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Analysis/Modeling of Actions and Interactions of FTAR Firms

PIs: G. Berkstresser, N. A. Hunter, R. E. King, H. L. W. Nuttle, J. R. Wilson, and S.-C. Fang (North Carolina State University), C. Jacobs-Blecha (Georgia Institute of Technology), and P. Butenhoff and B. Mazziotti (Textile Clothing Technology Corporation)

TEAM LEADER: G. Berkstresser

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I. PROJECT OBJECTIVES AND RELEVANCE TO NTC GOALS

The pipeline modeling project has continued and expanded the effort, begun under the auspices of CRAFTM, to develop and integrate accurate models of the firms in the U.S. apparel-supply complex. The project has three primary thrusts: research, education, and industry support. Our objectives can be categorized based on their primary orientation.

Research objectives:

1. Development and integration of accurate models of the firms in the pipeline, emphasizing demand activated manufacturing environments.
2. Analysis and modeling of relations between operational control parameters and the performance of the firms, both individually and collectively.
3. Development of improved strategies for attaining performance objectives of the firm and the pipeline, with emphasis on responsiveness, flexibility, and productivity.
4. Development of visual, interactive decision support systems incorporating the results from objectives 2 and 3 above.

Educational objectives:

1. Provide research opportunities in textile and apparel management for graduate and advanced undergraduate students.
2. Develop decision-making games to provide a hands-on complement to courses in operations and marketing management.

Industry support:

1. Provide decision support systems and training games to industry
2. Allow companies to reconfigure the models to represent their facilities in order to perform “what-if” studies.

The advantage of the modeling approach in understanding and exploring the modification of the pipeline operation, as well as for education and training, is the ability to observe the results of operational changes quickly, inexpensively, and without risk to the actual production system.

Our objectives center on the understanding and description of how information and material must flow through the apparel-supply pipeline in response to consumer demand and of how firms in the various manufacturing segments should react to this demand as it percolates back through the pipeline. Regardless of the conditions under which the pipeline operates in the future-whether

QR, traditional, or otherwise-decision making will still be in the hands of the management of the individual firms. Answering CEO-type questions- about the cost/benefit consequences of policy changes (such as installing QR, broadening the product mix, reducing the minimum order size, and adopting new quality procedures) is of special importance. Two basic goals of this project are to understand the operation of each firm and then to understand the interactions between the objectives of the various firms. This is necessary in order to understand the trade-offs required to make the U.S. complex responsive, flexible, and productive and, thus, viable and competitive.

Up to this point, the research effort has involved the collaboration of faculty and students in the Colleges of Textiles and Engineering (spanning 3 departments) at North Carolina State University, the School of Industrial and Systems Engineering at Georgia Institute of Technology, and the Textile Clothing Technology Corporation [$(TC)^2$]. We have been regular participants in steering committee and task team meetings for the AMTEX DAMA project. We plan to continue this interaction. We also anticipate expanding our research team to include faculty and students from the Department of Clothing and Textiles at UNC-Greensboro.

II. TECHNICAL APPROACH

A. Background and Concept

This project has its genesis in the development of Quick Response (QR) methodologies during the period 1984-86 by the industry-sponsored organization “Crafted with Pride”. Following a variety of market studies, QR was postulated as having massive benefits for the apparel pipeline if manufacturing process times could be shortened sufficiently to allow in-season reestimation of true consumer demand and reordering of merchandise by the retailer. This was in sharp contrast to the traditional pattern of preordering most of the merchandise and getting stuck with volumes and assortments of SKUs that were at odds with customers’ preferences. This dichotomy between supply and demand led not only to large stockouts of popular items but also to large residual inventories of unpopular items at the end of a season; the end result was low levels of retail service and significant loss of income through price markdowns.

During the period 1985-86, the validity of these findings was put to the test in a small number of full-scale industry trials involving partnerships of textile, apparel, and retail firms. The results strongly supported the use of QR procedures as well as the conclusion that more trials would have been beneficial to firms making different products or using other manufacturing and distribution procedures. The problem was the high cost and long duration of the trials.

