MODELLING FRESH GOODS SUPPLY CHAIN CONTAMINATION

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ABSTRACT
This paper proposes models of supply chain devoted to investigate food contamination with special attention to fresh goods; these phenomena are becoming more a more critical and the paper proposes models of both demand evolution, countermeasures for mitigating the impact, operations and logistics; an experimental analysis is provided in order to validate the models and the proposed approach.

keywords**:** Vulnerability, Supply Chain Contamination, Fresh Food Supply chain, Risks, Supply Chain Modeling; Supply Chain Recalling

INTRODUCTION
Supply chains are growing in term of complexity and evolve to be more and more vulnerable against risks due to many factors, in particular the high number of interdependencies introduces vulnerabilities in food and beverage logistics. Indeed the food and beverage industry is characterized by several risks affecting the logistics processes that have different origins; for instance they could be originated from market, from suppliers; sometime risks arise from processes internal to the supply chain itself (i.e. storage, distribution, …) other times they are originated from the external environment (i.e. epidemics, wars, politic problems, …). For what concerns food supply chain, events like contaminations are extremely dangerous in terms of effects, due to the fact that they introduce safety risks affecting health status of a large number of people; this fact obviously have a big impact in term of economic risks for Company stability.
These events are currently becoming more frequent due to several reasons (i.e. intensive food production, use of innovative solutions that could introduce risks of contamination, outsourcing versus not very reliable providers) so it clear the importance of preventing and mitigating these phenomena; Modeling & Simulation (M&S) is a powerful methodology to address this challenging problem, especially considering the high number of variables and interdependencies that are present in the supply chains and that becomes even more critical in food logistics (i.e. traceability, transport/storage conditions, variability of demand, recalling of products in case of contaminations, …).
In this paper is proposed a simulation based model devoted to study fresh fish supply chain; this model was developed based on Discrete Event stochastic simulator and it is implemented in Extendsim®. After the description of the conceptual model the paper proposes a case study related to a fresh fish supply chain specific for the North Italy (Bruzzone et al. 2009); the results are presented as demonstration of potential of this approach as well as example for its operational use; in addition the future research opportunities are summarized.

1. DEFINITION OF SUPPLY CHAIN RESILIENCE

Movement of people, goods and information have always been fundamental components of human society. Contemporary economic processes have been accompanied by a significant increase in mobility and higher level of accessibility, Rodrigue et. al. (2006).
Due to contemporary economic and globalizations of markets, supply chains have become more and more complex, particularly in the last two-three decades. Such complexity has the advantages to increase the business opportunities but makes the supply chains more vulnerable against risks; such events can lead to extremely catastrophic situations both for companies and for final customers.
The historical origins of the "Globalization Process" are the subject of on-going debate: some experts situate that process in the modern era and other attribute to that phenomenon a long history.
By the way, according to many economist experts, market globalization has started in 1980s mainly due to exponential improvement in transportation and telecommunications infrastructures and services.
Such easy way to transfer information and goods, has facilitated the globalization of the supply chain, first for global companies, and later for medium size enterprises, that have increased their flexibility at the "cost" of making each process more complex; the evaluation of the performance by using M&S was addressed by many authors due to the system complexity (Macias et al. 2004; Baruwa & Piera 2008;

Curcio and Longo, 2009; Merkuryev et al. 2008; De Felice et al. 2010; Merkuryeva et al. 2011; Vonoflen et al. 2011). Such complexity is due to the increasing number of interdependencies between all the legs along the supply chain, from the procurement phase up to the final customer. Outsource some process makes the supply chain itself more and more flexible and agile to the market, for example giving the possibility to outsource parts of the logistic or distribution (i.e. 3PL-Third Parties Provider, 4 PL-Fourth Parties Providers,…) or parts of the production process by sourcing globally from suppliers. Anyway, more the supply chains is slim and flexible, more it becomes vulnerable and exposed to risks due to the high number of interrelations. The "resilience" is a way to measure such vulnerability; Barroso et al (2011) define supply chain resilience (SCR) as "the ability to react to the negative effects caused by disturbances that occur at a given moment in order to maintain the supply chain objectives", and Falasca et al (2008) consider SCR as "the ability of a supply chain system to reduce the probabilities of a disruption, to reduce the consequences of those disruptions once they occur, and to reduce the time to recover normal performance". That definition is quite similar to Sceffi (2005), that define SCR as the "ability of an organization to successfully confront the unforeseen".

