National Textile Center

FY 2003 (Year 12) Continuing Project Proposal

Project No.

S01-NS01

Competency: Management Systems

Business-to-Business Collaboration in a Softgoods…

Project Team:

Leader: Russell E. King NCSU Modeling and Analysis of Production Systems

Email: king@eos.ncsu.edu Phone: 919-515-5186

Members: Shu-Cherng Fang NCSU fang@eos.ncsu.edu Systems Optimization; Fuzzy Mathematics

Jeffrey A. Joines NCSU jeffjoines@ncsu.edu Evolutionary Algorithms; Information Technology

Henry L.W. Nuttle NCSU nuttle@eos.ncsu.edu Production Systems Modeling; Planning/Scheduling

Objective:

For a successful e-supply chain collaborative effort, partner selection, contract negotiation, and dynamic pricing/cost sharing are essential issues requiring resolution. In this project we will conduct a thorough study of these critical issues, providing models and prototype tools to support collaborative efforts in the B2B environment. Successful resolution of such issues involves the simultaneous consideration of a number of possibly conflicting criteria including both quantitative factors such as cost and lead-time and vague qualitative factors such as "quality," "reliability" and "reputation." We will integrate new developments in Data Envelopment Analysis (DEA), cooperative game theory, and fuzzy mathematics to address not only quantitative but also qualitative data and decision criteria in selecting partners, structuring contracts, and collaborative forecasting, planning, and inventory management.

Progress Statement:

The effort to date has been to study the state-of-the-art of Data Envelopment Analysis and cooperative games and develop and demonstrate corresponding models for establishing collaboration and contracts in the increasingly global softgoods supply chain. In these models we use fuzzy mathematics to capture vague and uncertain factors.

Data Envelopment Analysis (DEA) is an important tool in the field of efficiency measurement, used to compare similar "Decision Making Units" (DMUs) such as potential suppliers in which one or more inputs secure one or more outputs. DEA provides the ability to perform objective, comparative efficiency analyses that go beyond purely financial measures of performance. While the traditional DEA requires precise data for its analysis, the evaluation environment often involves vagueness and uncertainty especially in the softgoods supply chain (i.e. quality of the product is good, the lead times are short, etc.).

In order to provide powerful tools for assessing the performance of a set of DMUs in the softgoods supply chain, we have integrated fuzzy modeling and possibility theory with traditional DEA analysis. Several models, which simply introduce fuzzy sets into the traditional DEA models in order to represent vague or imprecise data, have appeared in the literature. However these models lead to fuzzy linear programs which are not well defined due to the ambiguity that occurs in the ranking of fuzzy sets. To deal with this ambiguity we have now developed three new approaches: an alpha-level based approach, a possibility approach and a credibility approach. For the case in which the membership functions of fuzzy data are trapezoidal, these approaches transform fuzzy DEA models into unambiguous linear programming models. These new approaches, which are based on sound theoretical principles, permit the representation of a range of management perspectives and have been proven to be more robust and accurate than previous techniques. This theoretical work has led to a Ph.D. dissertation, two conference presentations and proceedings papers, and two articles accepted for publication in scholarly journals.

To communicate our results as well as apply Fuzzy DEA models to the softgoods supply chain, we initially implemented the alpha-level-based approach in a prototype software package. We have now enhanced the package to include the possibility and credibility approaches as well. This software uses fuzzy sets to quantify imprecise and vague data, and analyze the data by the DEA approach. The software provides insights into how well the individual DMUs are performing their activities, as well as how their efficiency can be enhanced. The user interface was built using Microsoft Visual Basic™ linked with a Microsoft Access™ database to store the data for subsequent analysis or changes. The Fuzzy DEA engine is written in C++ and dynamically linked to the interface. The software includes several key features helping users to implement the analysis. These features include data displays for data input, graphical tools for setting membership functions of fuzzy inputs and fuzzy outputs, alternative methods for solving fuzzy DEA linear program, and efficiency score table for data display.

A softgoods supply chain involves the activity and interaction of many entities. In this situation, each entity can be viewed as a "player in a game". *Cooperative game theory* is a potentially useful tool for achieving efficient and effective collaboration in the supply chain. It can be used in selecting partners, structuring contracts, and sharing profit/cost. Cooperative game theory can also be used to optimize the performance of a supply chain, i.e., increase the total profit of the supply chain.

In this project, we have conducted a thorough study of the theory of cooperative games for potential application in the softgoods supply chain. We have also explored game theoretic approaches to the determination of optimal ordering strategies of retailers in a distribution system, where the retailers compete for both supplier capacity and for customers, as is common in softgoods scenarios. Specifically, we have analyzed two, two-retailer supply chains with different cost and revenue structures. For the first supply chain, we have been successful in developing an approach to determine the equilibrium ordering strategies of the retailers for the case under which neither is the dominant player. We can also determine the optimal strategies of both the "leader" and the "follower" for the situation in which one retailer (e.g., a Wal-Mart) is dominant. For the second supply chain, we have studied both decentralized and centralized decision making settings. Applying the concept of "channel coordination", we have shown how to set the wholesale price so that the retailers in optimizing their own profit will act so as to optimize the profit of the whole supply chain. This work has led to a Ph.D. dissertation proposal, two national conference presentations, and three papers, two of which have been submitted to scholarly journals

To communicate our results, we have developed a demonstration software package implementing the "game theoretic approach." The software provides insights into how well the retailers are performing, as well as how their performance can be enhanced. The user interface is written in Microsoft Visual Basic™ while the engine is written in Matlab and dynamically linked to the interface.

