ± 0.73 [ab]	22.3 ± 1.16 [bc]	17.2 ± 4.9 [ab]	21.6 ± 1.01 [b]	24.3 ± 0.43 [bc]	29.8 ± 1.54 [c]	0.71	0.56	-	-	-	-
Isoamyl acetate	0.54 ± 0.03	0.64 ± 0.07	0.91 ± 0.07	0.79 ± 0.28	0.78 ± 0.11	0.66 ± 0.02	0.57 ± 0.09	-	-	-	-	-	-
Ethyl hexanoate	0.66 ± 0.20	0.64 ± 0.07	1.15 ± 0.04	1.03 ± 0.26	1.04 ± 0.06	0.97 ± 0.01	1.07 ± 0.19	-	-	0.580	-	-	-
Hexyl acetate	0.11 ± 0.00 [a]	0.13 ± 0.03 [a]	0.26 ± 0.02 [b]	0.33 ± 0.03 [b]	0.29 ± 0.06 [b]	0.26 ± 0.01 [b]	0.30 ± 0.05 [b]	-	0.742	-	-	-	-
Ethyl lactate	5.17 ± 0.73 [a]	11.5 ± 1.75 [b]	4.22 ± 0.57 [a]	3.07 ± 0.47 [a]	3.24 ± 0.36 [a]	3.83 ± 0.21 [a]	2.65 ± 0.22 [a]	0.489	-0.311	-0.606	-0.475	-	0.519
Ethyl octanoate	0.74 ± 0.20 [a]	0.75 ± 0.14 [a]	1.42 ± 0.14 [c]	0.92 ± 0.08 [ab]	1.37 ± 0.22 [bc]	1.59 ± 0.05 [c]	1.80 ± 0.04 [c]	-	-	0.567	-	-0.602	-0.924
Ethyl decanoate (μg/L)	213 ± 128 [a]	157 ± 26.6 [a]	332 ± 80.9 [abc]	253 ± 127 [ab]	357 ± 157 [abc]	584 ± 5.59 [bc]	647 ± 12.0 [c]	-	0.836	-	-	-	-
Diethyl succinate	0.19 ± 0.00 [a]	0.14 ± 0.04 [a]	0.33 ± 0.02 [ab]	0.23 ± 0.11 [a]	0.34 ± 0.08 [ab]	0.47 ± 0.00 [b]	0.45 ± 0.06 [b]	-	0.993	-	-	0.266	0.292
Ethyl-4-hydroxybutanoate	2.17 ± 0.12 [a]	3.01 ± 0.81 [a]	9.01 ± 0.81 [bc]	6.34 ± 2.75 [ab]	9.70 ± 0.82 [bc]	11.2 ± 0.20 [c]	16.4 ± 1.53 [d]	-	0.944	0.412	-	-	-
Phenylethyl acetate	0.51 ± 0.04 [a]	0.72 ± 0.14 [ab]	0.86 ± 0.07 [ab]	1.19 ± 0.43 [b]	1.34 ± 0.08 [bc]	1.20 ± 0.00 [b]	1.88 ± 0.16 [c]	-	-	-	-	0.706	-
Ethyl hydrogen succinate	18.5 ± 3.01 [a]	33.4 ± 0.67 [ab]	58.4 ± 6.28 [c]	44.5 ± 9.71 [bc]	61.6 ± 11.5 [c]	66.9 ± 6.86 [c]	119 ± 1.83 [d]	0.818	0.774	-	-	0.376	0.568
1 year of storage													
Total esters (excluding *ethyl hydrogen succinate)*	18.6 ± 2.72 [a]	38.3 ± 8.57 [c]	27.9 ± 2.80 [abc]	21.1 ± 3.99 [a]	25.2 ± 4.73 [ab]	32.8 ± 1.56 [bc]	24.3 ± 1.11 [ab]	0.684	-	-	-	-0.456	-
Isoamyl acetate	0.21 ± 0.15	0.20 ± 0.06	0.24 ± 0.02	0.20 ± 0.05	0.21 ± 0.04	0.30 ± 0.01	0.26 ± 0.12	-	-	-	-	-	-
