*Proceedings of the 2003 Winter Simulation Conference*
*S. Chick, P. J. Sánchez, D. Ferrin, and D. J. Morrice, eds.*

# SIMULATION BASED DECISION SUPPORT FOR SUPPLY CHAIN LOGISTICS

Subhashini Ganapathy
S. Narayanan

Department of Biomedical, Industrial and
Human Factors Engineering
Wright State University
207 Russ Engineering Center
Dayton, OH 45324, U.S.A.

Krishnamurthy Srinivasan

System Software Lab
Intel Corporation
Chandler, AZ 85226, U.S.A.

## ABSTRACT

Supply chain logistics planning is a complex process in both military and civilian operations. Poor planning may lead to system instability that might seriously influence the ability of the supply chain to satisfy its customers or might affect a combat mission. Therefore, correct decisions need to be made to optimize the performance of the system. It is important that the right information is transferred to the concerned unit that needs to receive the right information. Our model features a decision support system that aids human in making decisions and studies the role of a decision support system in enhancing the performance of the supply chain logistics system. The model is object oriented in nature, which helps in rapid prototyping of the different components of the system.

## 1 INTRODUCTION

Supply chain logistics planning is a complex process in both military and civilian operations. Although there have been attempts to represent individual stages in a supply chain, there are not yet many models that represent real time interaction within an entire system in a holistic manner. Joint Vision 2010 is a plan that describes the emerging operational concepts and the technological advances of the armed forces, by Chairman of Joint Chiefs of Staff (Joint Vision 2010). Among the different emerging concepts discussed in the paper focused logistics is one of them. Focused logistics will be concentrating on providing rapid crisis response based on the aggregation of information.

The current effort has led to a computational platform that can be used to emulate the dynamic characteristics of the supply chain domain along with the real-time information updates typical of the collaborative enterprises emerging from advanced computing concepts. The decision support system follows the philosophy of mixed-initiative collaboration where human decision makers and automated agents work together in achieving high joint performance in the context modeled.

According to Shepherd and Lapide (2000), various trends are pushing the emphasis toward optimization of supply chain networks. These include:

- Customer demand for shorter cycle times.
- Globalization of operations (B2B) -including sourcing, production, sales and marketing.
- Greater outsourcing of manufacturing operations.
- Increased use of third party logistics (3PL) providers and third party warehouses. (Gopalakrishnan et. al. 2000)

Models used in supply chain systems analysis can be classified into deterministic analytical models, stochastic analytical models, economic models, and simulation models (Beamon 1998).

A deterministic analytical model is one in which the variables are known and specified, and the goal is to achieve a closed-form analytical solution through mathematical programming techniques. These models provide prescriptive solutions under certain assumptions, but are limited to static system representation. Examples of this work include research by Cohen and Lee (1988) and Cohen and Moon (1990). Cohen and Moon (1990) developed a model, called PILOT, that performed cost function analysis to investigate the effects of various parameters on supply chain cost.

A stochastic analytical model is one in which at least one of the variables is unknown, and is assumed to follow a particular statistical distribution. These models embody more realistic features of a supply chain in the form of stochastic representations. However, they are not dynamic because they do not account for real time updates of the entities and interactions of the system. Examples of stochastic models include a heuristic stochastic model developed by Lee and Billington (1993) for managing material flows on a site-by-site basis.

Economic models focus mainly on the buyer-supplier relationship in a supply chain from a cost perspective. Christy and Grout (1994) developed a framework modeled by supply and demand economics to explain the trading relationships that operate between companies.

Simulation models use computer representations to model the real-world interactions and are useful for what-if analysis. Although there have been several studies on simulating aspects of supply chain systems, there is a dearth of high-fidelity models that represent supply chain interactions at a detailed level that includes the incorporation of real-time information updates. We describe a simulation model and a decision support system that aids human in making decisions.

## 2 PROBLEM DOMAIN

The simulation model represents a multi-echelon supply chain system involving interactions associated with maintenance, inventory control, spare part suppliers, and scheduling of resources to perform repair of machines on a shop floor. The supply chain can be broadly abstracted to three stages: (1) procurement, (2) manufacturing, and (3) distribution, as illustrated in Figure 1.

