Supply Chain Risk Assessment Applying System Dynamics Approach
Case Study: Apparel Industry

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Abstract: A remarkable increase in the demand and supply uncertainty, as the primary sources of supply chain risk and other sources such as: capacity constraints, supply variability, parts quality problems, long lead times, war and natural disasters have increased the necessity of assessing and managing the risk in the supply chain. The purpose of this study is to investigate the impact of two categories of risk, demand uncertainty and delays, on the performance of an apparel supply chain. A system dynamics approach was used to study the behavior and relationships within the supply chain of this industry. The proposed model facilitates the study and identification of the critical components of the supply chain. In addition, the model provides a tool to generate multiple business scenarios for effective decision making.

1 INTRODUCTION

Uncertainty in the demand for products is the primary source of risk in the supply chain. Several interdependent factors such as higher product variety, shorter product life cycles, increased customer expectations, more complex and longer supply chains, and more global competitions have increased this uncertainty considerably in the recent years. Moreover, capacity constraints, supply variability, parts quality problems, long lead times, and manufacturing yields besides disruptions due to war and natural disasters are some other sources of risks in the supply chain (Sheffi and Rice, 2005). Therefore, it is essential for companies to understand supply chain interdependencies, identify potential risk factors, their likelihood and consequences (Tummala and Schoenherr, 2011). They need to develop plans for disruptions and contingency plans to decrease the likelihood of supply chain risks.

In the apparel industry, market demand is highly volatile and product life cycles are short. Low predictability and high level of impulse purchase are other characteristics of this market (Carugati *et al.*, 2008). All the previously mentioned factors increase the importance of risk assessment for the supply chain of these products. Barlas and Aksogan (1997) built a system dynamics simulation model for the textile and apparel pipeline which consisted of wholesaler and retailer levels. They studied the

effects of product diversity and quick response order strategies on customer demand, possible stockouts and inventory levels. The purpose of this study is to investigate the impact of two categories of risks - demand uncertainty and delays - on the performance of an apparel supply chain through a system dynamics approach.

2 MODEL

Industrial dynamics (Forrester, 1961) introduced a methodology for the simulation of dynamic models, which is the origin of system dynamics (Sterman, 2000). Extensive research in various fields, natural and social sciences, has been conducted using system dynamics. System dynamics is one of the best methods for analyzing complex systems (Campuzano and Mula, 2011). In this study, the system dynamics software, Vensim®, was used as a tool to build the supply chain model. The model (see Fig. 5) has three primary members: a manufacturer, a distributor and a retailer.

At the retailing level for an apparel store, when the customer's need is not satisfied, the customer usually leaves and does not wait for his/her need to be fullfilled. Therefore, the constructed model has considered the orders not delivered on time as the lost sale at this stage. If the warehouse contains the sufficient amount of products to meet the demand at

the time, the order is delivered. Otherwise, the final customer's demand is transferred to increase the "Retailer stockout" variable. Based on the inventory position, forecasted demand and lead time of this stage, the retailer's replenishment orders will be sent to the distributor through the "Orders to distributor" variable. The output of "On order products (retailer)" is "Products delivered to retailer" which is affected by the lead time and introduces a delay into the arrival of products. The delay is considered to be pure and not exponential, that means that the arrival of products at the warehouse happens exactly after the period defined in the "Retailer lead time" variable.

At the distributor level, if the orders are not met by the required date, they will be served when the distributor has enough stock available. The proposed model considered the orders not delivered on time as backlogged orders and they were included in the daily firm orders. The flow of information and material at the distributor level undergoes the same transformations as the previous level except the case of backlogged orders that do not exist in the retailing level.

The service and delivery policies for backlogged or delayed orders at the manufacturer level follow the same formulation as the distributor level. The manufacturer has a predefined daily capacity, so it can only manufacture the amount of units the factory is capable of.

The demand forecasts are calculated during each period based on a simple exponential smoothing technique.

In the proposed model, the total cost is calculated based on the unit cost, the amount of products delivered including delivered backlogged orders, products manufactured for the manufacturer level and products purchased for the other two stages. It is assumed that the distributor is the member responsible for all the transportations taking place in the supply chain. Therefore, the variables of "transportation revenue" and the "transportation cost" are included in this level. It should be mentioned that a variable to calculate the total revenue of each stage is not defined separately, but it is calculated inside the formula of the profit variable.