Ethyl hexanoate	0.54 ± 0.26	0.48 ± 0.20	0.78 ± 0.09	0.58 ± 0.10	0.68 ± 0.14	0.91 ± 0.04	0.83 ± 0.26	-	-	-	-	-	-
Hexyl acetate	0.13 ± 0.01 [a]	0.19 ± 0.02 [a]	0.28 ± 0.04 [ab]	0.69 ± 0.09 [c]	0.60 ± 0.13 [bc]	1.08 ± 0.05 [d]	0.59 ± 0.21 [bc]	-	0.677	-	-	-0.299	-0.444
Ethyl lactate	11.4 ± 1.39 [b]	27.9 ± 1.50 [c]	10.2 ± 0.16 [ab]	6.00 ± 1.35 [a]	7.01 ± 1.75 [ab]	9.07 ± 0.43 [ab]	7.95 ± 2.15 [ab]	0.611	-0.270	-0.584	-0.470	-	0.580
Ethyl octanoate	0.51 ± 0.17 [ab]	0.42 ± 0.18 [a]	0.85 ± 0.02 [bc]	0.64 ± 0.12 [ab]	0.81 ± 0.07 [abc]	1.07 ± 0.05 [c]	0.85 ± 0.08 [bc]	-	-	0.650	0.570	-0.431	-0.711
Ethyl decanoate (μg/L)	159 ± 136 [ab]	28.5 ± 14.6 [a]	83.3 ± 5.73 [a]	43.1 ± 18.5 [a]	142 ± 81.3 [a]	393 ± 18.7 [b]	111 ± 77.1 [a]	-	-	-	0.942	-0.747	-0.660
Diethyl succinate	1.80 ± 0.40 [a]	2.28 ± 0.77 [ab]	4.35 ± 0.62 [bc]	3.60 ± 0.68 [abc]	4.69 ± 0.39 [c]	5.49 ± 0.26 [c]	3.97 ± 1.15 [abc]	-	-	0.589	-	-0.485	-0.667
Ethyl-4-hydroxybutanoate	0.25 ± 0.08 [a]	0.45 ± 0.19 [ab]	1.28 ± 0.30 [bc]	0.76 ± 0.26 [ab]	1.29 ± 0.15 [bc]	1.71 ± 0.08 [c]	1.18 ± 0.43 [bc]	-	-	0.648	-	-0.502	-0.646
Phenylethyl acetate	0.16 ± 0.08 [a]	0.24 ± 0.06 [ab]	0.29 ± 0.06 [ab]	0.38 ± 0.02 [b]	0.39 ± 0.03 [b]	0.44 ± 0.02 [b]	0.37 ± 0.10 [ab]	-	0.695	-	-	-	-
Ethyl hydrogen succinate	165 ± 107	222 ± 49.9	177 ± 19.4	186 ± 55.3	243 ± 47.8	330 ± 15.7	219 ± 51.1	-	-	-	-	-	-

Table 4. Concentrations of the major esters (mg L^{-1} ± STD) in wines at the end of the alcoholic fermentation and after 3 and 1 year of storage. Influence of the tested factors on their production, as assessed by multiple regression analysis, are also shown (p <0.01). C: Control, L: Lysozyme addition, LT: Lysozyme and tannin addition, S: Sulphur dioxide addition, ST: Sulphur dioxide and tannin addition, SL: Sulphur dioxide and lysozyme addition; SLT: Sulphur dioxide, lysozyme and tannin addition). In the same row, different letters denote significant differences at $p < 0.01$.

*Only standardised regression coefficients (beta values) with $p < 0.01$, are reported.