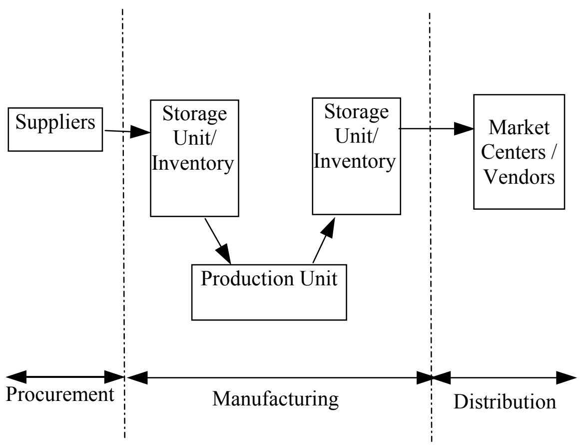


Figure 1: Supply Chain Process

Procurement is the stage in which the manufacturing unit of the supply chain system acquires the raw materials or the spare parts for the machines from different suppliers. In the manufacturing stage there are three substages, the inventory/storage unit, production unit and inventory/storage unit. The inventory for these products is controlled by the storage unit/inventory control stage. The raw materials are processed through the production unit, and the finished product is transferred to another storage unit. In the distribution stage the finished product is exported to the vendors or the different market centers of the product.

The different stages or echelons of the supply chain are interconnected with the forward flow of materials and backward flow of information (Beamon 1998; Vrijhoef and Koskela 2000). Also, the use of third party logistics (Thomas and Griffin 1996) and third party warehouses (Gopalakrishnan et. al. 2000) complicates decision making in a supply chain system.

The supply chain is a very important component of any manufacturing system. The concept of supply chain management was introduced in the 1890's (Croom, Romano, and Giannakis 2000; Douglas and Martha 2000). In "Educating the Supply Chain: A Holistic Approach," Evans, Naim, and Towill (1996) identify supply chain management as a means to achieve global attention. The Global Supply Chain Forum (GSCF) defines supply chain management as follows: " . . . Supply chain management is the integration of key business processes from end user through original suppliers that provide products, services, and information that add value for customers and stakeholders" (Lakhal et. al. 2001).

A fair knowledge of each of the three stages is necessary to integrate the different levels of the supply chain system. It is not only the information that is important, but also it is equally important that the right information is transferred to the concerned unit that needs to receive the right information. A Decision Support System (DSS) is a very important part in integrating all the different stages of the supply chain unit.

Many previous studies have limited themselves to considering a supply chain as individual stages rather than looking at it as a system. Studies have focused on only a single stage of a supply chain and have not considered a supply chain system as decentralized components interconnected across the components.

A very early simulation model developed to study supply chain dynamic behavior was by Forrester (1961). The "Forrester Model" can be described in terms of six interacting flow systems, namely the flows of information, materials, orders, money, manpower, and capital equipment. It is a model of a production-distribution system. Based on the development and use of a system dynamics simulation model, Forrester analyses issues evolving around supply chain management (Angerhofer and Angelides 2000).

The simulation model developed by Towill (1997) discusses reduction of material flow delays, information flow delays, and some information distortion by eliminating complete echelons and performing time compression within individual echelons. Information flow improves the resource planning and inventory management.

Traditional models have numerous problems with respect to modeling supply chain systems at high fidelity. They are based purely on a networks of queues abstraction, following an uncomplicated seize-hold-release behavior, suitable for "passively" scheduled systems. They typically, do not feature reusable software components and have difficulty in representing decentralized decision making (Narayanan et. al. 1998). They generally, do not account for the uncertainty and dynamic feature of supply chain systems and do not account for dynamic information updates.

