

INTEGRATING SIMULATION AND OPTIMIZATION RESEARCH INTO A GRADUATE SUPPLY CHAIN MODELING COURSE

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ABSTRACT

This paper addresses the on-going work of integrating supply chain research into the graduate curriculum in the form of a Supply Chain Modeling course. This course integrates research from Oklahoma State University, the University of Arkansas, and the University of Pittsburgh. In this course, the students and the professor develop and implement supply chain models and tools that combine linear optimization and simulation. This paper focuses on the simulation development in the course.

1 INTRODUCTION

Supply Chain Management is very critical in today's world and the analysis of running a Supply Chain effectively is complex. Both the product design and supply chain design are very important factors in overall supply chain efficiency because the design has a direct impact on supply chain decisions such as sourcing and inventory. Also, 75%-90% of opportunity to influence total life cycle cost is gone by the time that the design is released to production (Gökhan 2007). As companies try to become profitable, supply chain costs can be substantially reduced by designing an optimal supply chain structure. With this direct link between design decisions and overall supply chain costs, it is critical that these decisions be made in concert with each other.

Most researchers considering either the design of the Supply Chain or the design of products. However, Gökhan (2007) has created a model that takes an initial step in analyzing design decisions with supply chain decisions in mind. As part of a NSF project between the University of Pittsburgh, the University of Arkansas and Oklahoma State University, Gökhan's work is being extended to include a much wider range of supply chain decisions.

This research project addresses the problem of how to effectively synchronize product design and supply chain design for new and existing products. This concept is given the name Design for Supply Chain (DFSC). The team uses DFSC analogous to the Design for Manufacturability (DFM) concept of the 1980s where manufacturing processes of a product are taken into account in the product design phase. Academic studies and industry experience show the benefits of incorporating different aspects of the production phase into the product design process. In this research, we propose that conducting supply chain analysis during the product design phase has important benefits and needs to be investigated similar to how manufacturing is considered in the design phase in DFM (Gökhan 2007).

Another important perspective of the project is to combine two tools to analyze the supply chain design and the product designs. Gökhan (2007) created an optimization model as the basis for his work. This research project extends that work by using both optimization and simulation integrated in one tool to analyze the effectiveness of the Supply Chain.

2 LITERATURE REVIEW

2.1 Overview of Supply Chain

A supply chain represents the series of activities an organization uses to deliver value either in the form of a product, service, or a combination of both, to its end customers. The goal of supply chain management is to integrate suppliers, manufacturers, warehouses and end customers efficiently so that merchandise is produced and distributed in the right quantities, to the right locations and at the right time in order to minimize system wide costs while satisfying service level requirements (Simchi-Levi et al. 2003). The operations of a supply chain were traditionally managed as independent silos with conflicting objectives. For example the

goal of manufacturing to reduce the average production cost by maximizing the lot size directly conflicts with the goal of inventory control that tries to minimize inventory carrying cost with lowest possible inventory levels. Those corporations that were able to recognize the conflicting interests that exist in managing a supply chain in silos and the interdependence that exists among the constituents of a supply chain have pioneered a new way of managing supply chains. By treating the entire supply chain as a single holistic entity and by integrating and coordinating various activities of the supply chain to attain profitability overall, corporations have been able to drive their costs down, increase their customer service levels and gain tremendous competitive advantage.

Figure 1 shows a typical supply chain structure that involves different alternatives of suppliers, manufacturers, distribution centers and transportation modes; each of them could have different costs structures, taxes and/or tariff and duties. Supply chain design tries to select the best alternatives to satisfy a set of constraints like service levels, strategic sourcing, etc. to minimize costs or maximize revenue.