	Wines							Regression coefficient*					
	C	L	LT	S	ST	SL	SLT	L	S	T	$Lyso x SO_2$	LysoxTan	$SO_2 x Tan$
End of fermentation													
Total acids	13.4 ± 2.81	10.5 ± 1.51	12.9 ± 0.91	10.5 ± 1.75	12.8 ± 1.15	13.7 ± 4.40	15.4 ± 2.04	-	-	-	-	-	-
Isobutyric acid	1.46 ± 0.19 b	1.55 ± 0.15 b	0.12 ± 0.01 a	2.20 ± 0.29 b	1.87 ± 0.23 b	2.00 ± 0.29 b	2.13 ± 0.20 b	-	0.533	-1.360	-	-	1.026
Butanoic acid	0.35 ± 0.06 ab	0.35 ± 0.03 a	0.33 ± 0.02 a	0.60 ± 0.09 b	0.46 ± 0.15 ab	0.37 ± 0.00 ab	0.38 ± 0.05 ab	-	1.147	-	-	-	-
Octanoic acid	8.61 ± 1.93	6.48 ± 1.25	8.88 ± 0.79	5.44 ± 1.02	8.36 ± 0.16	6.91 ± 3.11	8.96 ± 1.22	-	-	-	-	-	-
n-Decanoic acid	2.31 ± 0.94	1.40 ± 0.42	2.77 ± 0.19	1.32 ± 0.33	1.74 ± 1.01	3.39 ± 1.03	3.07 ± 0.50	-	-	-	1.402	-	-
Dodecanoic acid	0.15 ± 0.06	0.10 ± 0.03	0.19 ± 0.01	0.17 ± 0.12	0.13 ± 0.03	0.24 ± 0.03	0.27 ± 0.07	-	-	-	-	-	-
n-Hexadecanoic acid	0.53 ± 0.20 ab	0.60 ± 0.02 ab	0.61 ± 0.11 ab	0.80 ± 0.12 b	0.21 ± 0.12 a	0.81 ± 0.07 b	0.57 ± 0.09 ab	-	-	-	-	-	-
3 months of storage													
Total acids	15.9 ± 4.65 ab	15.4 ± 1.99 a	17.5 ± 0.74 ab	18.4 ± 4.14 ab	18.8 ± 0.87 ab	26.0 ± 0.30 b	43.5 ± 4.03 c	0.625	0.736	-	-	0.439	0.399
Propionic acid	0.03 ± 0.02	0.03 ± 0.00	0.03 ± 0.00	0.03 ± 0.00	0.03 ± 0.00	0.04 ± 0.01	0.03 ± 0.00	-	-	-	-	0.852	-
Isobutyric acid	0.97 ± 0.30 a	1.22 ± 0.05 ab	1.41 ± 0.13 abc	1.68 ± 0.19 bc	1.55 ± 0.07 bc	1.81 ± 0.10 c	1.32 ± 0.03 abc	-	-	0.851	0.426	-0.484	-0.583
Butanoic acid	0.25 ± 0.03	0.26 ± 0.04	0.30 ± 0.00	0.17 ± 0.15	0.28 ± 0.01	0.28 ± 0.00	0.29 ± 0.02	-	0.433	0.515	-	-	-
Pentanoic acid	0.72 ± 0.16 ab	0.57 ± 0.09 a	0.68 ± 0.07 ab	1.00 ± 0.08 b	0.87 ± 0.11 ab	0.85 ± 0.01 ab	0.95 ± 0.07 b	-	-	0.600	0.568	-	-0.420
Hexanoic acid	1.92 ± 0.39 a	1.86 ± 0.23 a	2.24 ± 0.18 a	1.99 ± 0.44 a	2.08 ± 0.05 a	2.46 ± 0.12 ab	3.22 ± 0.30 b	0.453	0.406	-	-	-	-
Octanoic acid	6.40 ± 1.64 a	6.45 ± 1.06 a	8.43 ± 0.66 a	8.06 ± 2.33 a	8.27 ± 0.83 a	10.0 ± 0.36 a	17.1 ± 1.89 b	0.570	0.840	-	-	0.542	0.495
n-Decanoic acid	2.10 ± 0.82 a	1.49 ± 0.25 a	2.11 ± 0.23 a	2.17 ± 0.78 a	2.74 ± 0.43 a	4.59 ± 0.02 b	7.04 ± 0.40 c	0.609		-	-	0.738	
Dodecanoic acid	0.18 ± 0.00 a	0.47 ± 0.32 a	0.29 ± 0.06 a	0.32 ± 0.08 a	0.38 ± 0.09 a	0.60 ± 0.03 a	1.16 ± 0.08 b	0.712	0.617	-	-	0.697	0.597
