Resiliency and Vulnerability in Short Life Cycle Products' Supply Chains: a System Dynamics Model

ENRICO BRIANO ☒
CLAUDIA CABALLINI *
PIETRO GIRIBONE #
ROBERTO REVETRIA #

☒ DIP CONSORTIUM
Office Tower, Voltri Distripark Europe, 16158 Genoa, ITALY
* CIELI – Italian Centre of Excellence in Integrated Logistics
Via Bensa 1, 16132 Genoa, ITALY
DIPTEM – Department of Industrial Production, Technology, Engineering and Modelling
Via Opera Pia 15, Genoa, ITALY
enrico.briano@dipconsortium.org; claudia.caballini@cieli.unige.it; giribone@itim.unige.it;
roberto.revetria@unige.it

Abstract- The work is focused on the study of a supply chain related to short life-cycle products, that are goods produced and sold for a limited period of time like fashion goods, electronic devices, health care service and particular foodstuffs. The case study belongs to the last one category and regards a particular good produced by an important Italian food company, with several branches all over the world, operating in the field of snacks, biscuits and bread substitutes.

Currently the data in the simulation model are assumed by the authors due to a delay on the provision, but the real company data should be available, properly modified for reasons of confidentiality, for the extended version of the paper.

In the following sections a simulation model, implemented using the System Dynamics methodology, will be described. System Dynamics approach is suitable for complex dynamic systems like the one object of this work; this methodology considers in fact time delays and feedback loops, which heavily affect the system structure and behavior. The model has been implemented using one of the most known System Dynamics commercial software: Powersim Studio™, because of its flexibility and completeness, allowing also integration with databases, external files and ERP systems.

The aim of the simulation is to identify and focus on the criticalities along the supply chain in order to minimize the total costs and, consequently, maximizing the company profits. *"What If"* analysis have been carried out in order to show which is the best policy to adopt in terms – for instance – of safety stock or demand planning.

Moreover, the concepts of vulnerability and resiliency applied to these kinds of supply chains have been analyzed. After a short classification of threats and risks for supply chains, the case in which an environmental risk (an earthquake) occurs, striking the raw material supplier, is modeled and simulated with the System Dynamics methodology. The obtained results show that with a more resilient supply chain, characterized by the procurement from two different suppliers (instead on only one) located in different geographical areas, business continuity is guaranteed even in the case of a natural catastrophe.

Key Words- Short life-cycle products, simulation, supply chain management, System Dynamics, Powersim Studio, vulnerability, resiliency.

1. Introduction

Nowadays supply chain management for short life-cycle products is a significant issue for companies dealing with this kind of goods. For definition, a good which has a short life-cycle is produced and sold only for a limited period of time, typically under 12 months; after that period it is dismissed from the market and/or it is substituted by an updated version. Short life-cycle products significantly differ from products that have a medium-long life cycle, and all these differences have to be taken into account. Items belonging to the first product class are trendy, emotional and hi-tech goods such as electronic devices (i.e. mobile phones) and fashion goods, and the reason of this shortness is determined by the high innovation rate or by the high importance of emotional or trend factors.

Companies have to face many issues that negatively affect their ability to respond quickly to the floating market demand; among them there are long production lead times and uncertain economic situations. These issues to be fixed however represent a stimulating challenge for companies.

In particular our focus is on short life cycle products, which are often emotional or trendy, so one of the main differences between them and classical long life cycle products is the fact that customers buy them driven by the emotional impact in terms of brand and popularity rather than for the product technical quality, which is taken for granted. However one aspect that it is not guaranteed is the closeness between the item and the customers' aspirations (what they want to be or what they are expecting owning this item). What they buy is first of all the idea revolving around the product, enforced by the brand and by the distinctive details in which they better identify themselves.

In this work we propose a simulation model devoted to study the supply chain behavior focusing on short life cycle products, confirming the fact that simulation is a precious and powerful tool to better understand complex systems dynamics – like the one object of this study – and to analyze the effects caused by different changes to the system structure and configuration, in order to find the best suitable policy to adopt.

The use of simulation models has significantly increased for the analysis of production systems in order, for instance, to increase products' competitiveness, to improve the supply chain performances or to increase profits and customer satisfaction.

One simulation methodology particularly devoted to study complex, continuous systems is System Dynamics, developed in the '50s by Prof. J. Forrester at Massachusetts Institute of Technology (M.I.T.).

This approach allows studying current and future behavior of continuous systems over time, analyzing internal feedback loops and time delays, which significantly affect the whole system behavior. The main difference between System Dynamics and other approaches is the utilization of feedback loops and stocks and flows, which help describing how even seemingly simple systems display nonlinearities.

This methodology also allows formulating "What If" analysis in order to test policies devoted to provide an aid on understanding the system changes over time.

System Dynamics approach has been intensively used for studying company supply chains, even in case regarding short life cycle products.

Wu and Aytac, in [1], present a new approach to characterize the short life cycle technology demand, indicating how companies can structure their supply chains in order to better respond to upside demand and to absorb downside risks avoiding excessive inventory or capacity levels.