In 1988, CRAFTM, an industry-university consortium, was formed at North Carolina State University to support research in a number of areas, one of which was the modeling of QR systems. Several members of the current project team began working together at that time. The first QR model was a simulation of a retail establishment selling seasonal apparel-that is, goods with a limited shelf life. With this model it was easy to compare performance of traditional retailing practice with that of QR retailing, where a smaller initial shelf stock is committed preseason and frequent within-season sales reestimation and reordering, based on point-of-sale (POS) data, is used to adjust for differences between anticipated and actual customer preferences. Study of a wide range of operating scenarios showed that QR leads to much better retail performance than traditional practices, including increased inventory turns and service levels as well as reduced stockouts and residual inventory. However, this superiority diminishes as the total season’s requirement per SKU drops below about 25.

We have had two opportunities to validate the utility of algorithms embodied in the retail model-one involving an industry trial for a swimsuit season; and the other, a major retailer whose offerings included men’s jeans in over 40 sizes. Both product lines had pronounced swings in the seasonal purchasing pattern. In the latter case, a new system based on a modification of the retail model has been installed by the company.

The retail model was based on the assumption of a perfect supply of garments so that all reorders *were* met precisely by the vendor and with response times of 2-3 weeks. The realism of this assumption was uncertain; and this uncertainty prompted the development and modeling of an apparel-supply system that was compatible with QR requirements and was linked to the retail model. The principal features of this apparel-supply model were: (1) the use of approximately level production volumes; (2) the placing of regular, small fabric orders on the dye house; (3) operation with minimum work-in-process garment and fabric inventories; (4) continual reshaping of the SKU mix in the working inventory as reorders are processed; and (5) effective elimination of remaining inventory during the last few weeks of the season. The results obtained from the apparel-supply model using a variety of input parameters were extremely promising; moreover, the results proved to be rather insensitive to the error between retail plan and actual demand, provided the selling season was 15 weeks or longer.

The apparel model was based on the assumption of a perfect supply of (often small quantities of) dyed fabric in a specified (short) leadtime; and at this point it became apparent that the apparel simulation model had to be expanded to include the textile industry in order to determine how closely the fabric supply could come to QR standards. Building on this earlier work and now operating under the auspices of NTC, the expanded research team has been specifying and developing an integrated set of simulation models of the firms in the apparel pipeline, from spinning through cut-and-sew. Figure 1 provides a schematic overview of the system.

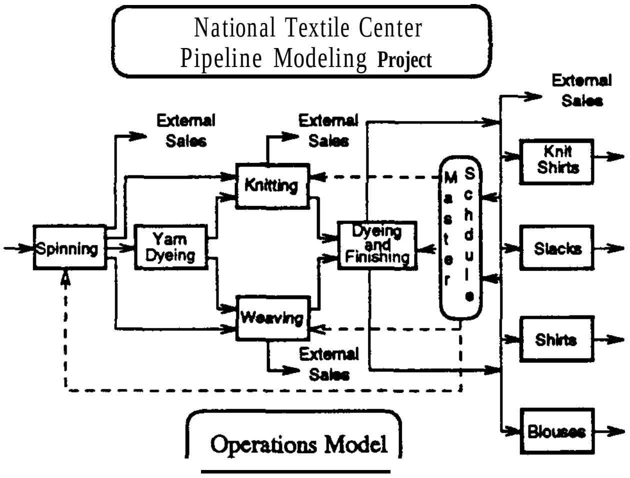

Figure 1: Overview of the Textile-Apparel Pipeline

The overall textile-apparel system is sized to produce/process about 25 million pounds of yarn per year, about half of which will be consumed by 4-5 pipeline apparel manufacturers; and the rest will be sold to outside customers for yarn and fabric. A testbed set of garments (including basic, seasonal, and fashion garments) to be assembled in the apparel plants, in turn, specifies the variety of colors, fabrics, and yarns to be produced in the other plants. The simulation models comprising this system provide a vehicle for: (a) understanding the interactions of decisions within one firm with those in another; (b) analyzing and developing operational practices within individual firms and across subsets of firms; (c) developing CEO-type information systems; and (d) training personnel in making operational decisions.

B. ACCOMPLISHMENTS TO DATE

Much of the effort to date has focused on developing computer simulation models of the individual plants in the pipeline, along with a testbed of garments and a master schedule generator (Figure 1).

However, using the plant models, we have also studied the impact of input parameters (such as number of yarns and target inventory levels) on selected performance measures (such as order response times and inventory levels). With the spinning model, we have done comparative analysis of alternative frame-scheduling strategies. We have explored the development of both classical response surfaces and neural network models that relate plant performance to key decision parameters to provide the computational engine for an interactive CEO-type information system; and we have made a first cut at developing an object-oriented version of the spinning model, along with a user-friendly interface, to provide for easy modification of the model to specific plant operational paradigms.