Providing logistics support for military missions is very critical in the execution of the mission. Some of the logistics model for military support have looked at planning and execution. Wilkins and Desimone (1994) developed a model, called SOCAP (System for Operations Crisis Action Planning), that supports joint military courses of action in less time when responding to a crisis. Ruck (1998) has developed a model called FLEXLOGS (Flexible Experimental Logistics Simulator) that treats the model as a transportation network with defined rules for ordering and shipping material.

Poor planning may lead to system instability that might seriously impact the ability of the supply chain to satisfy its customers. Therefore, right decisions need to be made to optimize the performance of the system. The decision that needs to be taken is defined in most cases based on the time frame. Thus, decisions can be either for strategic or tactical planning. Tactical planning deals with ongoing situations, whereas strategic planning deals with the near future (Doherty and Leigh 1986).

The cognitive process of decision making in logistics planning can be divided into five steps —problem identification, alternatives to solve the problem, evaluation of the alternatives, selection of the best alternative, and implementation of the selected alternative.

The different decision-making theories useful to capture the human decision making processes are image theory, cognitive continuum theory, recognition primed decision making, subjective expected utility theory, and multi-attribute utility theory. The image theory suggested by Beach (1997) talks about using three categories of images to set standards to guide decisions, and the decisions can be made by sorting the alternatives in a preference order. The cognitive continuum theory of decision making as suggested by Hammond, McClelland, and Mumpower (1980) differentiates the intuitive decision-making ability from that of the analytical decision-making ability of the human. Klein (1989) developed the theory of recognition primed decision making, based on the observations of people in a naturalistic environment and their behavioral responses to a change in the environment.

Subjective Expected Utility Theory (SEU) was very popular in the eighteenth century. In this theory, the expected outcome of the solution is converted into utilities. These utilities are weighted based on probability of occurrence and the effects over other events (von Neumann and Morgenstern 1947).

The multi-attribute utility theory extends the SEU theory to cases with multiple attributes of interest. Each of the attributes is weighted, and alternatives are chosen (Keeney and Raiffa 1976). Multi-attribute utility theory models selects alternatives through the application of utility functions and weights. Multi-attribute utility methods let us obtain the values of alternatives that have more than one useful attribute, thus involving evaluation on more than one criterion (Bose, Davey, and Olson 1997)

We have implemented multi-attribute utility theory in our decision support model. The next section describes the simulation architecture that was built to support an interactive multi-echelon supply chain system. The architectural framework supports multiple scenarios. For the purpose of this study we have created three instances of the system, the first one is where a decision support system is used, in the second one the supervisory controller interacts with the simulation with no decision aid. In the third instance the system is completely automated, hence there is no human intervention.

## 3 SIMULATION ARCHITECTURE

The simulation model supports real time supervisory control in which a human interacts with the underlying simulation. It accounts for the dynamics and uncertainty of the supply chain system.

The different modules of the multi-echelon logistics system are (a) Basic Simulation Module, (b) Inventory Control Module, (c) Shop Floor Module, (d) Suppliers Module, and (e) Interface Module. The relationships between the components are shown in Figure 2.

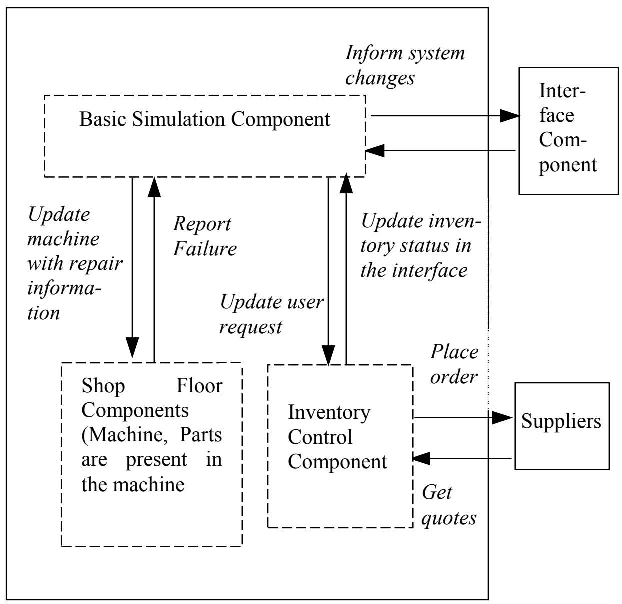


Figure 2: Components of the System

All the modules are implemented in Java 2, and the database is connected using the JDBC-ODBC Bridge. The simulation architecture is based on an object-oriented architecture, called Java-based Architecture for Developing Interactive Simulations (JADIS), and is used for developing interactive simulations (Narayanan et. al. 1997). Interactive simulation models address the possibility of a human-in-the-loop during the simulation process in which the human can act as a supervisory controller by overriding the automation at any point of time.