Kamath and Roy, in [2], thanks to a loop dominance analysis method, discovered that the dynamics of the "capacity growth" variable is significantly affected by the loop that connects retail sales with production order. This means that, in order to satisfy the market demand, changes over time on the plant capacity are needed.

In our research the plant capacity has assumed to be fixed, because the capacity adaptation takes a long time, if compared with the speed of change in demand for short life cycle products, implying a more critical situation in respect to the case in [2].

Again Kamath [3] proposes a method for identifying critical information flows regarding a two-echelon supply chain using a system dynamics mode, in order to properly study its feedback loop structure. The outcome is a set of dominant loops determining how the capacity growth behaves.

The Powersim Studio 7 software, developed by Powersim Software AS from Norway, has been chosen and used for the model implementation. This software allows simulating complex systems using System Dynamics approach.

After the modeling of a short life-cycle product supply chain, it has been analyzed and studied how to make it more resilient.

Vulnerability of supply chains is a problem that affects many companies, which have to deal with current markets, uncertain and turbulent.

Vulnerability's sources may be very different – globalization, outsourcing, demand volatility, earthquakes or terroristic attacks – and all the supply chain's actors, from the supplier to the ultimate customers, are deeply involved in avoiding the occurrence of damaging risks.

In order to identify solutions to increase the performance a short lifecycle products' supply chain, an approach composed of four main steps has been followed, based upon the theory of the MIT

Professor Yossi Sheffi, one of the most important subject matter expert.
After an accurate analysis of the supply chain under study, the vulnerability analysis has been arranged through the identification of the potential risks and their introduction in a vulnerability framework, in which the attention has been put on high impact/low probability risks like, for instance, an earthquake. Then, thanks to the software Powersim, a solution to make the supply chain more resilient has been implemented.
The paper is divided as follows: Section 2 provides a description of short life cycle products supply chain, while in section 3 the short life cycle products supply chain System Dynamics simulation model, implemented in Powersim, is described and analyzed, in terms of structure and results. Section 4 presents aspects strictly related to resilience in short life cycle products supply chains, proposing an approach to face the impacts of an earthquake on the raw materials supply and finally in section 5 some conclusions are presented.

2. Overview on short life-cycle product supply chain

As seen in Section 1, the management of short life cycle products supply chain is different from the one relative to standard life cycle products in several aspects.
The main differences between the two supply chain typologies are described in Table 1 below:

Table 1: Differences between short and long life cycle product supply chains (see [4]).

Activity areas	**Supply chain for a short life cycle product**	**Supply chain for a long life cycle product**
Planning	- Elementary planning - Accurate and separate demand estimation for every product and service, followed by computing a single value for the company	– Global/General planning – a single sales forecast is estimated for the company; it is possible with a robust range of products
Forecasting	– Heuristic methods of forecasting – Qualitative methods – Forecast by analogy	– Quantitative methods – Statistical methods of forecasting
Manufacturing	– Flexible manufacturing systems – Highly automated systems – Manufacturing of a wide range of products – Outsourcing – Hybrid manufacturing processes	– Highly automated systems – Production lines
Inventories and warehouse management	– Manufacturing to order – Reducing a number of stored materials and products	– Manufacturing for stock – Purchasing of products for stock
Replenishment (suppliers)	– Global replenishment systems – Long term contracts enabling flexible time planning and ordered quantities – Reducing a number of suppliers to those who offer the widest ranges of raw materials – Consolidation of orders from multiple sources	– Domestic and local suppliers – Frequent changes of suppliers – Long delivery times – Large number of suppliers – Traditional way of communication, no common and shared information systems

Short life cycle products necessarily require a more responsive, flexible and agile organization, compared with long life cycle ones.
M.L. Fisher [5] states that products with short life cycles require a supply chain that is completely different from the one suitable for standard products. Supply chain managers must be able to face the effects of an unstable demand and to learn to adjust it taking into account the continuous changes in customers' needs and requirements.
For this particular kind of products the demand forecasting must be more accurate and precise because it is concentrated in a shorter time period and it must be accurately followed by production. It is also important, because the product duration is limited, to adopt a precautionary approach, especially at the end of the life cycle, in order not to remain with unsold items on stock.
Also the demand pattern is pretty different if we consider short life cycle and long life cycle products: as a matter of fact, considering the same conditions of total cumulative demand, long life cycle products present an higher variance, and so a more spread pattern distributed on a lower peak, underlining the typical behavior of the life cycle curve divided in four phases (introduction, growth, maturity and decline). On the contrary short life cycle products have a high peak and a shrinking curve associated to a smaller variance, constraining the production to be reactive and timely in the product launch.
This particular shape requires an accurate study of the demand for the whole life cycle of the product, closely associated with the available production capacity.

