Analysis of Supply Chains Using System Dynamics Simulation

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Abstract— **Supply chain management is a critically significant strategy that enterprises depend on in meeting the challenges of today's highly competitive and dynamic business environments. An important aspect of supply chain management is how enterprises can detect the supply chain behavioral changes due to endogenous and/or exogenous influences. A methodology for addressing this problem using system dynamics is proposed in this paper. A case study in the electronics manufacturing industry is used to illustrate the methodology.**

***Keywords*— Supply Chain Management (SCM), System Dynamics (SD) Simulation, Stability**

I. INTRODUCTION

The use of system dynamics (SD) simulation in supply chain management (SCM) started with Jay Forrester's Industrial Dynamics [1]. Forrester described a production-distribution system that consisted of the flows of information, materials, orders, money, manpower, and capital equipment across a supply chain (SC). Since then, SD has been widely applicable to SC applications to address various issues. One of the serious SCM problems is the changes in the SC behavior due to external market factors and/or internal system and managerial factors. For example, a change in federal policy to allow private companies to sell warfare materials can cause a sudden increase in demand at weapons manufacturing companies. If not detected early enough, companies would not be able to respond to the increasing demand and would lose potential business to competitors. In the service sector, a sudden decrease in interest rates can cause sudden increase in demand for loans, which a loan company might not be able to satisfy. Both manufacturing and service sectors need to equip themselves with tools to detect changes in their SC and be prepared to counteract any undesirable consequences. What makes it a significantly serious problem is that SC behavior is dynamic and controlled by nonlinear interrelationships and interactions among its components. Small variations in demand, for example, can simply cause disproportional major fluctuations and oscillating reactions along the SC.

II. BUSINESS ENVIRONMENT – CASE STUDY

A system dynamics model of the SC of an actual electronics manufacturing company [2] is used in this paper to demonstrate the proposed methodology. This company was facing a problem of persistent oscillations in its finished goods inventory and desired capacity. Even though the company has maintained its market share, it has experienced serious competition and demand fluctuations, which in turn impacted its work strategies. The company has been implementing the following SC strategies:

- Utilization of several supplier companies to minimize their bargaining power [3].
- Utilization of supply relationship management to guarantee that suppliers (1) provide excellent product quality, (2) meet due dates, and (3) offer competitive prices.

As a market leader, this company supplies its products to major Original Equipment Manufacturers (OEMs) such as Dell and Hewlett-Packard. Many OEMs have changed their strategies by adopting Build-To-Order (BTO) and Just-In-Time (JIT) processes. These changes in the PC in addition to its short life cycles have amplified the coordination problems, which in turn have caused excess inventories and sometimes difficulties to keep up with demand. Another main factor is the intense competition from other companies. The competition has forced the company to introduce more product varieties at lower prices into the market to protect its existing and potential market share. Production capacity is another factor that adds to SC complexity because of its long delays, huge investments, and new products with more complex manufacturing processes than previous generations. In addition, these complementary PC products are at the upstream of the SC for PCs and their resulting fluctuations are higher.

III. SD SIMULATION MODELING

Building the SD model of the company's SC in the previous section followed the steps of [4]. The first step defining the problem. The following steps are understanding the formulations, developing the causal loop diagrams, developing the stocks and flows diagrams, validation, and testing.

A. Problem Definition

Problem definition includes identifying the relevant parameters and their respective perceived trends, and stating the problem statement. Several participants (at different levels of the managerial hierarchy) from various departments (e.g., information technology, strategic planning, supply chain, manufacturing) were interviewed in addition the analysis of historical data in order to define the problem. The relevant parameters are listed below [2]:

1. Product Life Cycle
2. Actual Capacity Relative to Desired Capacity
3. Change in Customer Orders
4. Raw Materials Inventory Write-0ff
5. Average OEM Margin
6. Pre-Assembly Component Inventory
7. Throughput Time and Work in Process Inventory
8. OEMs' Inventory
9. Product Inventory

Two problematic issues were then stated as:

- The fluctuations and oscillations in the finished goods inventories with relatively large amplitudes, and
- The growing oscillations in actual capacity relative to desired capacity.

B. Causal Loop Diagrams

Causal loop diagrams are the basis on which the SD model is built. They depict, graphically, the interactions and cause-and-effect relationships among the different system parameters. The causal loop diagrams in our case consisted of several segmental loops. Figure 1 depicts the complete causal loop diagram of the current case study. The principal causal loops included are described below:

- **Market share needs production capacity**: Capacity increase means more orders and this translates into more future demand. But if demand increases beyond capacity customers will become unsatisfied because of delivery delays and might shift to competitors.
- **Investments in production capacity depend on market share**: Higher revenues are realized with increases in market share and then more investments can be made on production capacity.
- **Competition increases with the increase in profits and vice versa**: Higher profits create an environment that attracts new entrants to the market and hence competition and lower profits create less motivation for new entrants. In addition, the market growth increases the competition.
- **Growth, new product development and product life cycle**: Higher revenues are realized with increases in market share and then more investments can be made on new product developments. The increase in new product development could lead to the obsolescence of old products.

C. Stocks and Flows Analysis

The following step in building a SD model is converting the causal loop diagrams into stocks and flows diagrams and defining the mathematical formulation. The basic SD model in this paper follows the generic models of [5]. The model is composed of the three connected stocks and flows models that are described below.