The simulation module accepts stimulus from outside entities, including the supplier component and users. This module simulates the system under different conditions. Various functions such as machine failure, part acquisition, technician assignment, machine repair, and part outsourcing are performed by the simulation server. The simulation server runs an inventory control unit that monitors the inventory and updates the parts storage database on an "as and when needed" basis.

The basic simulation component is responsible for the scheduling of the events and coordinating the multi-threaded architecture. It is comprised of an event calendar, clock, simulator, and distributions.

The suppliers have the parts needed for machine repair provide inventory control with information about the part name, the price associated with the part, the shipping time for the part, and the quantity present when inventory control requests information about a part. The suppliers update their database as soon as a request for order is placed. The supplier module runs on Java™ Servlets. Servlets run inside the Java Virtual Machine. Servlets extend javax.servlet class that is contained in the Java Servlets Web Development Kit. The supplier servlets sends information to the inventory control through HyperText Transfer Protocol.

The inventory control component tracks the parts inventory and acquires parts from the supplier to keep the inventory in control. This module requests quotes and orders parts from the suppliers based on a trade-off analysis of priority, time, cost, and quality of the part. The interface with the simulation module facilitates updating the information on the server side. When a supplier is selected either by the system or the user (depending on the operating mode), the inventory control unit places an order with the supplier. After the given shipping time, it updates the database with the quantity of order placed.

The shop floor component consists of the machines and the technicians present. The module updates its status to the simulation that is reflected on the interface. The Machine class embodies the characteristics of the machine and the failure of machines based on its parameters (such as mean time between failure of its components). Each failure necessitates a specific part or set of parts based on the repair requirements. The primary cause of failure could be either a single factor or a combination of factors such as fatigue and fracture, wear, corrosion, and distortion (Engineering Statistics Handbook 2001). The failure can be identified due to change in parameters measured.

### 3.1 Simulation Interface

This section describes the design of the interface to reflect the changes for the simulation. The goal in developing the interface is to present all the information in the best possible way to the user, so that they would not need much training. Using on-screen animations in the simulation model enabled the status of the model to be viewed as its development progressed

As shown in Figure 3, the interface is divided into four primary sections. The first section(top left) consists of information about the machine. It reflects the status of the machine and, after a machine failed, information about the parameters for the machine, a list of parts of the machine, and the time taken to repair the machine. The second section (top right) of the screen contains information about the inventory. The third section of the interface (lower left) displays the technician schedule chart presented to the user so that he or she could decide on assigning a particular technician for the repair based on the schedule. The fourth section (lower right) gives information about the different suppliers, their price quotes, quantities, and their part shipping times.