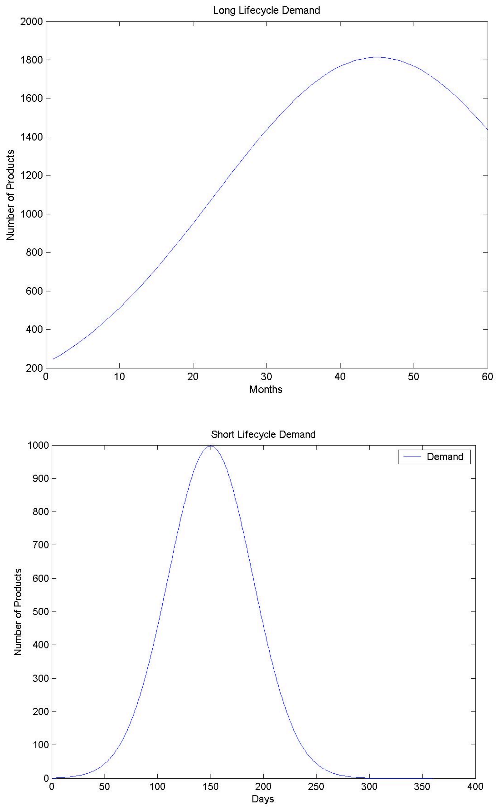

Fig.1 Typical demand patterns for long (upper curve) and short (lower curve) lifecycle products

The big demand concentrated in a short period compels the production to be very reactive in order to strictly follow it, under an uncertain regime. In order to do that, it is important to study in an accurate way the demand, considering the constraint of the available production capacity.
Real production systems have often a stochastic demand; this implies the possibility of rapid and unpredictable changes that require a continuous demand update.
During the product lifecycle could happen that the demand exceeds the maximum plant capacity, in this case the company can choose among different alternatives to face this request and satisfy all customers: adapt the capacity to demand or produce item for stock to be used to face the “overcapacity” periods.
Supply chain managers have to sustain demand growth by building inventory or holding excess capacity to buffer against demand variability.
Moreover it is preferable to adopt a precautionary policy instead of producing a quantity surplus because, after the end of the product life cycle, this item will not be sold anymore, burdening companies with a significant inventory cost due to the lack of sales.

3. The System Dynamics Model applied to a food supply chain

This section presents a real business case of an Italian food company dealing with a short life cycle product supply chain. To better understand the supply chain behavior a System Dynamics model has been implemented using Powersim™ software. The product analyzed has a life cycle of just few months.
It must be underlined that food companies consider products with short life cycles (less than one year) as products not successful that have failed the launch on the market. However there are some products that may be considered as short life cycle ones: they are standard products for the ingredients, but with a temporary different packaging or with a gift inside, produced only for few months and related to a particular marketing campaign or a particular event (for instance Christmas, Valentine Day, Olympic Games, Football World Cup, etc.).
Figure 2 shows schematically the supply chain considered, composed of three main steps: items are processed in two different steps, each one having different production times. In the specific raw materials are ordered mainly from just one supplier, even if it is considered the option to refer to more suppliers in order to protect the company from eventual stops and disruptions, introducing a concept of resiliency, which will be analyzed in detail in a further work.
The first step transforms raw materials in semi-finished products, called WIP (Work In Progress): this intermediate step is necessary in our case study because the extruded products need to be fried. The desired WIP is a function of the safety stock and the future forecasting.

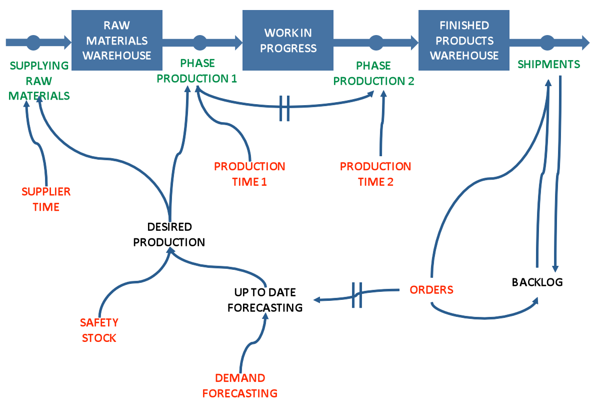

Fig.2 Conceptual model

Half-finished fried items are finally transformed into final products after another productive process characterized by a third lead time.
The demand forecasting is a model input and it is continuously updated considering the gap between a double exponential smoothing determined on the basis of the actual sales and the forecasted demand.
Forecast is checked every three weeks and every time is updated and compared with the previous forecast value in order to monitor the customers demand and to optimize the production rate.
As initial conditions, the values of the initial warehouse levels of raw materials, semi-finished products and finished items are given as inputs. All levels are regulated by a safety factor associated with the updated demand.
After the realization of the finished products, shipments have been taken into account considering the market demand, the finished products available in the stock, and also backlog.
In this specific case the backlog is reintegrated by subsequent orders, but in some other cases, not considered in our study, the recovery of lost orders is not possible.
It is also determined the total profit company, by the calculation of the difference between the total revenues and the total costs. Costs are composed by three terms: inventory, order and shortage costs added together, while revenues are calculated multiplying the number of sold items for the unit revenue.
It is important to notice that the customers for this company are represented by shops and retailers and not by single users.
Moreover it is not considered the option of the capacity increasing during the production time because of high investment costs required for the augmentation, contrarily on what happens for instance in [1]. In our case plant capacity represents a fixed model constraint.
However, in order to overcome this limit, in case of demand exceeding the maximum capacity, it is necessary to advance the production in the time slots where the demand is less than the fixed plant capacity in order to cover the exceeding amount.
However, in order to minimize the inventory costs, the advanced production must be postponed as much as possible.
Before the product launch on the market, Marketing function provides the relative demand forecast –as accurate as possible – covering the whole product life cycle.
These information need to be shared with the Supply Chain and the Trade functions, in order to be validated and to assure that production follows it; in the specific Supply Chain must verify the satisfaction of the capacity constraints, while Trade verifies if the demand effectively meets the retailers' necessities and peculiarities.
The System Dynamics model is presented in Appendix 1.
In order to understand how the system behaves after changes in the model significant parameters, we have analyzed different scenarios over a simulation time period of one year.
The data related to each scenario and the relative results obtained are presented in Table 2, highlighting the varying parameters in red. In the specific case the scenario 2 presents a modified WIP production time of 3 days instead of 0,5, while scenario 3 presents a less precise demand forecasting profile as input.
All the three scenarios present a value of the state variable "Final Products" different from zero (50 pieces in every scenario) because the company has already some products in stock before the product launch on the market in order not to incur in shortage costs at the beginning.