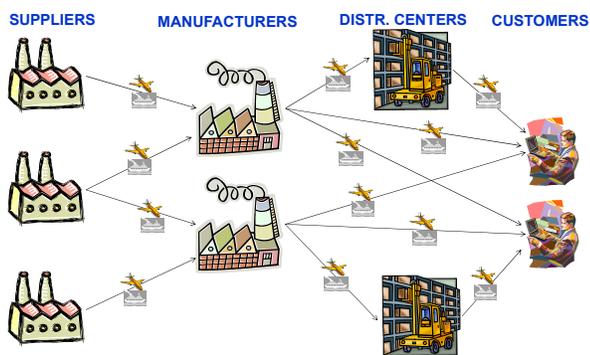


Figure 1: Supply chain structure

2.2 Supply Chain Enhancement Techniques

For this purpose, the two most widely used supply chain enhancement techniques are optimization and Simulation.

2.2.1 Optimization

Optimization, when applied to a set of input variables, will result in the determination of the best model as defined by the fitness of an objective function. Optimization offers the opportunity to enhance the following activities in supply chain management:

- Customer demand planning
- Customer order fulfillment and customer service
- Strategic sourcing and procurement

- Production logistics
- Distribution networks
- Warehouse management
- Transportation and shipment management
- Analysis of revenue, cost and profitability of any portion or the entire supply chain.

2.2.2 Simulation

Simulation is a computer based modeling approach which uses a chain of cause and effect relationships to help the user build complex models from the ground up one link at a time (Ambiye et al. 2005). Simulation allows the identification and assessment of the following outcomes of a supply chain:

- Bottlenecks
- Capacity issues
- Issues and outcomes related to delay/timing
- The utilization of resources over time
- The impact variance on the expected revenue, cost and profitability of any portion or the entire supply chain.

Given a mathematically optimal solution as recommended by optimization, simulation shows how that optimal solution will perform under dynamic conditions.

2.3 Supply Chain Modeling

Simulation models can be applied for evaluating the efficiency and effectiveness of a supply chain system. Simulation can give visibility of the entire supply chain that allows users to test numerous “what-if” scenarios such as outsourcing, consolidating vendors, collaborative planning, or implementing e-business. Another key feature of simulation which naturally supports supply chain modeling is stochastic inputs of the model where users can easily use random variables as inputs into the models.

Bagchi et al. (1998), explained the structure of IBM Supply Chain Simulator. The simulator consists of seven processors as follows:

- Customer – this processor represents outside customers issuing orders from the supply chain with a certain level of service for each customer. The order data is also used to aid demand forecasting and supply planning activities.
- Manufacturing – This module assembles and keeps raw material and finished goods inventory as well as suppliers. During the simulation, the manufacturing process makes use of modeled information such as the types of manufactured products, manufacturing time, bills of material, manufacturing and replenishment policies and so forth.

- Distribution – The processor models distribution centers, including finished goods inventory and material handling. It can also be used to model a retail store.
- Transportation – The module simulates transportation time, vehicle loading and transportation costs. Order batching policies, material handling resources and transportation resources are identified in this module.
- Inventory planning – The module represents periodic setting of inventory target levels using Inventory Optimizer that recommends inventory levels at various locations in a supply chain.
- Forecasting – The processor models product forecasts including promotional and stochastic demand of future periods.
- Supply Planning – This process models the allocation of production and distribution resources to forecast demand under capacity and supply constraints

Archibald et al. (2003), uses IBM Supply Chain Analyzer to compare different scenarios of a supply chain as follows:

1. Base Case - GFM's current supply chain practices with an internal emphasis
2. Transportation - A change from a Full Truckload to a Less Than Truckload approach to reduce transportation lead times
3. Continuous Replenishment - A shifting of inventory management to the manufacturer or wholesaler
4. Collaborative Planning - A sharing of information among all participants of the supply chain
5. Combined Supply Chain Management – A combination of the above three scenarios applied to the base case

The results showed that through using the simulation model, the net result is a significant improvement in operational and financial performance for all participants in the supply chain, including the end customer.

Petrovic et al. (1998), used simulation models for supply chain planning under uncertainty. A supply chain is viewed as a series of facilities that performs the procurement of raw materials, its transformation to intermediate and end-products and distribution and selling of the end-products to customers. Two types of models, the generative SC models, that involve both fuzzy and optimization methods, to determine the order-up-to levels of the inventories and the SC evaluative model, based on simulation techniques, to assess the effects of the selected order-up-to levels, are put in a coordinated work. In order to show the power of the approach proposed, an illustrative example of

how to compensate the negative effects of an unreliable external supplier is given.