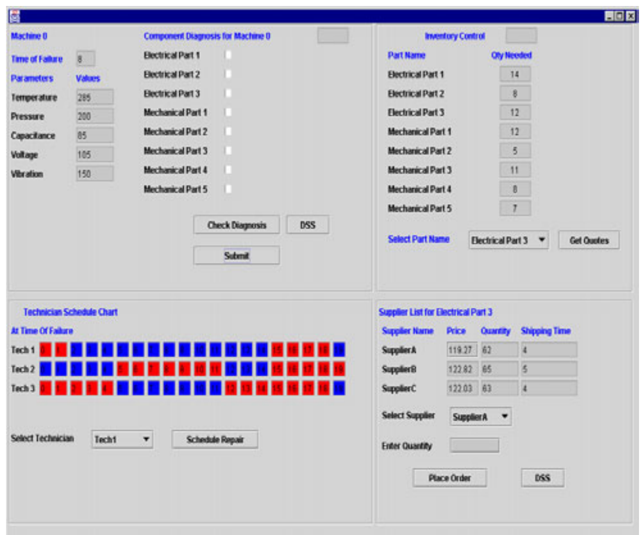


Figure 3: Interface

### 3.2 Decision Support System (DSS)

The decision support system has two decision scenarios, as shown in Figure 4. The objective of the supplier identification module is to select the supplier based on conditions like cost, shipping time, and quantity present. The DSS was developed based on the multi-attribute utility theory of decision making. The features of the suppliers were identified and incorporated into the decision making process. Weights were assigned to the different attributes depending on the priority of the part.

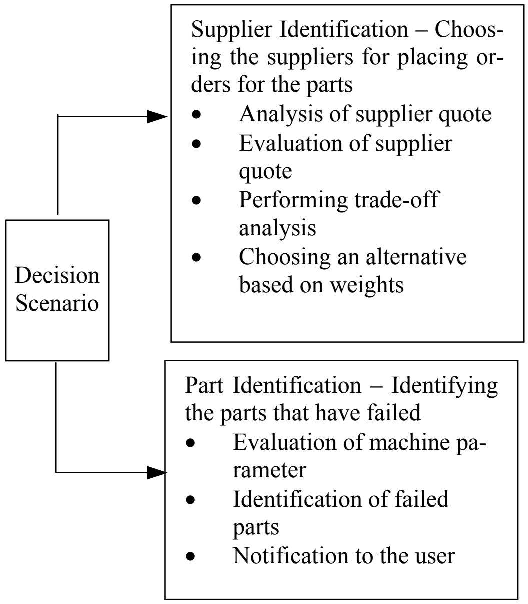


Figure 4: Decision Scenarios

Figure 5 describes the decision-making process as a block diagram. The assumptions made in this module are (a) parts can be ordered from any supplier, (b) ordering of parts can be divided among different suppliers, (c) multiple parts cannot be ordered at the same time, (d) multiple parts cannot be selected simultaneously

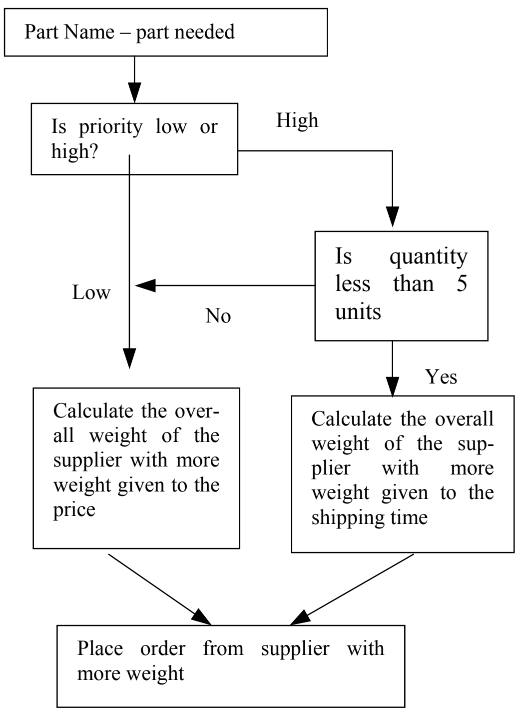


Figure 5: Decision Process for Selection of Supplier

The objective of the part identification module is to select the parts failed based on the parameters of the machine. The parts of machine affect the parameter of the machine based on a predefined data structure. The decision process for the selection of a failed part is as shown in Figure 6.

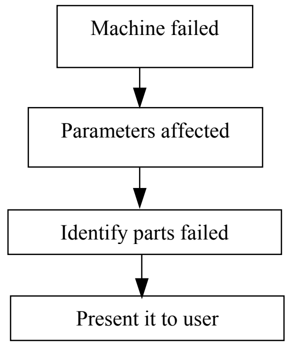


Figure 6: Decision Process for Part Identification

## 4 RESULTS

In order to evaluate the DSS, it was compared to a system with non-DSS and to an automated system, in terms of the performance measures. The performance measures were machine down time, number of times supplies ordered, the mean number of times part identified incorrectly, and the number of times parts ordered.