Table 2: The scenarios analyzed

	Scenario 1	Scenario 2	Scenario 3
Initial Raw Materials	0	0	0
Initial WIP	0	0	0
Initial Final Products	50	50	50
Initial Backlog	0	0	0
Initial Sold Products	0	0	0
Safety Stock	1 da	1 da	1 da
Supply Time	2 da	2 da	2 da
WIP Production Time	0,5 da	**3 da**	0,5 da
FP Production Time	2 h	2 h	2 h
Max production	6 wdg/da	6 wdg/da	6 wdg/da
Sell Price	40 €	40 €	40 €
Shortage Unit Cost	2 €	2 €	2 €
RM Inventory Unit Cost	0,5 €	0,5 €	0,5 €
WIP Inventory Unit Cost	1 €	1 €	1 €
FP Inventory Unit Cost	2 €	2 €	2 €
Order Unit Cost	1,7 €	1,7 €	1,7 €
Demand Forecasting	Type A	Type A	**Type B**
	Results		
Total Profit	€ 14.182,69	€ 7.701,31	€ 2.115,02
Total Costs	€ 12.468,49	€ 12.742,47	€ 14.887,79
Total Revenues	€ 26.651,18	€ 20.443,78	€ 17.002,80
Finished Products	0,24 wdg	0,18 wdg	0,14 wdg
Sold Products	666,28 wdg	511,09 wdg	425,07

Graphs represented in figures 3 to 5 present the results obtained by the model in relation to the different scenarios.
The first graphs of figures 3,4 and 5 show the cumulative profit, revenues and costs and, comparing the results, all the three scenarios present a positive profit, but in the first scenario it is maximum, where the WIP production time is smaller and the demand forecast is more precise in respect with the other two cases.

It is not strange that a more accurate demand forecasting allows producing and selling items with higher quality, as shown in the bottom graphs.
In addition, scenarios 2 and 3, which present result less favourable in terms of profit than scenario 1, backlog value is definitely higher.