3 A BRIEF HISTORY OF SUPPLY CHAIN MODELING CLASS AT OKLAHOMA STATE UNIVERSITY

3.1 Objective of the Supply Chain Modeling Course

At Oklahoma State University, a Supply Chain Modeling class was created as an initiative of Dr. Ingalls in order to give the students a taste of building and analyzing large-scale supply chain models. Based on his corporate and consulting experience of modeling large-scale supply chains with spreadsheets, optimization and simulation, Dr. Ingalls wanted the students to face modeling problems without defined solutions. The class has always involved a large-scale supply chain modeling project. In the last two classes (Fall 2005 and Fall 2007), the entire class was involved in a single class project (Ingalls et al. 2008).

3.2 Class Development

The prerequisites for the course include a course in supply chain strategy, a course in optimization and a course in simulation. In the four times that the course has been taught, the course has continually changed due to the desires of the students involved in the class. In the Fall of 2001, the course was centered on two software packages – Insight's Global Supply Chain Model and Gensym's e-SCOR. These two packages gave the students a look at both optimization and simulation for the supply chain. In the Fall of 2003, the course centered on Insight's SAILS package, a comprehensive supply chain optimization package. In both 2001 and 2003, the class was split into teams and each team competed against each other to model a realistic supply chain problem that resembled, in size and scope, a typical supply chain problem from Dr. Ingalls' work at Compaq Computer Corporation, (Ingalls et al. 2008).

In the Fall of 2005, Dr. Ingalls gave the students the following proposition. "We can do what previous classes have done. We can learn a commercial software tool and apply it. However, I want to propose an alternative. I have built these types of optimization and simulation models from scratch. We can build a working system that includes a database, an optimization program and a simulation program as the project for this class. What do you want to do?"

The class chose to build a system from scratch. The project was successful, in that it built a database that communicated with both the optimization and the simulation modules. The optimization module would determine the optimal supply chain structure and the simulation module that would evaluate, under dynamic conditions, the optimal supply chain structure. Of the six students in that class,

four received job offers because of the experience that they got in that project.

In the Summer of 2007, the University of Pittsburgh, Oklahoma State University and University of Arkansas received funding for a research project that included modeling of design decisions as part of the supply chain. As a part of this grant, the Supply Chain Modeling class at OSU was tasked to incorporate components of e-Design into the supply chain modeling system (SCMS).

With the task to make the SCMS able to evaluate e-Design decisions, the class in the Fall of 2007 decided to make several changes to the project developed in Fall 2005. The list of modifications for the project can be seen in Table 1. Figure 2 shows the tradeoff of effort vs. impact on each of these modifications. In addition to these modifications, the class made considerable progress on a graphical user interface.

Table 1: Changes made in SCM Class - Fall 07

Item	Modifications	Database / U.I.	Optimization	Simulation
1	Design Alternatives	x	x	
2	Volume Pricing	x	x	
3	Service Level	x	x	
4	Shipment Priorities	x	x	x
5	Scrap percentage	x		x
6	Tariff and Duties	x	x	x
7	Inventory Carrying cost	x	x	
8	Minimum deployment %	x	x	
9	Initial open	x	x	
10	Forced open	x	x	
11	Lead Time Variation			x

The improvements to the system included:

1. Design Alternatives: The ability to have a number of different designs for a given product. The model would then choose the design that maximize profit to manufacture and sell.
2. Volume Pricing: Some costs will be reduced due to economy of scales.
3. Service Level: Service level is the amount of product that is guaranteed to reach the customer in a given time period. This is input into the database as a percentage of the demand.
4. Shipment Priorities: This prioritizes the shipment of product to customers based on their priority level. Priorities were set from 1 (the highest) to 3 (the lowest).
5. Scrap Percentage: The amount of product coming from a supplier that you expect to scrap.
6. Tariff and Duties: Tariff is a charge imposed by a country for products being imported. In this project, it is considered that each site could have a different tariff and it could be different for the different products. The tariff is based on the expected value of the product at that stage in the supply chain.