In order to test the validity of the model, three different tests including direct extreme conditions test, dimentional consistency test and direct structure test, by comparing the model equations with available knowledge in the literature, were conducted.
The main characteristics of the model including model parameters and assumptions are as follows:

- It is possible to serve only one part of the order when the whole order is not available.
- Inventory management is performed applying inventory review policy.
- The raw materials used for manufacturing are considered to be available all the time.
- Simulation takes place over 365 periods.
- The stock of the initial inventory for the manufacturer level is 10 units and for both, distributor and retailer, are 5 units.
- The manufacturing capacity is 25 units per period.
- The manufacturing lead time is 8 periods and the manufacturing lead time to the distributor and then to the retailer are 2 and 1 periods, respectively.
- The adjust factor for forecasting is equal to 2.
- The pattern selected for the number of customers entering the retail store per period corresponds to a normal distribution with the $\mu = 25$ and $\sigma = 9$.
- Since a customer who enters the store may leave without buying an item, a binomial distribution was selected to calculate the probability that a customer will prefer a SKU in the retail store.
- Actual customer's demand is calculated by multiplication of the number of customers entering the retail store and the probability that a customer will buy an item after entering the store.
- Number of color, style and size varieties of products are 5, 12 and 10, respectively.

3 RISK ASSESSMENT

As mentioned previously, this paper studies the effect of demand variability and the risk of delay on the supply chain performance of an apparel industry. The cumulative cost in each stage of the supply chain is used as the performance measure.

3.1 Risk of Delay

In order to investigate the impact of delay, four different scenarios have been considered. In the *Main* scenario there is no increase in the lead time of any of the stages; in *LT1* there are 6 periods of time increase only in the lead time of manufacturer; in *LT2* there are 5 periods of time increase only in the lead time of distributor; and in *LT3* there are 2 units of time increase only in the lead time of the retailer. Figures 1 to 3 depict the results of the simulation. It

can be seen that the *Main* scenario, with no delay in the model, has the least cost in all the three stages of the supply chain. Also, delay in the lead time of manufacturer level, *LT1*, causes the highest cost increase in the manufacturing and distribution stages. The costs in the retailing stage are mainly sensitive to the delays in the same stage, retailing (not shown).
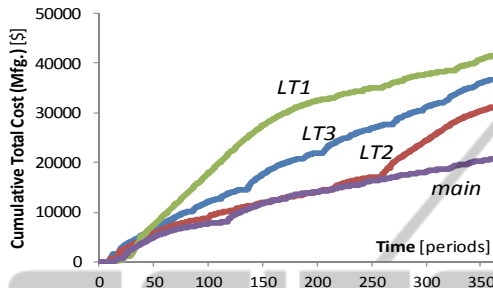

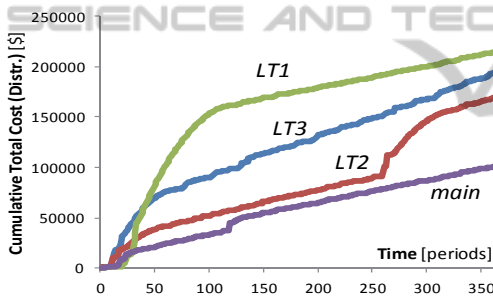Figure 1: Effect of delay in lead time on manufacturer cumulative total cost.

Figure 2: Effect of delay in lead time on distributor cumulative total cost.

3.2 Risk of Demand Variability

Three scenarios were defined to compare the performance of the supply chain under various variabilities of demand patterns. The number of customers entering the retailing store (potential customer demand) follows a normal distribution with the following characteristics

- Main: *Range* = 40 and $\sigma = 9$,
- Dem 1: *Range* = 40 and $\sigma = 25$.
- Dem 2: *Range* = 90 and $\sigma = 9$.

From Fig. 3, it can be interpreted that increasing the variation of demand has a higher impact on the manufactuer and distributor compared to the retailer, considerably increasing their costs. In addition, these two stages perform worse when the data related to the demand comes from an interval with longer width (Fig. 4). In the designed supply chain, the

retailer stage shows the least sensitivity to the variation and uncertainty in demand.
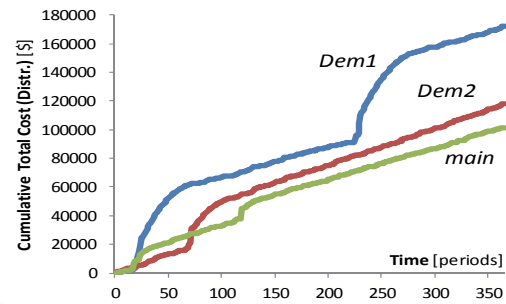

Figure 3: Effect of demand variability on manufacturer cumulative total cost.
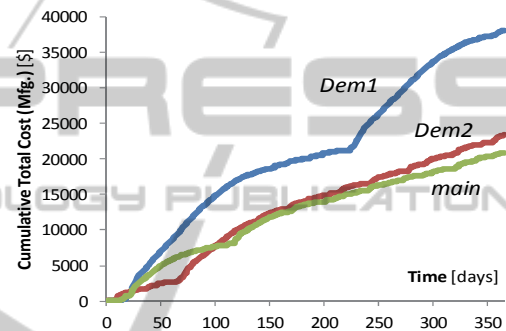

Figure 4: Effect of demand variability on distributor cumulative total cost.