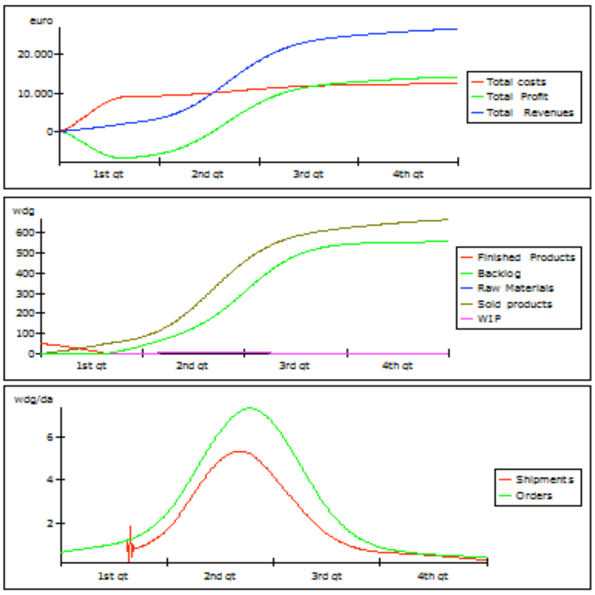

Fig.3 Scenario 1 – Results

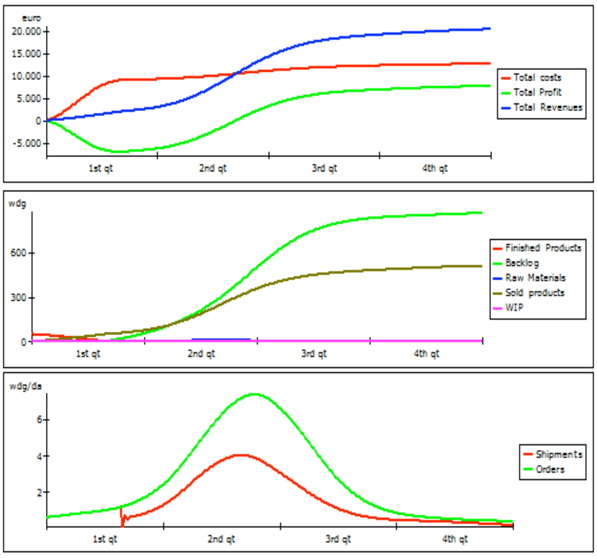

Fig.4 Scenario 2 – Results

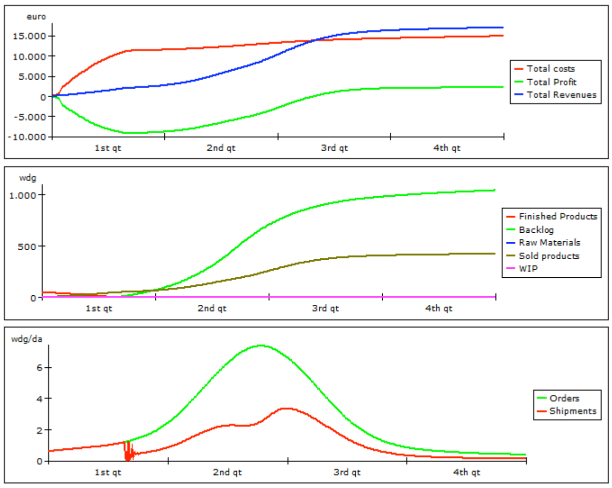

Fig.5 Scenario 3 – Results

4. Resiliency in the short life cycle products field

Supply chain vulnerability and their risks exposure to unpredictable events is amplified by different aspects like global sourcing policies, the huge number of actors involved in the materials flow (vendors, brokers, carriers) and the inventory reductions due to Just-in-Time and Lean Manufacturing philosophies. Moreover, it is important to consider the fact that it is not sufficient to focus on the security of the company to face the impacts of an unpredictable event, but a wider analysis of the whole supply chain is required, including, for instance, not only the suppliers, but also the suppliers of the suppliers. Therefore, regardless of the cause (a hurricane, a supplier's bankruptcy or a terrorist attack), a supply chain interruption generates incalculable damages, especially in a modern global market that requires flexibility and efficiency.
So the question is: how is it possible to reduce the impact of these unpredictable events?
It is possible to create flexibility in the supply chain in order to hold out supply and demand fluctuations and to be able to regenerate it after a catastrophe. First it is necessary to lead a vulnerability analysis, whose approach is based on the major theories developed in the field, with a particular regard to characterization modes and risks prioritization.
Bjørn Egil Asbjørnslett, Senior Scientist and Co-ordinator for the "Resilient Global Logistics" project and Marvin Rausand, Professor in Reliability Engineering, describe the steps useful for a vulnerability analysis:

1) develop an assessment scenario, listing threats and the probability correlated to every potential risk scenario, and investigate

if there are contingency measures or risk mitigation initiatives in action.

2) Analyze in a quantitative way the factors detected in the previous point, classifying threats and scenarios on the basis of the criticalities determined in terms of impact on human, environmental, commercial and real estate resources.
3) Report threats in an appropriate vulnerability map, which can be implemented in different ways.
4) Select critical events in the vulnerability map and then explain how they should be faced in order to reduce the probability of the risky events and their consequences.

Subject matter experts on business vulnerability proposed the classification of all the potential risks for companies in two main categories: internal risks and external risks.

This classification, according to Martin Christopher, is artificial, in fact, in North America, September 11, 2001 event caused a proliferation of articles focused on supply chain risks and vulnerabilities, with a great emphasis on external risks and, in particular, on the needs and implications of measures against terrorism implemented by US institutions and their impact on domestic and international business.

On the contrary, in the Academy world the interest on supply chain internal risks is growing, especially for manufacturing industries. However, even if several dangers for business (wars, epidemics, earthquakes) are recognized as a risk source by the companies' management, internal risks related to the demand-offer network are less clearly visible.

According to Cristopher, this is due to the fact that supply chains are still thought as "linear" structures, where the products' flows pass through several structures until they arrive to a final user, instead of complex realities connected to each other in a non-linear way.

Therefore, supply chain risks can be classified in different ways and with different perspectives, but, on the basis of a framework suggested by Mason-Jones & Towill, Christopher suggests to divide them into three categories, with a further subdivision, generating a total of five categories (Fig. 6).

1) Internal Risks:

- process;
- control.

2) External risks (but internal to the supply chain network):

- demand;
- supply.

3) Risks external to the network:

- environmental.

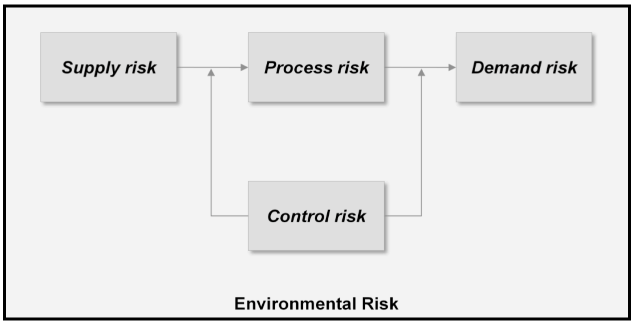

Fig. 6 Risks classification
Source: Martin Christopher

Internal risks include risks related to processes, or the sequences of value added and management activities undertaken by the company. The process risk implies the interruption of the process itself.