7. Inventory Carrying Cost: The cost of carrying inventory over time. We assume that the inventory carrying cost percentage (or rate) is the same for all sites, but can vary for products over time.
8. Minimum Deployment Percentage: This allows a customer (any site receiving product) in the supply chain to specify a minimum source percentage for its suppliers for a given product. When a company requires that a certain percentage of its products needs to be supplied by a specific site, the minimum deployment percentage concept is used.
9. Initial Open: This is defined for sites that are required to be open at the first time period, but they could be closed in later periods if the model decides so in order to maximize profit.
10. Forced open: The model is able to identify sites that need to be either open or close at some point in time in order to maximize profit. Forced open keeps a site open for all of the time periods.
11. Lead Time Variation: Shipment and production lead times were allowed to be random in the simulation model.

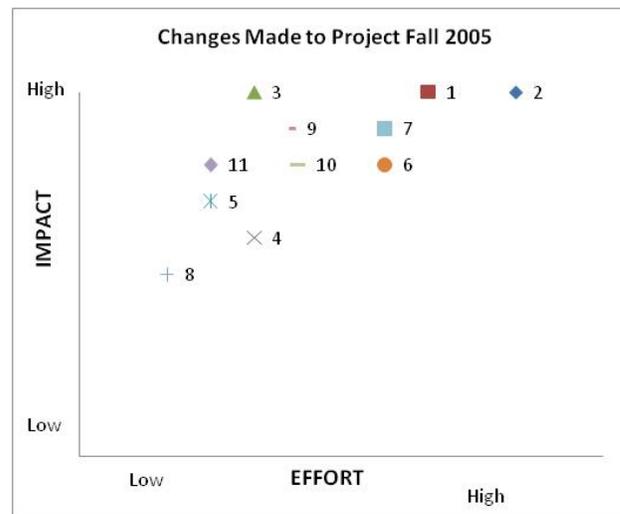


Figure 2: Impact-Effort Diagram that shows Changes Made to Project

In an effort to collaborate the CED (Center for e-Design) and the Center for Engineering, Logistics and Distribution (CELDi) efforts, during the semester, Nuri Mehmet Gökhan of the University of Pittsburgh was a guest lecturer in the class. He shared his dissertation work, “Development of a Simultaneous Design for Supply Chain Process for the Optimization of the Product Design and Supply Chain Configuration Problem.”

The class was so successful that a group of the students had continued working with Dr. Ingalls on the SCMS in the Spring 2008 semester in a Special Topics course.

That group has continue to change and upgrade the model with special emphasis on incorporating supply chain design work performed at the University of Pittsburgh and migrating it into an open source language.

4 THE SUPPLY CHAIN MODELER

The students in the Supply Chain Modeling class in Fall 2005 and 2007 developed a tool that provides the best design alternative for products and its supply chain. This tool has three different modules: Database/User interface, Optimizer and Simulator and they are going to be briefly discussed below. Figure 3 depicts the supply chain modeler tool.

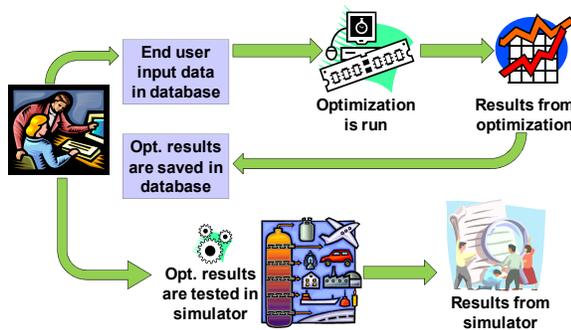


Figure 3: The Supply Chain Modeler

4.1 Database/User Interface

This module is used by users to input all the information of all the possible design alternative of the products, its bill of material, suppliers, manufacturers, forecast demands, lead times, capacities, transportation modes, etc. All the information is automatically accessed by the optimizer to read the information of the parameters; and when the optimizer is run and finishes it store the result in the database where users can access financial reports.