D. The Production Model

This company runs a push-pull manufacturing process: a push process from the pre-assembly processes to the assembly process and a pull process from the assembly process to the packaging and shipping.

Main state variables in this production model are the inventories. Three types of inventory, which also represented the sequence of the production process, were included in this production model. These are the pre-assembly inventory (PAI), the assembly inventory (AI), and the finished goods inventory (FGI). In the system dynamics notations these state variables are represented as stocks and mathematically as integrations as follows:

$$PAI = \int (PSR - NPR - PR)$$

Where PSR represents the production start rate, NPR the net start rate, and PR the production rejection rate.

$$AI = \int (ASR - NAC - AR)$$

Where ASR represents the assembly start rate, NAC the net assembly completion rate, and AR the assembly rejection rate.

$$FGI = \int (NAC - S)$$

Where S represents the sales rate of the final product.

E. The Market Share and Shipment Model

This consists of two sub-models: the market share sub-model and the inventory, backlog and shipping sub-model. The market share sub-model mainly represents the causal relationship involving demand, orders filled and company market share. The inventory, backlog, and shipping sub-model represent the links of inventories and shipment orders filled from the finished goods inventory to customers. Main state variables of interest are the finished goods inventory (given above) and the channel order backlog level (COB), which is represented mathematically as follows:

$$COB = \int (CD - OFR)$$

Where CD is the channel demand for the company's product, and OFR is the order fulfillment rate.

F. The Demand Forecast and Capacity Model

This model represents the link from demand to production capacity. The state variables of interest are the perceived present demand (PPD) on the company's product, which is mathematically the integration of the change in the perceived demand over time (this change is a function of historical demand and present channel demand), and the available capacity (AC), which is represented mathematically as follows:

$$AC = \int (CA - CO)$$

Where CA represents the rate of capacity acquisition, and CO represents the rate of capacity obsolescence.

The SD model was built in Vensim SD simulation environment [6]. For the details of the development of the SD model and its mathematical structure and validation results refer to [2].

IV. CONCLUSIONS AND FUTURE WORK

This paper proposed and discussed a methodology to detect changes in the SC behavior due to external and/or internal factors. Supply chain management solution methods available today do not have the capability to detect changes taking place in the business environment and hence are not able to provide the companies with accurate predictions for the effects of these changes. The proposed methodology used systems dynamics simulation. System dynamics simulation was used to capture the dynamics of the supply chain behavior. It is proposed, for future work, that optimization techniques be used with the decomposed, linearized SC models. The methodology suggested here can be applied to assist in implementing six sigma programs and other lean enterprise initiatives as well.

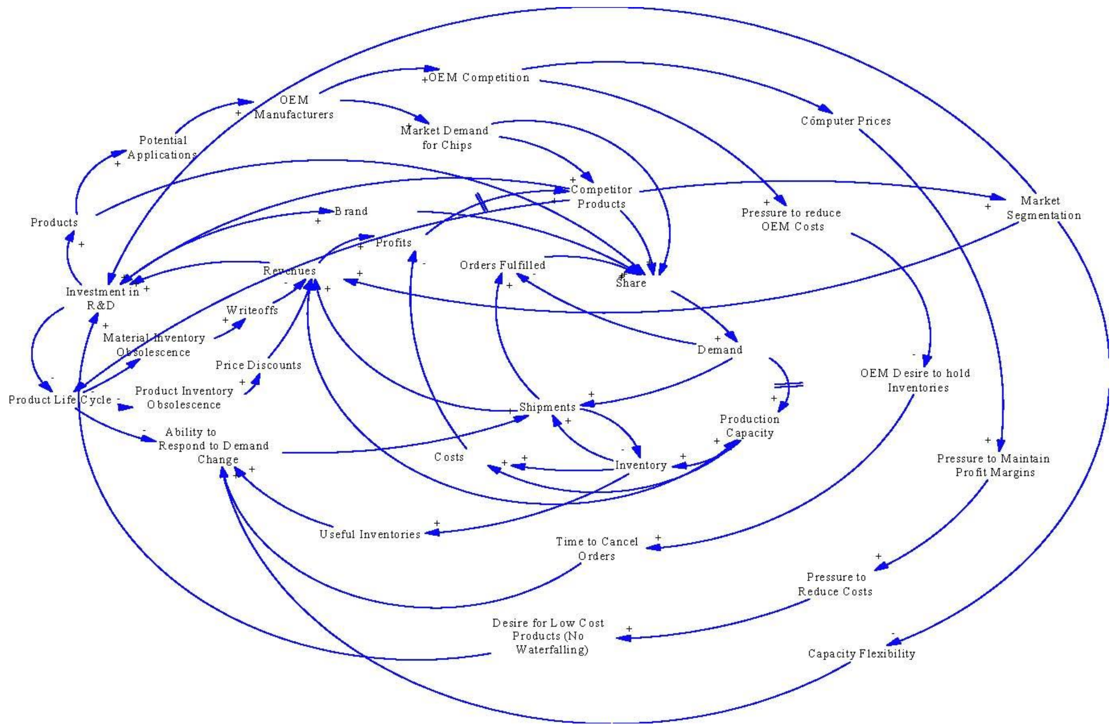

Figure 1: Causal Loop Diagram for the SD Supply Chain Model

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