The results indicate there is significant difference between the performance of a DSS compared to the performance of a non-DSS as well as automated system with respect to machine down time, and mean error rate of part identification. Mean error rate of the part identification is defined in terms of the mean of the number of times the user identifies the part incorrectly. In real time, the identification of part involves both time and money. Fewer incorrect part identification leads to increased efficiency. Data were set up in a 3 x 2 within subjects design with repeated measures, and an Analysis of Variance was conducted using JMP, Version 4. SAS Institute Inc., Cary, NC, 1989-2000 for sixteen data points. The level of significance for Type I error was 0.05. The dependent variables are machine down time, number of times supplies ordered, mean error rate for identification of part, and the number of times DSS was used.

As derived from Table 1, there was a significant difference between the system with DSS and the system without DSS and automated system . An all pairs Tukey-Kramer test was conducted to find the difference between means of these systems. It was found that there was a significant difference between the system with DSS and the system without DSS. The difference between mean error rate is as shown below in Figure 7.

The automated system was not highlighted in the Tukey-Kramer test as being different from the other two

Table 1: Summary of Results for Mean Error Rate

| Dependent variable | Source | DF | F-Ratio | Prob >\| f \| |
|---|---|---|---|---|
| Mean error rate | Type of systems | 2 | 8.4977 | 0.0013 |

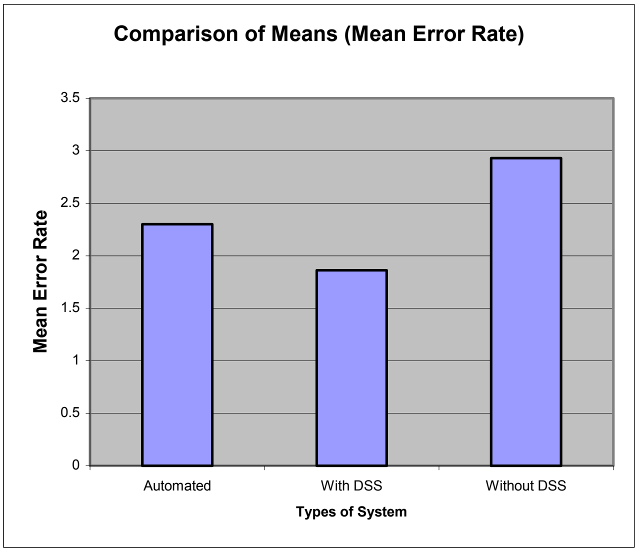


Figure 7: Comparison of Means between Different Types of System for Mean Error Rate of Part Identification.

systems. Essentially it means that the automated system was statistically not different from either of the other two systems.

Table 2 summarizes the result for the dependent variable machine down time. As derived from Table 2, there was a significant difference between the system with DSS and the system without DSS and automated system. The conclusion is that the down time for the machine is different for the three systems. An all pairs Tukey-Kramer test was conducted to find the difference between means of these systems. It was found that there was a significant difference between the system with DSS and the system without DSS.

The difference between means is as shown in Figure 8.

Table 2: Summary of Results for Machine Down Time

| Dependent variable | Source | DF | F-Ratio | Prob >\| f \| |
|---|---|---|---|---|
| Machine down time | Type of systems | 2 | 4.8168 | 0.0125 |

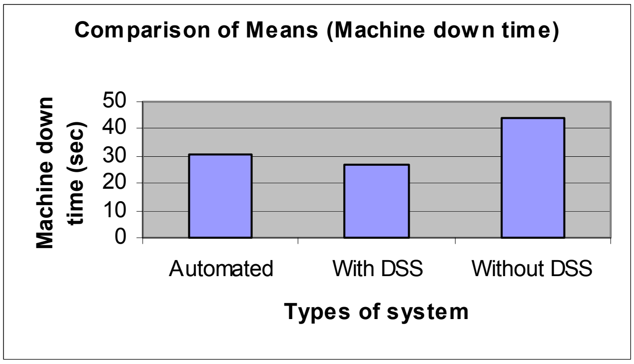


Figure 8: Comparison of Means between Different Types of System for Machine Down Time

## 5 DISCUSSION

The major limitation of the system was that the data used were from theoretical distributions and were not from a real world system.