For a detailed review of the possible definitions of "supply chain resilience" see Stravos et al. (2012).

Furthermore many authors (Merkuryev et al. 2009) have defined the basic elements that affect supply chain resilience as: flexibility, agility, velocity, visibility and redundancy and in Longo & Oren (2008) is presented an overview of many examples of real case studies of supply chain disruption.

The importance of that topic is proved not only in academic research but also "in the business world", both for global firm and for Small and Medium Enterprises (SMEs). For example, recent surveys for Global Firms, such as "Understanding Supply Chain Risks; Mc Kinsey Global Survey", underlines that 65% of the surveyed executives believe that supply chain risk is growing and Jüttner & Ziegenbein (2009) confirm that this topic is important also for SMEs, because they are often exposed to the same risks as their large international firm counterparts but they miss the necessary resources, structures and processes.

This paper focuses on modeling and simulating a particular risk on a supply chain: the risk of contamination.

In particular for certain products, such as fresh food, the contamination of products can cause extremely dangerous situation, both in term of health and in term of money. In fact, when such kind of events happens, the consequences can be really serious: loose of brand image, loose of sales, cost for recalling the products and health problems or diseases.

Food contamination refers, in general, to the presence in food of chemicals or microorganisms that can cause consumer illness.

In this work a fresh fish supply chain is considered and a simulation model is defined in order to create a tool for supporting decision, prevent and mitigate risks by means of simulation techniques.

This work consists of 6 Section; Section 1 is an introduction to the topic of supply chain resilience and Section 2 provides a state of the art on the use of M&S to face supply chain risks. Section 3 is a short description of different source of contamination in fresh fish supply chain and in Section 4 the description of the model is presented. Section 5 provides a case study for the fish supply chain in the North of Italy and finally, Section 6 provide conclusion and possible next steps for future researches.

2. STATE OF THE ART

Supply chain stability should be attacked by many threats; these are usually emerging from potential risks affecting logistics and operations as well as market environment; in "Understanding Supply Chain Risks; a Self Assessment Work Book (2003)" risks are classified in external or internal. The external risk identifies epidemics, wars, politic problems, natural disasters, which can be considered totally external to the supply chain and are hardly predictable and quite impossible to face. Risks coming from the market or from suppliers are considered external to the company but internal to supply chain, and finally, risks related to the process and activities are considered totally internal to the company (Fig.1).

Also Christopher and Peck (2003) categorized risks into 3 similar macro-areas, and identifies five categories:

1. Internal to the firm:
    - i) Process
    - ii) Control
2. External to the firm but internal to the Supply Chain:
    - i) Demand
    - ii) Supply
3. External to the Supply Chain:
    - i) Environmental

Longo & Oren (2008), trying to clarify the complex problem of supply chain resilience, have also identified a possible classification of some areas of research:

1. Supply chain vulnerability, security and resilient management
2. Methods for demand forecasting and supply risk analysis in supply chain
3. Information management and visibility along the supply chains
4. Supply chain Life Cycle Costing
5. Modelling / Simulation devoted to support supply chain resilience

For what concerns the last point, Modeling and Simulation (M&S) is proved to be a useful instrument to consider the complex interrelations between all the constraints and the variables in the supply chain, in particular for fresh food, which needs much more processes instead that traditional foods. (Bruzzone et al. 2008).