As with DEA, when vagueness is taken into account, data is represented by interval-valued fuzzy numbers. Our work on interval computations for fuzzy relational equations and applications in cooperative game theory is documented in a Ph.D. dissertation, a conference proceedings paper and a paper which has been accepted for publication in a scholarly journal. Another paper is currently under review.

As the sourcing and marketing in the softgoods industry becomes increasingly global, on-line auctions provide a potentially useful mechanism for purchasing and marketing of product and capacity. Much of the early work on auction theory is based on game theory that turns out to be difficult to implement in practical situations and not a viable approach for the more complicated auction structures that are coming into use.

In cooperation with a visiting scholar, we have conducted and documented a thorough study of the literature on *auction theory*. Realistic auction scenarios often involve vague and uncertain factors such as a bidder's estimation of the price an object will probably bring and the bidder's perception of the value of the object. This has led us to examine the formulation of auctions using fuzzy sets and fuzzy logic. Our work is documented in two papers submitted to scholarly journals.

During the last year this project has led to two completed Ph.D. dissertations plus a third dissertation proposal, two conference papers, three papers accepted for publication in scholarly journals, four additional papers under review, a new prototype cooperative game software package, and substantial enhancements to the prototype DEA software. In addition, two students working on the project completed their Masters degrees. More detail on our accomplishments to date, including papers, references, and software can be found at <http://www.ie.ncsu.edu/fangroup/NTCpage/NTCI01S1/index.html >.

Next Year's Goals:

1. Expand research on cooperative games for partnership formation and contract negotiation.
2. Demonstrate the use of cooperative games in a softgoods supply chain scenario.
3. Develop web-based versions of the prototype software packages to allow online access.
4. Investigate new tools for collaborative forecasting, planning , and supply chain inventory management
5. Test the tools from (4) utilizing test bed data from a real softgoods supply chain.

Approach:

Our “cooperative games” approach will be extended for partnership formation and contract negotiation. First, the two-retailer distribution system model will be generalized to a more realistic scenario involving multiple retailers who sell substitutable products. Next, the retailers’ optimal decision making in terms of “Nash equilibrium” in a centralized control scenario that maximizes the expected profit of the entire supply chain will be studied. The third stage is to study a decentralized scenario and design channel coordination mechanism that influence individual retail’s decision to go for chain-wide profits. Considering the current trend of doing business on the Internet, we will build new models for scenarios involving competitive retailers who sell products through both local and online (website) stores. In such a scenario, each retailer will face an important decision of how to allocate his/her finite capacity for local and on-line sales. The game theoretic approach that has been developed may lead us to derive the existence and uniqueness conditions for the “Nash equilibrium” of the underlying cooperative game. A sensitivity analysis of the equilibrium solution in terms of different cost parameters for optimal decision making will be conducted.

To date we have developed different theoretical models for the DEA and cooperative game approaches and built prototype software packages for demonstration purposes. However, the effectiveness of these techniques for supply chain applications has not yet been fully explored. An additional goal for our work is to find applications in the softgoods supply chain and apply these new techniques to these scenarios. In support of this, we will develop web-based versions of the prototype software to permit online access. With such software, for example, a company such as JC Penny, which has many local stores, could establish a DEA evaluation site with a database and the DEA engine. Local stores could login to the web page by and submit their current data through the web. Then the server could run the DEA engine and send each store (and corporate headquarters) its results.

It has been shown in the literature that jointly maintaining a common forecasting system is good for the entire supply chain. A "Collaborative Planning, Forecasting and Replenishment (CPFR)" initiative provides significant benefits to all the entities in the supply chain that participate. The core objective of CPFR is to increase the accuracy of demand and replenishment plans as necessary to lower inventories across the supply chain while attaining high service levels (i.e. helping supply chains become more demand-driven). This is possible when companies collaborate by sharing demand, production, and inventory data. However, when certain entities of the chain refuse to share information or give incomplete or inaccurate information, the collaborative advantage may be lost. Currently, there is no effective way to deal with this problem. We plan to develop an approach using fuzzy mathematics. Initially we will study how information is shared and how collaborative forecasting and planning is performed. Then we will utilize fuzzy math models (e.g., fuzzy regression and control) to solve these problems.

Often long lead times force manufactures to operate in a make-to-stock mode in order to be responsive to their customers’ demands. To have high service levels, the manufacture normally carries large inventories that can become obsolete. Therefore, carrying the right amount of inventories coupled with planning the appropriate production mix is very important. The demand forecast becomes even more critical for these operations since the plan is put into place long before orders become firm. Also, many companies forecast and plan target inventories at the category level (style and color), that can lead to inappropriate levels at the SKU level. We will evaluate the use of f neural networks and fuzzy control to appropriately forecast and plan inventories at the SKU level. New locally weighted learning paradigms can be used to retrain neural networks to ease application in a rolling horizon operation.

Ultimately we plan to develop a web-based database and forecasting engine that will act as a neutral site where entities in the supply chain can supply their information and the engine will generate a forecast based on the information it currently has, even if the information is incomplete or inaccurate. The system will not reveal the other entities’ information unless given permission to do so. Hopefully, with this sort of anonymous system, accurate information sharing can be encouraged, resulting over time in better forecasts and plans.

Outreach to Industry:

We are currently working with a large manufacturer who is providing us with past data from its supply chain. This will allow us to test the new forecasting and inventory planning methods and compare with actual company performance. We have created and continue to enhance the web site documenting our reports, papers and links to the technologies that we draw on and applications thereof.

New Resources Required:

The resources required are for student and faculty time plus travel to the annual forum, industry sites, and conferences.