Future research should focus on further validating this study. Recent advances in wireless computing and the Internet open up opportunities to connect these collaborating units within a supply chain to provide seamless access to dynamic information. These technologies can be used to feature computational platforms including the accommodation of real-time interaction between distributed agents (both human and software), dynamic discovery of services, automatic ordering of parts for repair under certain triggering conditions (based on the system state), and Web-based access to information about suppliers.

## ACKNOWLEDGMENTS

The research was sponsored by Intel Corporation.

## REFERENCES

Angerhofer, B. J. and M. C. Angelides. 2000. System Dynamics Modeling in Supply Chain Management: Research review. Winter Simulation Conference Proceedings, 1, 342–351.

Beach, L. R. 1997. The Psychology of Decision Making: People in Organizations. Thousand Oaks, CA: Sage Publications Series in Foundations for Organizational Science.

Beamon, B. M. 1998. Supply Chain Design and Analysis: Models and Methods. International Journal of Production Economics, 55(3), 281–294.

Bose, U., A. M. Davey, and D. L. Olson. 1997. Multi-attribute Utility Methods in Group Decision Making: Past Applications and Potential for Inclusion in GDSS. Omega, 25(6), 691-706.

Christy, D. P. and J. R. Grout. 1994. Safeguarding Supply Chain Relationships, International Journal of Production Economics, 36, 233–242.

Cohen, M.A. and H. L. Lee. 1988. Strategic Analysis of Integrated Production-Distribution Systems: Models and Methods. Operations Research, 36(2), 216–228.

Cohen, M.A. and S. Moon. 1990. "Impact of Production Scale Economies, Manufacturing Complexity, and Transportation Costs on Supply Chain Facility Networks", Journal of Manufacturing and Operations Management, Vol.3, 269-292

Croom, S., P. Romano, and M. Giannakis. 2000. Supply Chain Management: An Analytical Framework for Critical Literature Review. European Journal of Purchasing & Supply Management, 6(1), 67–83.

Doherty, M. E. and W. E. Leigh. 1986. Decision Support and Expert Systems. Cincinnati, OH: South-Western Publishing Co.

Douglas, M. L. and C. C. Martha. 2000. Issues in Supply Chain Management. Industrial Marketing Management, 29(1), 65–83.

Engineering Statistics Handbook NSIT, Sematech. 2001. Available online via <http://www.itl.nist.gov/div898/handbook> [accessed April 12, 2001].

Evans, G. N., M. M. Naim, and D. R. Towill. 1996. Educating the Supply Chain: An Holistic Approach. International Journal of Materials & Product Technology, 11(5-6), 464–476.

Forrester, J. W. 1961. Industrial Dynamics. Cambridge, MA: The Massachusetts Institute of Technology.

Gopalakrishnan, M., S. Narayanan, D. A. Bodner, K. K. Patchigolla, R. P. Kantamneni, N. R. Edala, and H. A. Ruff. 2000. A Computerized System for Storage Location Assignment in Third Party Warehouses. International Journal of Industrial Engineering, June, 8(2), 159 -167.

Hammond, K. R., G. H. McClelland, and J. Mumpower. 1980 Human Judgment and Decision Making: Theories, Methods, and Procedures. New York: Praeger Hogarth, R.M.

Joint Chiefs of Staff, Joint Vision 2010, Washington D.C. Available online via <http://www.dtic.mil/jv2010/jv2010.pdf> [accessed May 27, 2003].

Keeney, R. and H. Raiffa. 1976. Decision With Multiple Objectives: Preferences and Value Tradeoffs. New York: Wiley Lopes, L. L. 1987.