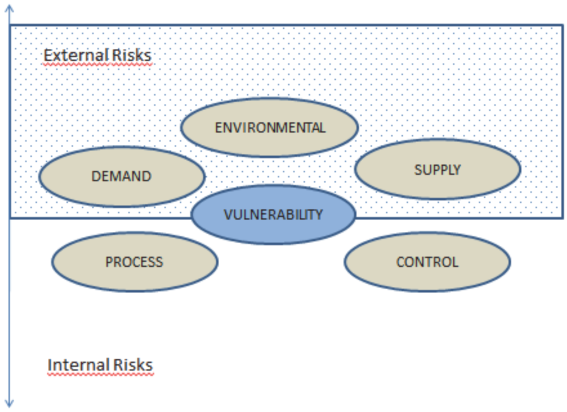

Figure 1: External and Internal Risks for the supply chains

Examples and applications of M&S for fresh food supply chain are reported in Bruzzone & Tremori (2006), that apply M&S in fresh fish and meat supply chains, providing the opportunity to test methodologies and to develop decision support systems based on optimization techniques.
Another work, Busato & Berruto (2009) describes and simulates the recall process of contaminated product by using a discrete event simulation; such kind of simulation is used also in R. Rossi (2012), for investigating the impact of dual sourcing strategies on quality of fresh fruit traded in international supply chains.
Bruzzone & Tremori (2009) focuses on modeling adverse events impacts on retail networks; the model simulates phenomena such as terrorism actions, contaminated or defective product lots, including the influence of media broadcasting news and fear of the market, by making use of System Dynamics Techniques.
For what concerns the economical aspect of catastrophic events on the supply chain Ernst & Young (2011) gives an overview of how companies can quantify recall losses and maximize recovery of those losses from suppliers and insurers, in particular for recall cost. Furthermore, the demand variability in case of these events and the probability distribution of loses is investigated by Sun and Yu (2005).

3. THE FRESH FISH SUPPLY CHAIN RISKS

In order to build a model by which simulate the contamination phenomena, it is necessary to have a good understanding of the supply chain for fresh food products.
Fish can be classified by their origin/production in

- Farmed fish
- Fished fish

or by their storage condition in:

- Fresh fish
- Frozen fish

These differences have a strong influence in the structure of the supply chain, because they determine the range of temperature to be respected in the whole process (i.e. handling, transport, processing,…).
For example distribution is really critical because each time the cold room or the refrigerated truck is opened, there is a change on the temperature, which can cause and accelerate the reproduction of micro-organism, causing contamination.
Also the quality of fodder and water plays a primary role both for the fished product and for the farmed one.
Farmed fish has a high probability to be contaminated by suppliers that provides the animal fodder while fished fish can be contaminated because it is fished in an area where the level of pollution is high or exceptional event are happened discharging in the sea toxic substances.
Furthermore, the transportation in cases (tanks of aluminum, wooden or polystyrene with dry ice), or manufacturing at sea by sea water (cutting of the head, evisceration, storage, freezing, or packaging), or transport (i.e. vessels can remain at sea for days, then there is truck, plane and or train), or finally the storage places (cool box, refrigerated containers, cells, shelves) can be point of risk and possible causes of contamination and alteration of the quality of the product.

4. MODEL DESCRIPTION

In this section the mathematical model is described; the final aim is to reproduce the dynamic behavior of the whole supply chain for fresh fish from the supply side (fishing/farming) up to the final customer in case of a contamination event.
In this work a Discrete Event Simulation (DES) approach is used. DES is a discrete-state, event-driven system: this means that its state evolution depends entirely on the occurrence of asynchronous events over time, Cassandras & Lafortune, (2006) ,Discrete event Simulators are powerful instruments to model the complex dynamics in systems where many variables interact each other.
When contamination occurs, the “stationary” conditions of the goods flow that moves towards the supply chain are perturbed by the contamination of a certain quantity of products. That infected items can be potentially contaminated in each leg of the supply chain with a given probability P and will reach the market or the final consumer in a given time, depending on the structure of the supply chain itself (i.e. number of legs, frequency of orders, quantity of stock in the chain).
Obviously, later the contamination is discovered, more the consequences will be heavy because the contaminated product may be already in the shops or, in the worst case, already consumed.
The main events and main time of occurrence are defined in Tab. 1; the process considered starts from the contamination instant and ends when all the effect of the contamination are totally finished in each leg of the chain.