4 SUMMARY

This paper presented a system dynamics model that can be used to study and observe the processes and relationships in the supply chain of an apparel industry. It is also useful as a high-level tool to analyze the impact of different types of risks associated with the supply chain of this industry.

This study investigated the impact of demand uncertainty and risk of delay on the supply chain performance. The main limitation of the model is the data used as the inputs. Due to the inability to obtain more accurate industry-specific data, the absolute numbers that this model presented are used for comparative analysis of different scenarios. Nevertheless, the model helps to study the relationships between supply chain stages and to analyze the effect of changing values for the variables of the model.

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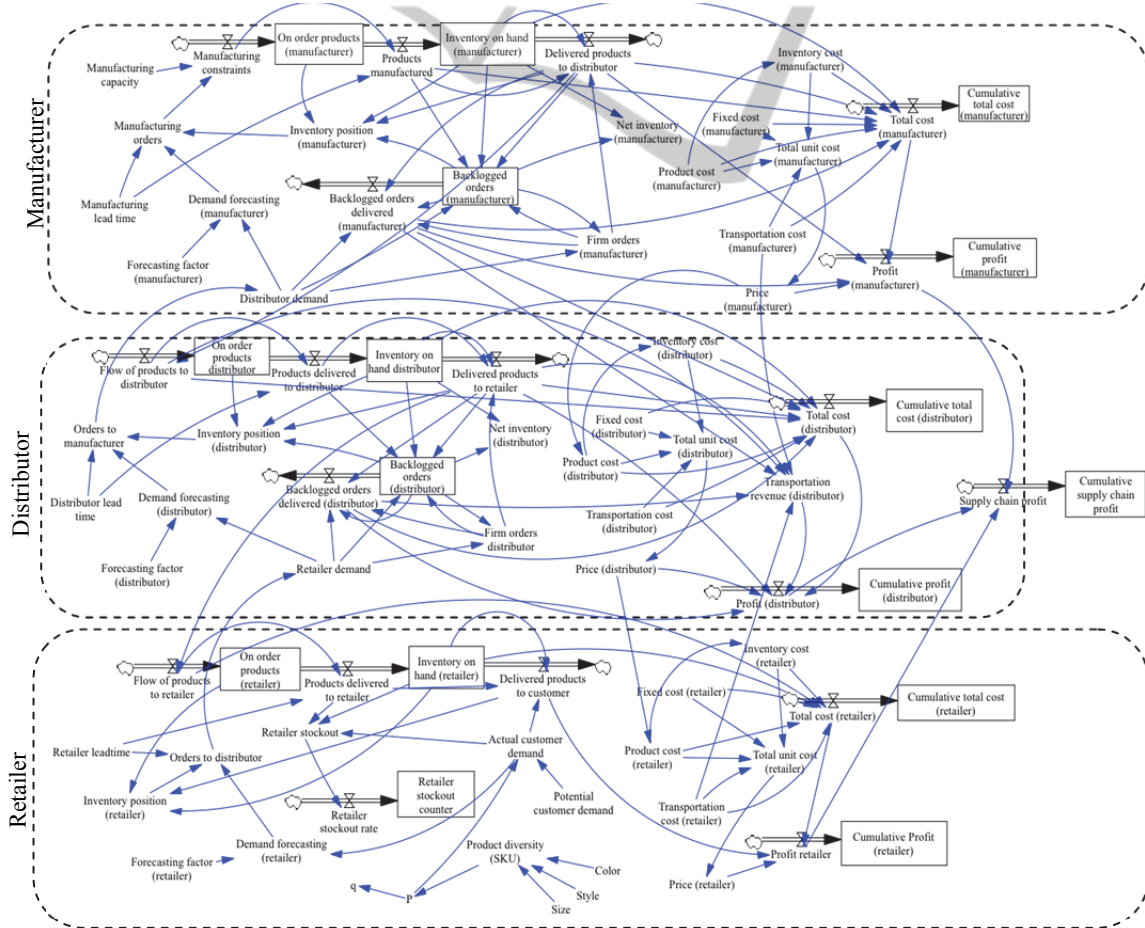
APPENDIX

Figure 5: The stock flow diagram of an apparel supply chain using Vensim software.