Klein, G. A. 1998. Recognition-Primed Decision Making. In Klein, G.A. (Ed), Sources of power: How people make decisions (pp. 15–30). Cambridge, MA: MIT Press.

Lakhal, S., A. Martel, O. Kettani, and M. Oral. 2001. On the Optimization of Supply Chain Networking Decisions. European Journal of Operational Research, 129(2), 259–270.

Lee, H. L. and C. Billington. 1993. Material Management in Decentralized Supply Chains. Operations Research 41(5), 835–847.

Narayanan, S., N. L. Scheider, C. Patel, N. Reddy, T. M. Carrio, and J. DiPasquale. 1997. An Object-Based Architecture for Developing Interactive Simulations using Java. Simulation, 69(3), 153–171.

Narayanan, S., D. A. Bodner, U. Sreekanth, T. Govindaraj, L. F. McGinnis, and C. M. Mitchell. 1998. Research in Object-Oriented Manufacturing Simulations: An Assessment of the State of the Art. IIE Transactions, 30(9), 795–810.

Ruck, L., J. 1998. An Object-Oriented Discrete-Event Simulation of Logistics (Modeling Focused Logistics). Thesis Report, Department of Operations Research,Naval Postgraduate School Monterey, California.

Shepherd, J. and L. Lapide. 2001. Supply Chain Planning: Just the Facts. Available online via <http://www/ascet.com/ascet/wp/psheperd.html> [accessed March 10, 2001].

Thomas, D J. and P. M. Griffin. 1996. Coordinated Supply Chain Management. European Journal of Operational Research, 94(1), 1–15.

Towill, D. R. 1997. The Seamless Supply Chain-The Predator's Strategic Advantage. International Journal of Technology Management, 13(1), 37–56.

von Neumann, J. and O. Morgenstern. 1947. Theory of Games and Economic Behavior. Princeton University Press, Princeton, New Jersey, second edition.

Vrijhoef, R. and L. Koskela. 2000. The Four Roles of Supply Chain Management in Construction. European Journal of Purchasing & Supply Management, 6(3-4), 169–178.

Wilkins, D. E. and R. V. Desimone. 1994. Applying an AI Planner to Military Operations Planning. Intelligent Scheduling. Morgan Kaufmann Publishers Inc., San Mateo, CA.

## AUTHOR BIOGRAPHIES

**SUBHASHINI GANAPATHY** is a Research Assistant at Human Computer Interaction Lab, Wright State University. She is currently pursuing her Ph.D. in Humans in Complex Systems. Her research interests include predictive analysis in model-based information technology systems, design optimization, and simulation and modeling. Her email and web addresses are <sganapat@cs.wright.edu> and <www.wright.edu/~ganapathy.2>

**S. NARAYANAN,** Ph. D., P.E, is the Professor and Chair of Biomedical, Industrial and Human Factors Engineering at Wright State University in Dayton, Ohio, where he directs the interactive systems modeling and simulation laboratory. He received his Ph.D. in Industrial and Systems

Engineering from the Georgia Institute of Technology in 1994. His research interests are in interactive systems modeling and simulation, cognitive systems engineering, and human decision aiding in complex systems. He is a member of IIE, SCS, IEEE, IEEE Systems, Man, & Cybernetics, HFES, and INFORMS. He is a registered professional engineer in the State of Ohio. His email and web addresses are <snarayan@cs.wright.edu> and <www.cs.wright.edu/~snarayan>.

**KRISHNAMURTHY SRINIVASAN,** Ph. D., manages research and development activities in the areas of managed run-time environments and XML technologies in Intel's System Software Lab. His current interest is focused on aligning the performance needs of applications with the runtime and the platform capabilities. His group has made contributions to web service technologies including SOAP, UDDI, RosettaNet and THP. Dr. Srinivasan was one of the key contributors to Intel's 3rd Generation e-Business program. Before joining the Intel Labs, Dr. Srinivasan was an architect for Intel's corporate IT and the Planning & Logistics groups, responsible for the evaluation and introduction of EAI and Internet technologies. He is a member of the IEEE.