n-Hexadecanoic acid	3.22 ± 1.99 a	3.09 ± 0.68 a	1.96 ± 0.36 a	2.81 ± 0.79 a	2.52 ± 0.19 a	5.19 ± 0.24 ab	12.0 ± 6.02 b	0.550	0.773	-	-	0.524	0.569
1 year of storage													
Total acids	12.8 ± 2.87 a	13.7 ± 3.03 ab	14.5 ± 2.76 ab	15.2 ± 1.12 ab	16.1 ± 3.25 ab	23.0 ± 1.09 b	16.3 ± 4.17 ab	-	-	-	-	-	-
Propionic acid	0.03 ± 0.02	0.03 ± 0.00	0.04 ± 0.00	0.03 ± 0.00	0.04 ± 0.01	0.04 ± 0.00	0.04 ± 0.01	-	-	-	-	-	-
Isobutyric acid	0.93 ± 0.15 a	1.08 ± 0.01 ab	1.27 ± 0.13 abc	1.60 ± 0.18 c	1.24 ± 0.17 abc	1.46 ± 0.07 bc	1.48 ± 0.20 bc	-	0.869	-	-	-	-
Butanoic acid	0.24 ± 0.01 ab	0.24 ± 0.01 ab	0.26 ± 0.01 b	0.22 ± 0.03 ab	0.20 ± 0.01 a	0.27 ± 0.01 b	0.25 ± 0.01 ab	-	-	-	-	-	-
Pentanoic acid	0.73 ± 0.27	0.62 ± 0.04	0.69 ± 0.04	1.04 ± 0.15	0.84 ± 0.15	0.85 ± 0.04	0.83 ± 0.02	-	-	-	-	-	-
Hexanoic acid	1.97 ± 0.41	2.00 ± 0.45	2.23 ± 0.30	1.88 ± 0.16	2.02 ± 0.17	2.26 ± 0.11	1.84 ± 0.42	-	-	-	-	-	-
Octanoic acid	5.50 ± 1.63	5.36 ± 2.32	6.32 ± 1.85	6.06 ± 0.97	7.57 ± 1.24	9.30 ± 0.44	6.56 ± 1.95	-	-	-	-	-	-
Decanoic acid	1.21 ± 0.48 a	0.59 ± 0.30 a	0.91 ± 0.27 a	0.67 ± 0.17 a	1.57 ± 1.11 a	3.91 ± 0.19 b	1.20 ± 0.72 a	-	-	-	0.828	-0.775	-0.652
Dodecanoic acid	0.49 ± 0.47	0.84 ± 0.12	0.42 ± 0.13	0.17 ± 0.04	0.31 ± 0.16	0.64 ± 0.03	0.46 ± 0.22	-	-	-	-	-	-
Hexadecanoic acid	1.55 ± 0.15	2.74 ± 0.21	2.27 ± 0.95	3.49 ± 1.09	2.13 ± 1.23	4.26 ± 0.20	3.54 ± 2.02	-	-	-	-	-	-

Table 4. Concentrations of the major acids (mg L^{-1} ± STD) in wines at the end of the alcoholic fermentation and after 3 and 1 year of storage. Influence of the tested factors on their production, as assessed by multiple regression analysis, are also shown (p <0.01). C: Control, L: Lysozyme addition, LT: Lysozyme and tannin addition, S: Sulphur dioxide addition, ST: Sulphur dioxide and tannin addition, SL: Sulphur dioxide and lysozyme addition; SLT: Sulphur dioxide, lysozyme and tannin addition). In the same row, different letters denote significant differences at $p < 0.01$.

*Only standardised regression coefficients (beta values) with $p < 0.01$, are reported.

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