Table 1: main events in the studied scenario

τ_α	Time when contamination occurs
τ_β	Time when contamination is discovered by the company
τ_γ	first case of disease/illness/death
τ_ν	the media gives the first announcement of the event
τ_o	Time when the media campaign reach the maximum level
τ_ϕ	time when the fear reach the maximum level
τ_ε	time when the product reach the market
τ_ρ	time when the media campaign stops
τ_σ	time when the fears is equal to zero
e_α	contamination event
e_β	company realize the problem
e_γ	first announcement from the media
e_δ	media campaign stops
e_σ	fears is equal to zero

In Fig. 2 the logical time sequence of the events is reported: all the process starts with the first event that is the product contamination e_α and the whole process ends when the problem is completely solved and customer's fear stops in τ_σ.
The simulation starts in a stationary situation where CEDI, wholesaler, and retailers are refurbished of the requested quantity of food $Q_i(\tau)$, in order to satisfy a demand $D_i(\tau)$ of each i –cathegory of fish. At a given time τ_α, a quantity Q of fish is contaminated in a given part of the supply chain (i.e. fishing/farming, CEDI, wholesalers, retailers) and starts to propagate along the chain.

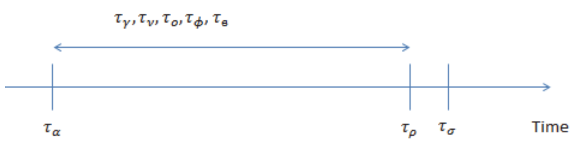

Figure 2: time sequence of the main events

All the other events, don't have a fixed schedule, because they can happen with different combinations and sequences. For example company can realize the problem of contamination before that the product reach the market, or in other cases it can be too late and the problem may already be on the shelves; furthermore diseases and effects on health can happen also before that the company realize of the contamination.
The intensity and frequency of quality control influence the probability of contamination in each leg and the quantity of product to be recalled; furthermore the structure of the supply chain determine the lead time and, consequently the speed in propagations of infected products in the both directions (distribution and recalling).
After contamination, there are two/three possibilities:

I. Company is the first that realize the fact and start recalling process
II. Media is the first to give the notice of the first contamination
III. No one understand the problem and contamination spread to many customers

In case I is the company itself that understand the problem through quality controls and starts the recalling process, before that people is contaminated.
There is a low damage in term of image of the brand and the main damages are in terms of lost sales due to the recalling of the products and the empty shelves. This is the best situation since the company can contain the damages. In case II the media give the notice and the company has many damages in terms of loss of image and compensations for contaminated people. There are also secondary effects: for example the demand of the other products of the same company may decrease because the low level of trustiness in the brand.
Case III is obviously the worst, because the contamination continues to spread postponing I or II and making the situation more and more serious.
As told before, when the process of recalling starts, a quantity of products is retired from the market; this is a cost not only for the process itself, but also because it determine lost sales due to the empty shelves and sales will be affected for a given time period Δ_τ that is needed to refurbish the market with the new and uncontaminated product. Contamination in production can be modeled as (1):

$$\Delta\tau_{Tot} = \Delta\tau_C + \Delta\tau_P + \Delta\tau_L \qquad (1)$$

Where:

$\Delta\tau_{Tot}$ = Total delay in market refurbishing
$\Delta\tau_C$ = Time to check the problem
$\Delta\tau_P$ = Time to change production/supplier
$\Delta\tau_L$ = Lead time

That is because production may stop for a given time in order to find the source of contamination $\Delta\tau_C$, and after that a time period $\Delta\tau_P$ is needed in order to check/change/substitute some production process or supplier and restart with the production, and finally, the product reach the market after the lead time $\Delta\tau_L$.
In this model, the demand risk after a supply chain contamination is supposed to be function of demand in normal condition; in order to considerer the effect of media campaign the Fear Level Function is introduced. That function depends on the amount of information provided by media, which are represented by the Media Campaign Function.
Fig. 3 defines the relation between the shape of the media campaign and the fear level.

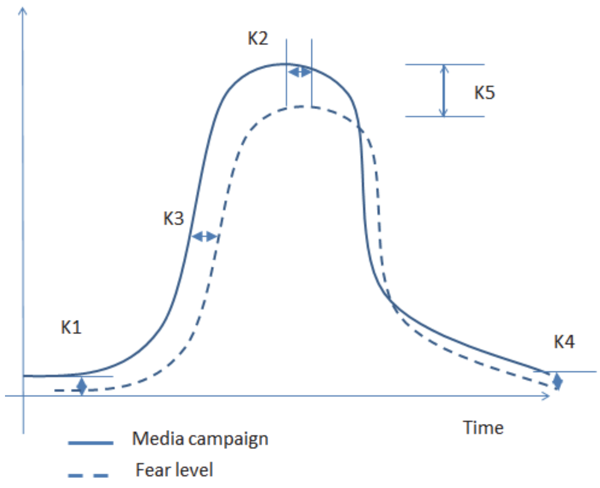

Figure 3: Fear level and Media Campaign in case of contamination event

Parameters k_i allow obtaining the fear function in time, in function of the Media Campaign curve:

$K_1(\geq 0)$: media know the information before market

$K_2(\geq 0)$: maximum peak delay

$K_3(\geq 0)$: market delay to information

$K_4(\geq 0)$: fear stops only when media campaign stop

$K_5(\geq\leq 0)$: maximum peak difference

Fear level is supposed to be a proportional function of the Media Campaign curve; as is possible to note in Fig.3 the market have some delay respect the information provided by the media; some of the factors may be :

1. market don't trust to the emergency
2. market don't receive the notice
3. market have some "inertia" in change the behavior

The implicit assumption is that the market's fear will stop only after that the media campaign will stop ($K_4(\geq 0)$:).

Initial demand $D_i(\tau)$, that is the demand of product *i* before the contamination is supposed to be known, in order to evaluate the $D_i'(\tau)$, that is the demand after the event of contamination.

$D_i'(\tau)$ is the demand function after that the market have the notice of contamination; equation (2) express $D_i'(\tau)$ as a function of $D_i^*(\tau)$ that is the average demand before that event, the fear level, and a decreasing factor depending on time.

$$D_i'(\tau) = D_i^*(\tau) - F_i(\tau)a + \varepsilon(\tau) \quad (2)$$

Where:

$\varepsilon(\tau) =$ decreasing factor

$F_i(\tau) =$ fear function

a, b > 0 that are parameters to be determined

In Fig 4 the qualitative shape of $D_i'(\tau)$ is illustrated.

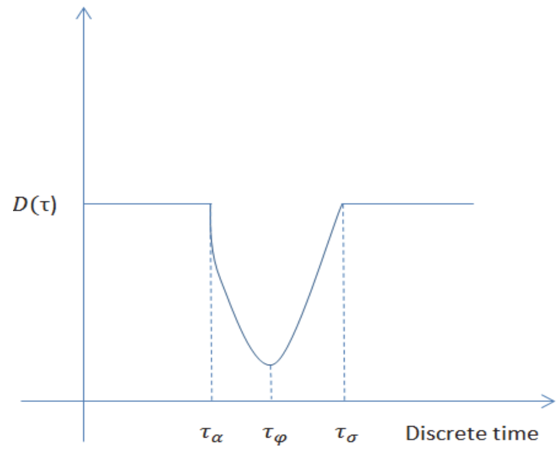

Figure 4: Qualitative shape of demand function in case of supply chain contamination

In general we can say that fear is driven by two opposite forces: is alimented by media and it is reduced by time $\varepsilon(\tau)$.

Other factors that could be considered, in general, when contamination occurs are the following:

- The demand $D_i'(\tau)$ of the contaminated i -class of food falls down af [3]
- The demand for similar products increases [4]
- The total fish demand falls down [5]

When

$$D_i'(\tau) << D_i(\tau) \quad (3)$$

$$D_j' << D_i(\tau) \quad (4)$$

$$\sum_\tau D_i'(\tau) + \sum_\tau D_j'(\tau) < \sum_\tau D_i(\tau) + \sum_\tau D_j(\tau) \quad (5)$$

5. CASE STUDY

In this section a simulation of a real supply chain of the fresh fish distribution in the North of Italy is reported. Four CEDI respectively located in Milan, Genova, Venice, and Bologna are considered and the relative market share considered is reported in Fig. 5.