1. Pipeline Simulation

At this point we have operational standalone simulation models of dyeing and finishing, weaving, knitting, and spinning plants plus the master schedule generator. Team members at $(TC)^2$ are using previous work of their own and from Georgia Tech to develop apparel plant models. An initial effort at linking individual plant models has been made with the spinning and knitting model.

The plant models are fairly high level, as opposed to being detailed shop-floor models. They are data-driven (that is, they require numerous inputs such as customer order streams, machine capacities and production rates), and they produce outputs including the sample mean and an empirical frequency distribution of order leadtimes and inventories. Each model includes flow of material from raw or semifinished material inventory, through the major production processes, through inspection, into final inventory, and “out the door”. These models simulate plant activity for a user-specified time horizon (for example, 52 weeks). The daily activity is directed by routines which generate weekly (or daily) schedules for major processes, but the activity is also influenced by randomness in factors such as cycle times and yields.

The pipeline models are coded in the SIMAN simulation language, supported by many user-supplied discrete-event subroutines coded in FORTRAN. With each model, most operational parameters (numbers and types of looms, cycle times, yields, etc.) are model inputs and may be easily changed to represent a wide variety of operational scenarios. The plant models are also constructed so that it is possible to replace, for example, the scheduling procedure.

2. Decision Surface Modeling

The objective of decision surface modeling is to develop an interactive information system that captures the essential features of each plant model (or an integrated collection of plant models) in mathematical relationships between plant performance (inventory, order leadtimes, etc.) and key decision parameters (product mix, number of machines, etc.). These “metamodels” are intended to provide CEOs with rapid, easy-to-use capability to predict the impact on system performance under various “what-if’ scenarios such as:

- What are the consequences of broadening the product mix?
- What are the costs and benefits of reducing order leadtimes?
- What are the costs and benefits of introducing new equipment?

We have explored metamodel development using both a traditional response surface methodology and the more recent, but less well developed and understood, neural network methodology.

For the spinning model, we have estimated response surfaces relating order leadtimes and inventory to a small set of input parameters. The results to date are mixed but promising.

We have developed sequential estimation procedures for fitting and testing the adequacy of classical response-surface metamodels involving polynomial functions up to third order in the plant's key decision parameters. The main objective of this sequential approach is to obtain the simplest approximation to the performance of the simulation that is sufficiently accurate and that is based on a feasible, cost-effective set of experimental runs. In applying this approach, our principal problem has been the formulation of a measure of diversity in the plant's product mix that can be used effectively as a predictor (design variable) in classical polynomial metamodels of the plant's performance. In future work, we will examine other flexible techniques for building simulation metamodels, including single- and multiple-response spline approximations, kernel-smoothing regression techniques, and radial basis functions. In all of this work, we seek accurate yet relatively simple mathematical expressions for selected simulation performance measures (outputs) that have an intuitively meaningful interpretation in terms of the key design parameters (inputs). Moreover, we seek statistical models for which we can obtain valid, meaningful measures of the accuracy of the predictions generated by those models-for example, valid 95% confidence bands about the fitted response surface.

Neural net models have been developed for the spinning plant and for the retail model originally developed under the CRAFTM project. In both cases a three-layered supervised network based on the back-propagation technique has been used to relate input parameters (such as number of yarns and utilization of frames) to performance measures (such as order leadtimes and inventory). Figure 2 depicts the type of neural net used in much of this research.

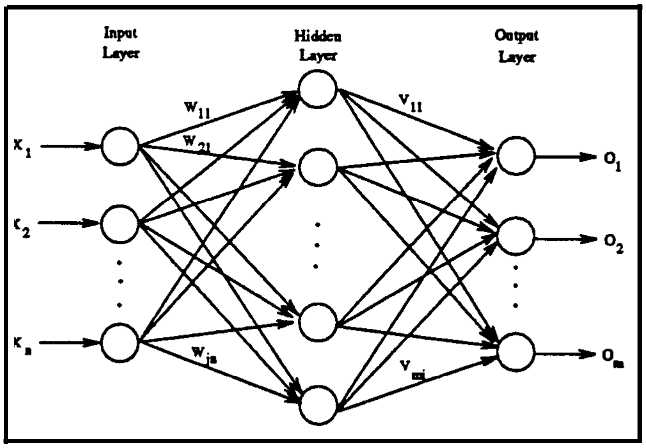

Figure 2: Neural Network Used for Spinning Plant and Retail Model

The neural nets have been trained with performance data obtained from running the spinning or retail simulations with various input combinations. The nets have been evaluated by measuring the mean square difference between predicted performance and actual simulated performance. For both the spinning plant and retail store models, the prediction errors were quite small. Ninety-five percent of all predictions fell in a confidence band ranging from 95% to 105% of the observed performance level, so long as every input falls within its range of values used for training. As with any kind of forecasting technique, prediction accuracy degrades noticeably when trying to predict performance for inputs that are out of the corresponding ranges used for training.

