AC 2008-1992: INTEGRATING DESIGN FOR SUPPLY CHAIN RESEARCH INTO A GRADUATE SUPPLY CHAIN MODELING COURSE – A COLLABORATIVE APPROACH

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Integrating Design for Supply Chain Research into a Graduate Supply Chain Modeling Course – A Collaborative Approach

Abstract

An ongoing research project addresses the problem of how to effectively synchronize product design and supply chain design for new and existing products resulting in not only a good product design, but a supply chain that is cost effective, minimizes lead time and ensures quality. The research investigates the impacts of product design and redesign on the supply chain structure. The aim is to quantify those impacts so that they can be used in the product design phase to better understand the tradeoffs between the benefits and costs of different supply chain alternatives. This collaborative research effort between the National Science Foundation Center for e-Design (CED) and the National Science Foundation Center for Engineering Logistics and Distribution (CELDi) will result in a synergy that integrates the expertise from each center examining this extremely complex problem, which is referred to as Design for Supply Chain (DFSC). Results from this project are being incorporated real-time into an existing graduate course being taught at the Oklahoma State University entitled Supply Chain Modeling. This course is a third-semester graduate course where students must have a background in supply chain strategy, optimization modeling and discrete-event simulation modeling. The aim of the course is for the students to work as a development team that designs and develops an integrated user interface, database, optimization and simulation prototype for the purpose of analyzing supply chain structures. In the most recent semester, the class has expanded its scope to deal with the DFSC problem. The results of the class can be used as a test platform for researchers and practitioners to make design decisions that create better, more flexible and cost effective supply chains. This paper will focus on the integration of the research into the Supply Chain Modeling course, discuss outcomes, and the next steps of this ongoing effort.

1.0 Introduction

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). We use 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 experiences showed 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.

Our main research hypothesis is that simultaneous (or parallel) product and supply chain design (as compared to sequential design where the product and supply chain designs are considered in sequence) leads to better performing supply chains for the associated products. It also helps reduce total production costs and lead times as well as increasing product quality and customer satisfaction.
satisfaction by better balancing both the product design and supply chain requirements. This research specifically aims to answer three major research questions which are: (1) How robust is the supply chain to product changes? (2) What is the relative importance of the product design and the supply chain design on product success and profits? and (3) How does the performance of the product and the associated supply chain differ for the simultaneous and sequential approaches? Answering these research questions will help practitioners better understand the relationship between product design and supply chain performance. The resulting analytical balancing of product design requirements and their supply chain impacts will help managers broaden and enhance their decision support mechanisms.

In order to answer these research questions and to test the research hypotheses, several mathematical models are developed and the product’s life cycle is simulated to understand the effects of different design decisions at different points in time. One important aspect of this research is that it incorporates both the customer side (front-end) of the supply chain and the supply side (rear-end) of the supply chain by considering demand generation and satisfaction which is dependent on the supply chain design. Therefore, this study investigates how the product and supply chain design decisions impact the product’s stakeholders including but not limited to customers, suppliers, manufacturers, and designers. Each product and supply chain design decision will be mapped to a series of events and parameters to be simulated throughout the product’s life cycle which will eventually provide a better decision support system for industry partners for long term strategic planning.

Development of a test platform with a user friendly interface will facilitate practitioners incorporating these complex models into their decision support systems. Development of efficient solution procedures will enhance the product design and supply chain research domains by incorporating the very complex impacts of product design into supply chain system design. In addition, it is also felt that incorporating this concept into graduate level supply chain modeling courses is beneficial to students. This paper gives background on the DFSC research project, shows how the research has already been incorporated into a graduate level course at the Oklahoma State University and then gives next steps for incorporating this research into future courses at other universities. Further details of the DFSC research are discussed in another paper by the researchers.

2.0 Research Partners

This research project is an ongoing, collaborative effort between the National Science Foundation Center for e-Design (CED) and the National Science Foundation Center for Engineering Logistics and Distribution (CELDi). The project is being funded through an NSF TIE research proposal. A TIE proposal results in a synergy that integrates the expertise from multiple centers examining an extremely complex problem, in a holistic manner. The two main sub-problems that comprise this over-arching problem are the product design, which is the focus of study by the CED, and the supply chain design, which is the focus of study by the CELDi.