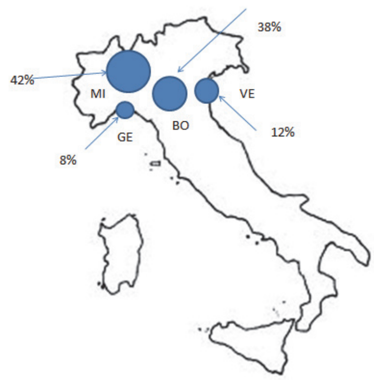

Figure 5: market share of main fish CEDI in the North of Italy

The entire supply chain is simulated with the software ExtendiSim®; in particular both the physical flow and the information flow is considered. Physical flow moves goods from supply to the customers, whilst information flows moves in the opposite direction providing the market demand and the respective orders from Retailers, Wholesalers and CEDI.
In Tab 2 the parameters determining the effectiveness of the recall process in each link of the supply chain are reported:

Table 2: parameters for effectiveness of recall

Parameter	Description	Value
Time when contamination occurs	The tracking system recognize the problem	Time of contamination, identification of the infected leg
Time when the problem is discovered	The recalling process starts	Time and leg of the chain where recall starts
Transit time	Longer is the transit time lower is the probability that contaminated product reach the market	Total delay of the interested legs of the supply chain
Inventory level	Gives the amount of goods stocked in the chain	Quantity and location
Information time	It's the time needed for sharing the information along the supply chain	Delay
Traceability index	Gives the % of product that needs to be recalled, it is a function of the level of traceability and integration of the supply chain	% of product that needs to be recalled
Time for organizing the product recall	Time that company need to start the process of recall	Delay
Time for physical recalling	Lead time for the recalling of all the product from the market	Delay
Time to restart new production/distribution of new product	Time needed by the company to produce/supply new non contaminated products	Delay

In Fig.6 there is a screenshot of the model: both the information and the goods flow is simulated along the supply chain. We make use of hierarchical blocks that allow building the model with a "black box" approach, by refining the details all the simulation also in a second time, without modifying the whole model.

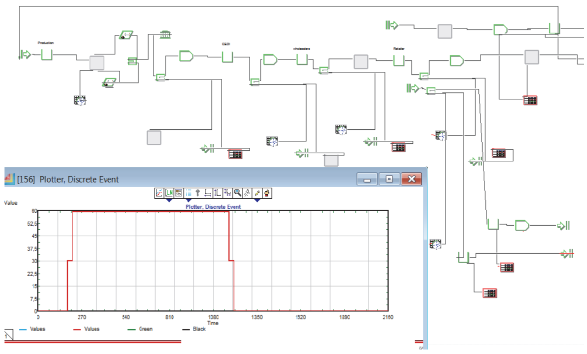

Figure 6: Screenshot of the model

The simulation starts with a demand profile that is known and propagates up to the production that produces the requested quantity to satisfy such demand. For sake of simplicity the demand is considered constant in time; after a certain time all the model reach a stationary condition..
After that the simulation is in stationary condition, in each leg is assigned a certain probability of a contamination event in function of the number of quality controls performed in each section; when contamination occurs, all the other probability are set to zero by the system and a quantity of goods Q starts to propagate in the chain.
When the company understand the fact, the recall process is activated and the goods starts to be retired from the market; in order to consider the effect of traceability systems, we can suppose that the quantities that needs to be recalled in each leg is just a fraction of the total stored quantity in each leg, that decrease in function of the efficiency of the tracking systems of the company considered. At the same time that the recalling process starts, the system simulates the contamination in the market by evaluating the number and gravity of contamination cases with a stochastic approach; ; it is evident the importance in this case study to adopt experimental design for addressing the effects introduced by stochastic factors and to properly estimate the confidence band (Montgomery 2000). Finally the model gives the possibility to introduce the cost for each process and activity performed, for example simulating the transport cost, or inventory cost, as well as the cost of lost sales due to the absence of the product in the shelves.

6. CONCLUSIONS

A model for the simulation of fresh fish supply chain phenomena is described and simulated by using Discrete Event Systems (DES) techniques., Media campaign and market fear have been considered and used in the determination of the demand function of a given product after a contamination event in the supply chain. Media induce and aliment the market fear, which determines the reduction of the previous demand.

In future research a more detailed model could be considered, by capturing the behavior of the single customer or groups of customers by a disaggregate simulation of the demand profile. For four different categories and different way to react to such kind of event may be considered:

I. Spike panic (no demand for all the type of fish)
II. Moderate panic (no demand only for the contaminated variety of fish)
III. Slow raising fear (decreasing demand of that particular contaminated fish)
IV. No fear (no change in demand)

Furthermore a more detailed simulation of the supply chain may be useful, in order to capture the influence of technologies like tag or sensor, that increase the traceability, reducing the risk and speeding up the recall phenomena.

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