To accelerate the training speed in order to support an interactive visual interface, we have also developed neural nets with fuzzy control schemes. By building in fuzzy membership for the control parameters, we have optimized the learning rate of the neural net. This results in a significant reduction in training time to reach a quality prediction.

We have also created a user-friendly interactive program to provide graphical representations of the relationships between input parameters and performance measures. For example, Figure 3 shows, for a certain spinning plant scenario, how customer service level (expressed as the percentage of orders shipped on time) is related to the number of frames in the plant and their average utilization. The program allows the user to rotate and zoom in and out to obtain other perspectives and to easily extract the performance measure associated with specific input parameter values.

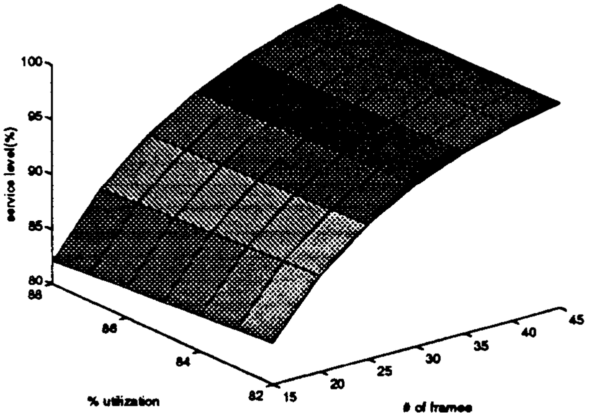

Figure 3: Response Surface Relating Service Level to Utilization and Number of Frames

3. Experimentation and Strategy Evaluation

The plant models provide an excellent vehicle to compare alternative operational strategies with respect to plant performance and, for a given strategy, to isolate the key input parameters (representing controllable or uncontrollable factors) which impact plant performance. This is exemplified by one of the master's theses from this project in which two inventory-control strategies for the spinning plant are evaluated and compared. The simulated spinning plant is operated as a make-to-stock system. There are two types of customer orders: contract orders and spot orders. Contract orders represent the plant's regular customers and are received once per week, while spot orders represent infrequent customers and are received at any time during the week.

One inventory-control policy is the minimum / maximum control (MMC), which seeks to maintain the level of inventory within a specified range. Frames can be dedicated or scheduled. Frames dedicated to the production of a given yarn type are shut down whenever the yarn's inventory rises above the specified maximum level, and production of that yarn is allowed to resume when the yarn's inventory falls below the specified minimum level. Scheduled frames are periodically reallocated to yarn types based on current need. We have also developed an alternative to the MMC policy called the single target level (STL) policy. Under the STL policy, all frames are scheduled. For each yarn, the STL policy attempts to eliminate any deviation from the yarn's target inventory level within a user-specified amount of time by regulating the number of machines running the yarn. A separate control equation is employed for each yam type. A frame-allocation procedure is used if the total number of frames needed across all yarns exceeds the number available.

In comparing the two control systems, we focused on average order leadtime, average inventory, inventory fluctuation, and number of frame changeovers as the performance measures of interest. The first three responses relate directly to the fundamental tenets of Quick Response, while the latter response relates to the variable component of operating cost. A full factorial experimental design of four factors with two levels for each factor was used in the comparison of the MMC and STL policies. Figures 4 and 5 depict the experimental results for three policies: STL, MMC with frame dedication, and MMC with no frames dedicated. For both MMC policies, the difference between the minimum and maximum control levels corresponded to a five-day supply of yam. The plots are based on averages taken over 16 independent replications of 52-week simulation runs.