The CED serves as a national center of excellence in information technology (IT) enabled design and realization of engineered products and systems. The center is comprised of the following
Researchers at the University of Pittsburgh are collaborating on this proposed research with the CELDi researchers from the University of Arkansas and Oklahoma State University. CELDi serves as a national center of excellence in technology and methods that improve the performance of logistics, distribution and supply chain systems. CELDi has nine member universities: University of Arkansas, Oklahoma State University, University of Louisville, University of Nebraska, University of Oklahoma, University of Florida, Lehigh University, Texas Tech University, University of Florida, and Clemson University.

CELDi research endeavors are driven and sponsored by representatives from a broad range of member organizations, including manufacturing, maintenance, distribution, transportation, information technology, and consulting. The industrial partners drive CELDi with a strong existing and ongoing financial commitment to logistics research. This partnership between academic institutions and industry represents the effective integration of private and public sectors to enhance the United States competitive edge in the global market place. CELDi provides integrated solutions to logistics problems, through research related to modeling, analysis and intelligent-systems technologies.

3.0 A Brief History of Supply Chain Modeling at Oklahoma State University

Dr. Ricki Ingalls created the Supply Chain Modeling class at Oklahoma State University (OSU) 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.

Supply Chain Modeling has been taught every other year since the Fall of 2001 and it serves as a capstone course in the Supply Chain M.S. curriculum at OSU. 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.

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 received in that class.

In the Summer of 2007, the University of Pittsburgh, Oklahoma State University and University of Arkansas received funding for their TIE Research Proposal. 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. (A more detailed description of each of these modifications can be found in Section 5.2.) Figure 1 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>
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<th>Simulation</th>
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<td>11</td>
<td>Lead-Time Variation</td>
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Table 1: Changes made in SCM Class - Fall 07
In an effort to collaborate CED and 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 will continue work with Dr. Ingalls on the SCMS in the Spring 2008 semester in a Special Topics course. That group will continue to change and upgrade the model with special emphasis on incorporating supply chain design work performed at the University of Pittsburgh and work already performed as part of CELDi.

4.0 Why the Supply Chain Modeling Class Is Important

The Supply Chain Modeling class is important for several reasons. This unique experience allows the students to be confident that they can tackle large-scale modeling problems when they graduate. The class also forces the students to work as a team on something that they could not have possibly done alone at this stage in their career with the timeframe provided. The students are not only forced to propose complex modeling solutions to difficult supply chain problems; they are responsible for implementing the solutions that they propose. Throughout the semester, there is extensive interaction about the pros and cons of proposed solutions, whether or not those solutions will be efficient, and whether or not those solutions will be meaningful to a potential user of the system. Because these are the types of decisions that the students will be making in their future work, the class prepares students to address those issues.

5.0 A Project Experience: Combining Design for Supply Chain Research Project with the Supply Chain Modeling Class
5.1 Literature Review – SCM Concepts, Related Projects

Students in the Supply Chain Modeling class were expected to have a working knowledge of databases, optimization and simulation. Therefore, students first learned the concept of supply chain modeling. In the class, Dr. Ingalls taught two core concepts of supply chain modeling: the modeling of site selection/transportation decisions and the modeling of financial metrics. These two models form the “skeleton” of any supply chain system. Then those models were enhanced by extending them to multiple time periods. With these underlying structures, the students were then taught how to model a supply chain by applying optimization and simulation techniques.

When the supply chain is mathematically optimized, the results determine the best (either least cost or most profit) supply chain structure. The optimization module can address the following issues in supply chain management:

- Customer demand planning
- Customer order fulfillment and customer service
- Strategic sourcing and procurement
- Production logistics, distribution networks and warehouse management
- Transportation and shipment management
- Analysis of revenue, cost and profitability

Simulation, on the other hand, is used to analyze the supply chain under dynamic conditions. Using the simulation module, the analyst can identify:

- Bottlenecks
- Capacity issues
- Issues and outcomes related to delay/timing
- Utilization of resources over time
- The impact variance has on the expected revenue, cost and profitability

In addition to the above mentioned concepts taught in the class, students were encouraged to review some related literature on their own. The literature reviewed in class included:

- The supply chain modeling project software and documentation from the Fall 2005 class
- “Reducing the bullwhip effect in supply chains with control-based forecasting,” a paper presented in the International Journal of Simulation & Process Modeling by Dr. Ingalls and his colleagues;  
- “Global Supply Chain Management at Digital Equipment Corporation,” a paper that appeared in Interfaces.