In the control framework we can find assumptions, rules and procedures that help an organization to control its processes. Risks related to control derive from the erroneous application of these rules.

External risks related to demand regard the damage – potential or actual – on the product flow, on information and money flow between the company and its market, while supply risks is analogous to this one, but it is referred to the product/information/money flow upstream the company.

The last category refers to the interruptions that are external to the supply chain network, with events coming from outside that can directly affect the company, upstream or downstream, or also the market. They can be the result of socio-political, economical or technological events not directly related to the supply chain, but whose effects can affect it.

This schema allows an easy detection of the risks that can affect every single block of the supply chain.

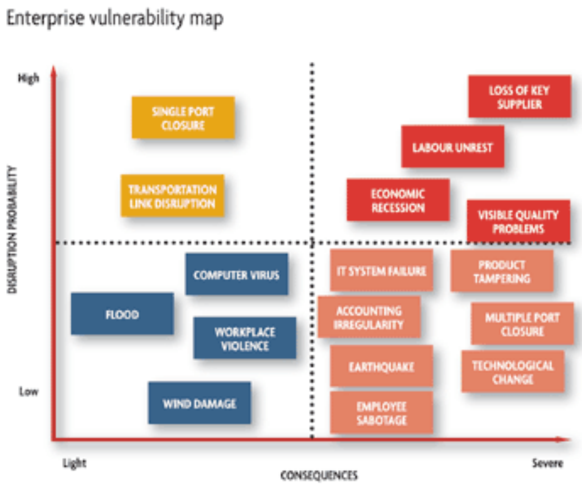

Fig.7 Enterprise vulnerability map
Source: "The resilient entrerprise"[13], page 32

Starting from the above considerations, the aim is to find possible solutions in order to make the short life cycle product supply chain more resilient on the basis of the theory developed by Yossi Sheffi.
The approach used has been divided in two main steps:

1) a vulnerability analysis detecting the risks that can affect the supply chain and positioning them in a probability/impact matrix;
2) analysis of one of the risks selected in order to find possible solutions.

Among the different risks that impact on supply chain stability, the environmental risk has been chosen. This typology of risk is very relevant for manufacturing companies, but it is considered in a different way, depending on the subject who evaluates it: for instance a citizen considers an environmental risk something that could negatively affect his health or the health of his relatives, while the businessman considers risks all that situations that imply additional costs for his company.
Mathematically, it is possible to describe the environmental risk as a result of formula (1):

$$risk = danger * vulnerability * value \qquad (1)$$

where:

- the danger represents the probability that a particular event, with a certain intensity, occurs;
- vulnerability is the attitude of an element to bear an event of a certain intensity;
- value represents the damages caused by an event in socio-economical terms.

In order to reduce risks, it is possible to apply some mitigation interventions devoted to reduce all the factors of (1) or just some of them.
Among all the possible environmental risks, it has been chosen to analyze the hypothesis of an earthquake that strikes the only company supplier, making not possible the raw material supply. The earthquake impact implies a permanent interruption of the supplying capability, canceling the incoming raw material flow. Figure 8 shows the original supply chain, while figure 9 represents the same supply chain after the earthquake, with the raw material flow removed. In order to properly assess the impact of the earthquake on the supply chain, it is necessary to analyze and compare the graphs of the most representative variables and parameters of the system.

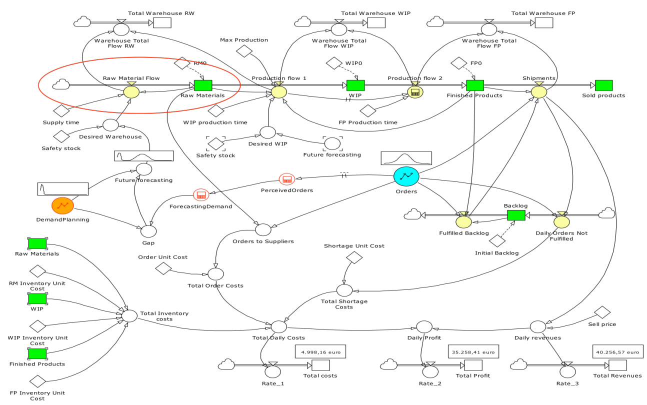

Fig.8 The original supply chain model – supply chain part involved

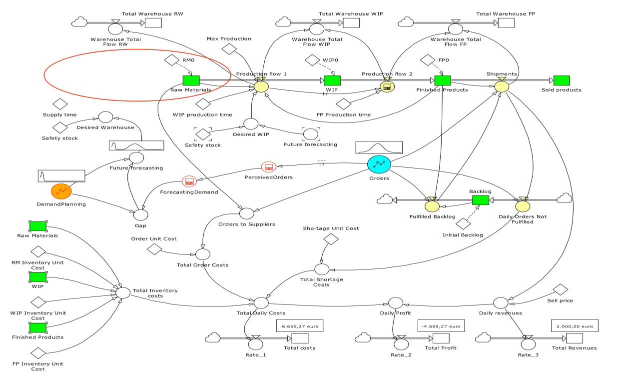

Fig.9 The Supply Chain after the occurrence of earthquake (without the Raw Materials flow)

The graphs in Figure 10 represent the total costs, revenues and profits before the damaging event (upper graph) and after it (lower graph).