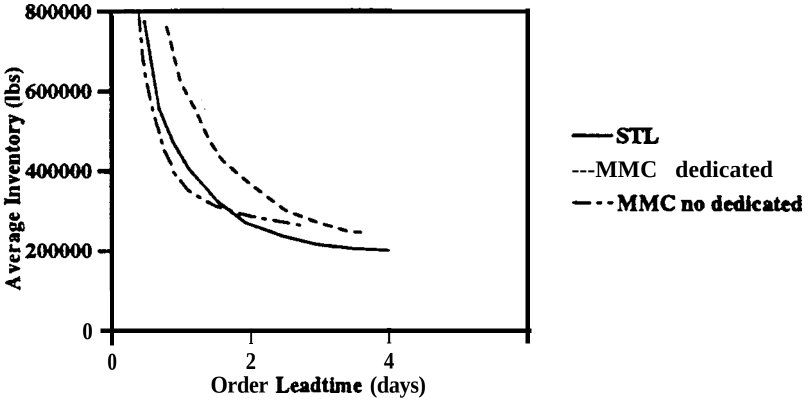

Figure 4: Relation between Inventory Level and Order Leadtime for Spinning Model

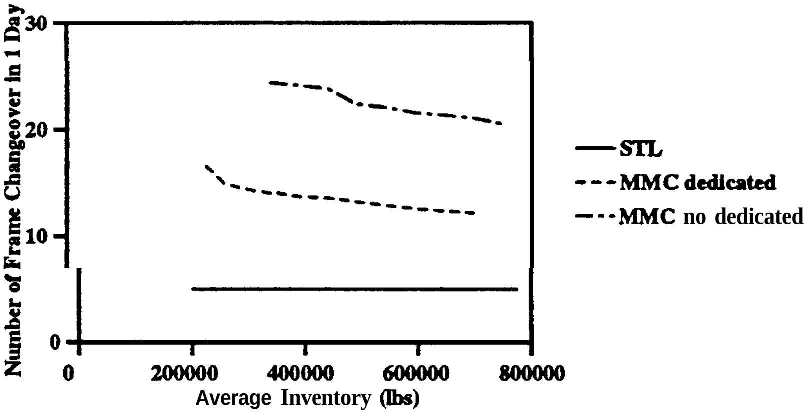

Figure 5: Relation between Frame Changeovers and Inventory Level for Spinning Model

From Figure 4, we see that for any average inventory level, STL achieves lower order leadtimes than MMC using dedicated frames. However, at the higher average inventory levels, STL is slightly outperformed by MMC with no dedicated frames. As shown in Figure 5, STL requires significantly fewer frame changeovers than the MMC policies. Other experimental results (not shown) demonstrated that STL has the smallest range of weekly high and low inventory levels. With STL the inventory level is steadier and more predictable, important for all plants, but especially for a quick response system. Fewer changeovers results in higher utilization of resources and more productivity.

A number of interesting conclusions have emerged from our experimentation with the spinning model operating under the STL policy to evaluate the impact of input parameters on plant performance. For a given number of frames, increasing the number of yarn types spun by the plant causes greater contention for frames. Results to date show an approximately linear relationship between the yarn-to-frame ratio and the order leadtime. This kind of information can help a plant manager to assess the trade-off between breadth of product line (or capacity) and order response time.

4. Object-oriented Plant Models

As a first step toward the objective of making the pipeline models available for use by industry, we have developed an object-oriented version of the spinning plant model. Object-oriented codes offer the potential for easy tailoring to model a specific company's plant(s).

The spinning plant model was developed by three exchange students from the Technical University of Chemnitz (Germany). The model is microcomputer-based, coded in C++, with an extremely friendly user interface. The apparel manufacturing model is being implemented as an object oriented modeling template. Future work in this area will be done in conjunction with the DAMA project and $(TC)^2$.

5. User Interfaces/Animation

In order to facilitate industry interaction and technology transfer, we have begun developing user-friendly interfaces, including animation, of the plant and decision surface models. The interfaces will have a common "look and feel" and a common structure so that the user can move easily among models.

The interface with the neural net decision-surface model is designed to provide the decision maker with a visualization of the relation between model inputs and performance measures. This interface is a Microsoft Windows application which incorporates a graphics package as well as a code for evaluating a neural net. This combination allows the user to select quickly one (or two) input parameters and a performance measure from pull-down menus. Two-dimensional and three-dimensional surfaces relating performance measures to input decision parameter(s) are then displayed. These surfaces can be rotated to provide alternate views.

Animations of plant models show, via icons, flows of products, **status and utilizations** of machines, buildup of work in process, etc., during the execution of a simulation run. In addition, various statistics may be plotted in real time to show the presence of trends. Animations of the spinning and dye house models are currently in progress.

