Using a System Dynamics Approach for Designing and Simulation of Short Life-Cycle Products Supply Chain

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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.
In this work “What If” analysis has been carried out in order to show which is the best policy to adopt in terms – for instance – of safety stock or demand planning.
Further developments will be focused on the resilience of these supply chains and so, to build structures able to face unexpected and damaging events.

Key Words- Short life-cycle products, simulation, supply chain management, modeling, system dynamics, Powersim Studio.

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 which 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.

Summarizing, these authors affirm that the information feedback based methodology is useful for designing DSS (Decision Support Systems) for capacity augmentation.

In our research 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.

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. Finally in section 4 some conclusions and future researches 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>
<thead>
<tr>
<th>Activity areas</th>
<th>Supply chain for a short life cycle product</th>
<th>Supply chain for a long life cycle product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planning</td>
<td>Elementary planning</td>
<td>Global/General planning</td>
</tr>
<tr>
<td></td>
<td>– Accurate and separate demand estimation for every product and service, followed by computing a single value for the company</td>
<td>– Demand for the company; it is possible with a robust range of products</td>
</tr>
<tr>
<td>Forecasting</td>
<td>Heuristic methods of forecasting</td>
<td>Quantitative methods</td>
</tr>
<tr>
<td></td>
<td>– Qualitative methods</td>
<td>– Statistical methods of forecasting</td>
</tr>
<tr>
<td></td>
<td>– Forecast by analogy</td>
<td></td>
</tr>
<tr>
<td>Manufacturing</td>
<td>Flexible manufacturing systems</td>
<td>Highly automated systems</td>
</tr>
<tr>
<td></td>
<td>– Manufacturing of a wide range of products</td>
<td>– Production lines</td>
</tr>
<tr>
<td></td>
<td>– Outsourcing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>– Hybrid manufacturing processes</td>
<td></td>
</tr>
<tr>
<td>Inventories and warehouse management</td>
<td>Manufacturing to order</td>
<td>Manufacturing for stock</td>
</tr>
<tr>
<td></td>
<td>– Reducing a number of stored materials and products</td>
<td>– Purchasing of products for stock</td>
</tr>
<tr>
<td>Replenishment (suppliers)</td>
<td>Global replenishment systems</td>
<td>Domestic and local suppliers</td>
</tr>
<tr>
<td></td>
<td>– Long term contracts enabling flexible time planning and ordered quantities</td>
<td>– Frequent changes of suppliers</td>
</tr>
<tr>
<td></td>
<td>– Reducing a number of suppliers to those who offer the widest ranges of raw materials</td>
<td>– Long delivery times</td>
</tr>
<tr>
<td></td>
<td>– Consolidation of orders from multiple sources</td>
<td>– Large number of suppliers</td>
</tr>
<tr>
<td></td>
<td>– Traditional way of communication no common and shared information systems</td>
<td></td>
</tr>
</tbody>
</table>
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.

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**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 by 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.

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.

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.
Table 2: The scenarios analyzed

<table>
<thead>
<tr>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Raw Materials</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Initial WIP</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Initial Final Products</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Initial Backlog</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Initial Sold Products</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Safety Stock</td>
<td>1 da</td>
<td>1 da</td>
</tr>
<tr>
<td>Supply Time</td>
<td>2 da</td>
<td>2 da</td>
</tr>
<tr>
<td>WIP Production Time</td>
<td>0.5 da</td>
<td>3 da</td>
</tr>
<tr>
<td>FP Production Time</td>
<td>2 h</td>
<td>2 h</td>
</tr>
<tr>
<td>Max production</td>
<td>6 wdg/da</td>
<td>6 wdg/da</td>
</tr>
<tr>
<td>Sell Price</td>
<td>40 €</td>
<td>40 €</td>
</tr>
<tr>
<td>Shortage Unit Cost</td>
<td>2 €</td>
<td>2 €</td>
</tr>
<tr>
<td>RM Inventory Unit Cost</td>
<td>0.5 €</td>
<td>0.5 €</td>
</tr>
<tr>
<td>WIP Inventory Unit Cost</td>
<td>1 €</td>
<td>1 €</td>
</tr>
<tr>
<td>FP Inventory Unit Cost</td>
<td>2 €</td>
<td>2 €</td>
</tr>
<tr>
<td>Order Unit Cost</td>
<td>1.7 €</td>
<td>1.7 €</td>
</tr>
</tbody>
</table>

### Demand Forecasting

<table>
<thead>
<tr>
<th>Results</th>
<th>Type A</th>
<th>Type B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Profit</td>
<td>€ 14,182.69</td>
<td>€ 7,701.31</td>
</tr>
<tr>
<td>Total Costs</td>
<td>€ 12,468.49</td>
<td>€ 12,742.47</td>
</tr>
<tr>
<td>Total Revenues</td>
<td>€ 20,631.18</td>
<td>€ 20,443.78</td>
</tr>
<tr>
<td>Finished Products</td>
<td>0.24 wdg</td>
<td>0.18 wdg</td>
</tr>
<tr>
<td>Sold Products</td>
<td>666.28 wdg</td>
<td>511.09 wdg</td>
</tr>
</tbody>
</table>

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.

### 4. 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. In the paper 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.
As a further development, starting from the simulation
model and considering the literature review provided by [7],
the authors will focus their attention on the resiliency and
vulnerability concepts, applied to short life cycle products
supply chains.

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APPENDIX 1
The supply chain of a case study short life cycle product – Powersim simulation model