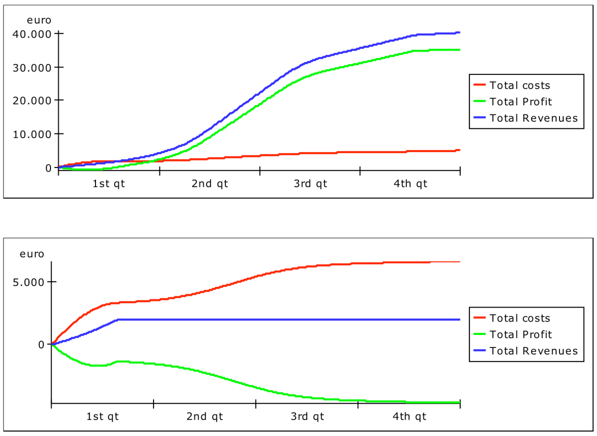

Fig.10 Total costs, revenues and profits before (upper graph) and after (lower graph) the earthquake

In the lower graph, the total costs curve grows rapidly, especially in the initial phase, because of the lack of raw material, while the total revenues, represented as a reservoir level fostered by an input flow rate, grow quickly until there is an inventory of finished products; after that, the revenues remain constant. Finally total profits, which are the difference between total revenues and total costs, are always negative because the company shows a loss.

According to Yossi Sheffi, the idea to rely on a unique supplier could be very dangerous in case of exclusion due to a natural event like an earthquake, because the company is not able to satisfy the received orders. This is what emerges from the simulation results when the raw materials flow is “canceled” from the supply chain after an earthquake. Sheffi, in “The Resilient Enterprise”, shows how many companies derived benefits from the use of two or more suppliers for the procurement of a critical item.

As a consequence, in our resilient supply chain model, we have assumed that the supply is not guaranteed just by only one supplier, but by two suppliers, with a 50% quote each (Fig.11). In the Powersim model we have added, to the original flow, another one related to the second supplier; so the solution obtained is different from the original model - which has demonstrated to be ineffective after the earthquake occurred - providing a clear improvement because it guarantees the continuity of raw materials procurement without interrupting the production process, even in the long term.

This means that, in the new model, when the earthquake strikes one of the two suppliers (removing one of the two flows), the company shows its resiliency guaranteeing the continuity of the finished products sells relying on the survived supplier (Fig.12). The only aspect that has to be considered is the fact that, until the stricken supplier is not restored, the production is halved.

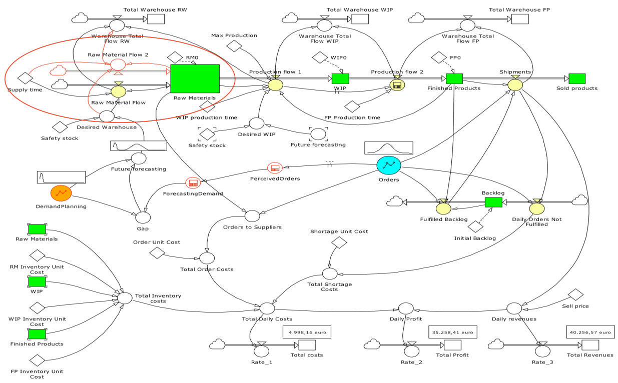

Fig.11 The modified supply chain with two suppliers – resilient case

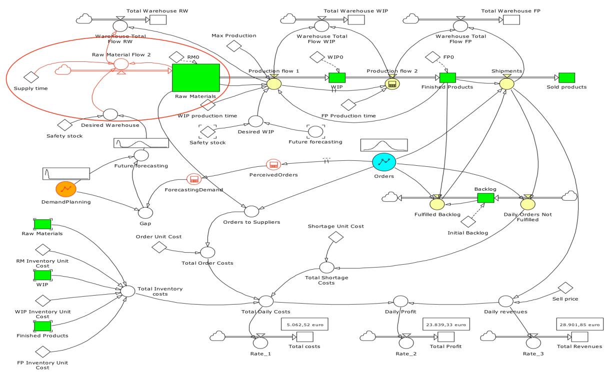

Fig.12 The modified supply chain after the earthquake – resilient case

The supply chain model related to a resilient enterprise for short life cycle products has been implemented in order to obtain, after a simulation run, analogous final results of the original model. The graphs in fig.13 show the total costs, revenues and profits curves before and after the earthquake.