The apparel manufacturing model is currently being developed as an object-oriented modeling "template". A template consists of a set of objects that represent the major components (departments/functions) of the apparel manufacturing process. The template is presented to the user in a graphical interface in which a specific enterprise can be quickly created by placing icons on the screen and filling in details in dialogue boxes. The model is automatically animated and relevant statistics are generated and collected.

III. RESOURCE MANAGEMENT AND TECHNOLOGY TRANSFER

From its inception, the success of the FTAR Modeling Project has hinged on the quality of the teamwork displayed by the participants. No individual or even a group from any one discipline could have undertaken this work. The scope is so broad that it has required a close association between Textile Management and Technology Professors Alan Hunter and Gordon Berkstresser on the one hand, Industrial Engineering Professors Russell King, Henry Nuttle, and James Wilson on the other hand, and Operations Research Professor Shu-Chemg Fang as the final element to complete the NCSU component of the research team. To date, these professors have worked closely with each other and with four doctoral students, six master's students, and six undergraduates from the Colleges of Textiles and Engineering who have been partially supported by this project. In addition, two master's and one doctoral student in Engineering, along with three German exchange students, have been involved in the effort at no cost to the project.

In addition to the NCSU component, Barbara Mazziotti of $(TC)^2$ has met regularly with members of the NCSU research team. In June of 1994, $(TC)^2$ took over the role of modeling the apparel manufacturing process from Dr. Charlotte Jacobs-Blecha of Georgia Tech, who had a change in job assignment. Over the last two years, we have interacted with faculty from Auburn and Clemson who are doing work on planning and scheduling in textile plants. During the next year, we plan to expand the research team to include faculty and graduate students from the Department of Clothing and Textiles at University of North Carolina-Greensboro and to begin additional collaboration with faculty at Clemson. We feel that the investigators and students have worked well together, and the interactions between these individuals have allowed the project to move forward and meet its goals in a timely fashion.

Beyond the NTC, members of the team have, through international conferences, met and interacted with researchers in Canada, Germany, and Japan. Dr. Thomas Fischer of the Institute for Textile Research in Denkendorff, Germany met with our team while attending the Textile CIM conference in Raleigh in June of 1993.

Members of our team have met and interacted regularly with the Analysis, Simulation, and Integration TACT of AMTEX. We have worked closely with the "Whole Industry Simulation Model" task team of the DAMA project, providing them with the plant models which we have developed, sending a student to work at the Los Alamos National Laboratory, and reviewing and commenting on their ITEMS model.

To date, three of the master's students and four undergraduates participating in this project have completed their degree requirements and have graduated. The following master's theses have been submitted and approved: (1) "Interactive Decision Support Modeling for the Textile Spinning Industry"; (2) "A Generalized Simulation Model of Weaving Mill Operations" ; and (3) "Development and Comparison of Yarn Inventory Feedback Control Algorithms in a Textile Spinning Plant". Technical papers on these theses are being written.

One of the doctoral students on this project presented a paper entitled "Multiproduct Scheduling on Parallel Machines with Setup Times and Due Dates" at the joint national meeting of the Operations Research Society of America and The Institute of Management Sciences, held in San Francisco in November 1992. Another doctoral student presented a paper entitled "Decision Surface Modeling of Textile Spinning Operations Using Neural Network Technology" at the IEEE 1994 Annual Textile, Fiber, and Film Industry Conference in Greenville, SC, in May 1994. He will also present a paper on neural net modeling of a retail model at the Third Annual Fuzzy Theory and Technology International Conference to be held at Duke University in November 1994.

Papers overviewing the project and discussing various aspects of the research have been presented at the following conferences: (1) the Fourth Annual Academic Apparel Research Conference held in Raleigh, NC on February 8, 1993; (2) a workshop on manufacturing innovation held at McGill University in Montreal, June 29-30, 1993; (3) Dr. Sueo Kawabata's Mt. Fuji Polymer and Textile Seminar held in Japan in August 1993 and July 1994; and (4) the 1994 Third Industrial Engineering Research Conference held in Atlanta in May 1994. The papers appear in the proceedings of the respective conferences.

A paper entitled "North Carolina Apparel Pipeline Modelling Project" has been published in the ***International Journal of Clothing*** Science ***and Technology.*** A paper on decision-surface modeling of a spinning plant based on neural nets has been submitted for publication. Technical reports have also been written on (a) decision-surface modeling of a retail operation using neural nets, and (b) demand reestimation and inventory replenishment for seasonal basic goods in a large specialty chain.

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