4.2 Optimizer module

The optimization model maximize profit through the products' life cycle subject to satisfy agreed service level, capacities, bill of materials, decisions to open/close sites, etc. Some of the costs considered are transportation costs, tariff and duties, facility maintenance costs, holding costs, etc. As it has been mentioned, the results are stored in the database and read by the simulator to test the results adding variation.

4.3 Simulator Module

In our model, the discrete-event simulation model is built using Arena to simulate the configuration recommended by the linear optimizer adding variation to transportation lead times, production cycle time, and demand. In order to increase the efficiency of the simulation and since we are more interested in a strategic level not in an operational level, only one type of entity is created. This entity carries out all the information and has to go through six basic repetitive tasks which mimic several key business processes any manufacturing facility must undergo in manufacturing a product on a daily basis. The tasks and time scheduled for each daily task are (Ambiye et al. 2005): 0.00 Read Data, 0.01 Reset Customer Demand Forecast, 0.02 Accept Shipment, 0.03 Calculate Inventories, 0.04 Scheduling, 0.05 Calculation of Financials. Below is a brief description of each task:

1. Read Data: The very first task the simulation model performs is to read the data from the database to be simulated.
2. Reset Customer Demand Forecast: The forecasting module of the simulator takes into consideration the original forecast that is assigned to each current week as is, and recalculation of forecast for the subsequent weeks based on the current weeks actual demand and forecast error – what is deployed in the model here is the exponential smoothing technique of forecasting. The forecast information of the current week will be used as the actual demand figure for the current week.
3. Accept Shipments: This step of the model updates the inventory information in the model after all shipments are accepted.
4. Calculate Inventories: The production planning includes calculation of current week demand, available inventory, the backlog, the amount of backlog already being fulfilled, and demand that remains to be fulfilled. The production planning module of the simulator takes care of end item level demand as well as item level demand planning which is tied to the MRP process. This information is then transferred from one site to the subsequent sites starting from the end customer to the final production site of the supply chain. (As we know the flow of material takes place from the final production site of the supply chain to the end customer).
5. Scheduling: The production scheduling part includes calculation of daily production quantity, assessed after considering the site capacity, inventory, the backlog demand and the current day demand. Once the production quantity is determined, this production quantity is first used to

fulfill the backorders, where the “backlog demand met” comes into picture. If the current production quantity is not large enough to fill the entire backlog, then the backlog that is still remaining to be filled becomes the difference between backlog demand and backlog demand met. The next day’s production quantity calculation will take into account this unmet backlog of today and the “current day demand quantity” of the next day.

6. Calculation of Financials: The calculation of daily financial information is based on revenue, cost and current applicable tax rate. The simulation model calculates costs and revenues of the entire supply chain and determines the overall Net Profit After Taxes for the corporation for a given supply chain configuration.

In doing so, the simulation model is also able to find answers to the following specific supply chain related questions:

1. What is revenue and cost tied to each product sold to the customer?
2. What tax advantages are we taking advantage of throughout the supply chain?
3. How are the dynamics of the supply chain can affect the performance; especially the most critical dynamics of demand variance and forecast variance affect the overall supply chain performance?

4.3.1 Assumption of the Model

There are several key assumptions in the simulation model. They include:

1. Demand is based on the end customer forecast only. No additional demand is added to this original demand information by subsequent constituents of the supply chain.
2. Information flow on demand from end customer to the first production site of the supply chain happens instantaneously, meaning that no information delay is introduced in the model.
3. There are no loops in the supply chain in the flow of material. All materials flow from source to destination, the final destination being a customer site.

4.3.2 Running Condition of the Model

The simulation may or may not have a warm up period depending on the preference of the end user. One condition that needs to be met in every simulation is that the overall length of the simulation should be greater than the week where the last demand occurs. For example, in our model the week where the last demand occurs is week 52 and the length of our simulation is 58 weeks. This additional time

is added to allow the system to process any backlogged demand that might exist.

5 FUTURE RESEARCH

To be able to use this research in any computer without the software constraint, we are going to implement this approach in a more general language which is easily to be implemented or written in any computer without any software purchase. The future model will be written in Visual Basic (VB) using an event graph structure.

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