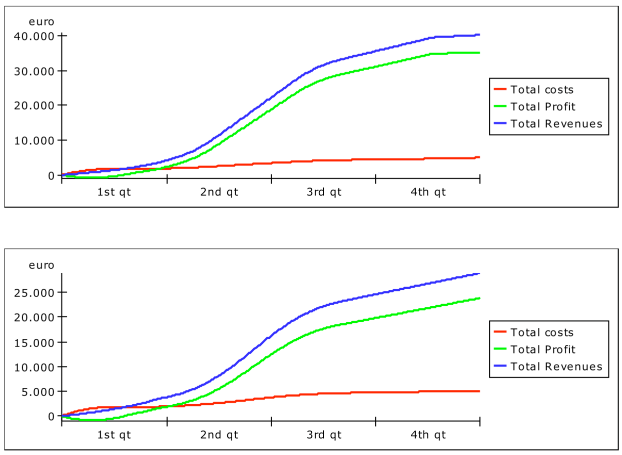

Fig.13 Total costs, revenues and profits graphs for the resilient organization

In this case the trend of the three curves is analogous before and after the earthquake; the only difference is reported on the maximum value reached because of the halved production.

5. Conclusion

In this work the attention is focused on the system structure and the dynamics behavior of supply chains regarding short lifecycle products.

Supply chains related to short life cycle products require a management that is very complex, because they take into account crucial aspects like the limited production and selling period.

This paper proposes a simulation model implemented using System Dynamics methodology to better understand this phenomenon. This model has been applied to a real business case related to an extruded snack produced by a well known Italian food company.

The simulation model has been implemented using Powersim™ software, considering the real stochastic behavior of market demand.

Three simulation scenarios have been analyzed underlining the importance of the accuracy of the demand forecast and of the production times, which have a significant impact on the overall system performance and on the final profit determination.

Starting from the simulation model developed, the focus of the research has been later shifted on the resiliency and vulnerability concepts, applied to short life cycle products supply chains. More specifically, after analyzing all the main risks and vulnerability categories related to supply chains, the model has been modified in order to become more resilient and the occurrence of an environmental risk has been simulated. The results of the simulations underlined the importance of the application of the resilience principles in terms of impact on costs, revenues, and so profits, for a supply chain.

References

[1] Narasimha B. Kamath, Rahul Roy, Capacity augmentation of a supply chain for a short lifecycle product: A system dynamics framework, European Journal of Operational Research 179, 2007, 334–351.

[2] S. David Wu, B. Aytac, Characterization of demand for short life-cycle technology products, Report No. 07T-005.

[3] S. David Wu, B. Aytac, R.T. Berger, C.A. Armbruster, Managing Short Lifecycle Technology Products for Agere Systems, Interfaces Vol. 36, No. 3, May-June, 2006, pp. 234-247.

[4] N. Szozda, A. Swierczek, The success factors for supply chains of a short life cycle product, Total Logistic Management no 1, 2008, PP.163-173.

[5] Fisher M.L. What is the Right Supply Chain for Your Product?, Harvard Business Review, March-April, 1997, pp. 105–116.

[6] C. Chung, M. Quaddus, H. Wee, Optimizing replenishment policy for short life cycle product with recovery considering uncertain delivery, Proc. 7th International Conference on Machine Learning and Cybernetics, Kunming, 2008, 12-15 July.

[7] E. Briano, C. Caballini, R. Revetria, Literature review about supply chain vulnerability and resiliency, Proc. 8th WSEAS International Conference on SYSTEM SCIENCE and SIMULATION in ENGINEERING, Genova, Italy, 2009, October 17-19.

[8] J. Sterman, Business Dynamics. Thinking and Modeling for a Complex World, 2000, Irwin/McGraw-Hill.

[9] A. Kurawarwala, H. Matsuo, Forecasting and inventory management of short-life products, Operations Research Vol. 44, No.1, January-February, 1996, pp. 131-150.

[10] R. Patil, B. Avittathur, J.Shah, Ordering strategies for short product life cycle made-to-stock products, Proc. 13th International Symposium on Logistics (13th ISL), Bangkok, Thailand, 2008, July 6-8.

[11] Sheffi, Y., Supply Chain Management under the Threat of International Terrorism. International Journal of Logistics Management, 2001, 12(2), 1-11.

[12] Sheffi, Y., Building a Resilient Supply Chain. Supply Chain Strategy - Harvard Business Review, 2005, 1, 1-11.

[13] Sheffi, Y., The Resilient Enterprise - Overcoming Vulnerability for Competitive Advantage. Cambridge, 2005, MA: MIT Press.

[14] Martin Christopher, Helen Peck, "Building the resilient supply chain", International Journal of Logistics Management, Vol. 15, No. 2, 2004, pp 1-14.

[15] Christopher, Martin & Denis Towill, "Developing Market Specific Supply Chain Strategies", International Journal of Logistics Management, Vol. 13, No. 1, 2002, pp 1-13.

[16] Mason-Jones, Rachel & Denis Towill, "Shrinking the Supply Chain Uncertainty Cycle", Control, September, 1998, pp 17-22.

[17] Asbjørnslett, B. E., & Rausand, M., Assess the vulnerability of your production system, No. 97018, Norwegian University of Science and Technology, 1997.

APPENDIX 1

The supply chain of a case study short life cycle product – Powersim simulation model