5.2 Class Discussion about Improvement of the Previous Supply Chain Model

The objective of the project for Fall 2007 was to evaluate the impact of product design decisions and the supply chain on the profit of the organization. In order to achieve this objective, it was necessary to make several modifications to the model that was developed in the Fall of 2005.
After the objective of the project was discussed and understood, all of the students proposed changes to the model. The resulting list of changes was very large. The class had extensive discussions about the changes and their impact on the objective of the class and the effort involved. As a result, only eleven changes were selected. Those changes are explained below, can be seen in Table 1 and are depicted in Figure 1.

A brief description of the changes:
1) Design Alternative: The ability to have a number of different designs for a given product. The model would then choose the best design to manufacture and sell.
2) Volume Pricing: The ability to choose suppliers based on volume pricing from those suppliers.
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.
9-10) Initial Open and Forced Open: Initial Open 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. 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.

5.3 Making a Plan and Assigning Responsibilities

The project had three different modules and a team was created for each. The three modules were the user interface module, the simulation module and the optimization module. Each student was allowed to decide which team to join based on his or her interests and skills.

Outside of class, the three teams met at least once a week to discuss the progress of each module, to determine what was needed from the other teams, and to learn from each other. A project plan was created and followed by the students. Changes were made to the plan as necessary. This portion of the project allowed the students to practice project management and teamwork skills.
During the project meetings, several questions came up that needed further explanation. The team looked for related information and then brought the issue to class for discussion. After the pros and cons were considered, a decision was made and implemented.

Project tracking and monitoring was an integral part of the weekly team meetings. Progress updates and tasks were posted on the Desire To Learn (D2L) website for the class which is a web-based platform where files and discussions can be posted and accessed by all the class.

5.4 Final Model Integration

When all three modules were complete, the next step in the project was integration. The integration process found many issues, including different variable names, different parameter names, and different references to database files. A list of problems was created and then they were worked through in a coordinated effort among all of the students. Overall, the integration process took approximately two weeks to complete.

5.5 Model Verification and Results

After the integration was finished, the completed supply chain model was verified with a small supply chain network comprised of ten sites (2 customer sites, 2 inventory sites and 6 manufacturing sites). The supply chain network is shown in Figure 2.

![Figure 2: The Supply Chain Network for Model Verification](image)

In this supply chain system, there were two product alternatives for Product 1. The optimization model was verified by the set of input data with known solutions. For the simulation model, on the other hand, no obvious verification had been done because it would require an actual set of data for doing so. However, the students did compare the results from the simulation model with no variation with one that had demand and lead time variation.

5.6 Class Benefits

Perhaps the greatest benefit of the class was the combination of theory and practice for the students. In addition, the students benefited through research experience, teamwork, and the application of project management skills. For the professor, this class is a joy to teach. In the
class, you are a teacher, a mentor, a boss, and a teammate. One of the best parts of the class is when the professor honestly says, “I don’t know” when a difficult problem arises. It is then that the students and the professor work together to address a difficult, and possibly unsolvable problem. This is an excellent way in which research and teaching begin to merge in the classroom.

6.0 Conclusions and Future Work

This paper describes the collaborative approach taken to integrate DFSC research into the Fall 2007 graduate supply chain modeling course at Oklahoma State University. With the initial course offering completed, several students from the course have decided to continue on with the multi-university team’s research agenda by continuing to develop and extend the computer model-based test bed containing the research project’s optimization and simulation engines. This is important, as the major objective of the TIE project is to develop a working prototype software-based algorithm/model test platform that optimizes and simulates a user-defined supply chain for products that have not yet been completely designed.

In addition, the students plan to develop their research interests in this important topic area by continuing to work on the TIE project research team. The TIE research team will continue its planned investigations, relying heavily on this test bed framework that was created in part during the Fall 2007 graduate course offering. In the future, the potential exists for similar courses to be offered at the University of Pittsburgh and the University of Arkansas, as the research team continues with its mission to both produce high quality, scholarly research and to disseminate research findings both in the literature and in the classroom. It is clear that allowing graduate students and other researchers hands-on use of the modeling test bed can only help to improve both the computer software’s and the TIE research project’s efficacy, visibility, and acceptance.

7.0 Acknowledgements

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References