Proceedings of the 2001 Winter Simulation Conference
B. A. Peters, J. S. Smith, D. J. Medeiros, and M. W. Rohrer, eds.

DEVELOPMENT OF A HIGH-LEVEL SUPPLY CHAIN SIMULATION MODEL

Sanjay Jain

Accenture
11951 Freedom Drive
Reston, VA 20190, U.S.A.

Russell W. Workman

Accenture
1 Liberty Square
Boston, MA 02109, U.S.A.

Lisa M. Collins

Accenture
100 Peachtree Street NW, Suite 1300
Atlanta, GA 30303, U.S.A.

Eric C. Ervin
Andrew P. Lathrop

Accenture
3773 Willow Road
Northbrook, IL 60062, U.S.A.

ABSTRACT

This paper describes an effort that involved development of a simulation model for evaluating the business processes and inventory control parameters of a logistics and distribution supply chain. A generic simulation tool, rather than a supply chain simulator, was developed for meeting customized needs of the effort. The paper describes the approaches used to model at the selected level of abstraction, the development of interfaces for data and experimentation and the development and delivery of animation for communicating the approach and results to the client.

1 INTRODUCTION

A supply chain includes the transition and transportation of material from raw form through several stages of manufacturing, assembly and distribution to a finished product delivered to the end customer. It includes the flow of information and finances in addition to the material flow. Each stage of material transformation or distribution may involve inputs coming from several suppliers and outputs going to several intermediate customers. Each stage will also involve information and material flows coming from immediate and distant preceding and succeeding stages. Indeed, 'supply network' may be a better name to represent the real life supply chains. Supply chains are complex operations and their analysis requires a carefully defined approach. It is easy to get lost in details and spend a large amount of effort for analyzing the supply chain. On the other hand, it is also possible to execute too simplistic an analysis and miss critical issues, particularly using tools that do not use simulation. This is particularly the case when there are sources of large uncertainties in the supply chain.

Simulation modeling is a suitable tool for analyzing supply chains. Its capability of capturing uncertainty and complexity makes it attractive for the purpose. However, it is easy to simulate at a level of detail that does not match the objective of the analysis. More often than not, a highly-detailed simulation model is built than that required for the objectives of the analysis. Additionally, it is expected that in the future the increase in computing power will lead to a higher tendency to use more detail than necessary (Jain, 1999). A number of other factors can lead to models being more complex than required (Chwif, Barretto and Paul, 2001). Admittedly, the appropriate level of abstraction in a simulation model designed to answer a certain question is somewhat subjective. In hindsight, the same team, after going through an analysis effort, may recommend a different level of abstraction. The level of abstraction chosen for modeling purposes is also influenced by several other constraining factors such as data availability, expertise of the modeler(s), simulation software capabilities, and time availability.

This paper describes the development of a high-level supply chain simulation model. The objective of the study was to determine the impact of some wide-ranging process and supply chain software changes at a large logistics and distribution operation. The model was developed at a high level of abstraction keeping in line with the objective of the study and the data availability. The next section briefly reviews some of the relevant work in the area of supply chain simulation and the abstraction process. Section 3 defines the scope of the supply chain model that is the subject of this work. Section 4 describes our approach in the context of different levels of abstraction. Section 5 describes the development of the process model that is used as a basis for developing the simulation model described in section 6. Conclusions are drawn in the last section based on the learning through the experience of this effort.

2 SUPPLY CHAIN SIMULATION

The need to simulate and redesign supply chain processes to allow decision makers to explore various options and scenarios that are customer and value driven has been recognized (Hennessee 1998). Simulation has been identified as one of the best means to analyze supply chains (Schunk and Plott, 2000). A number of commercial supply chain simulation tools have become available in recent years (For examples, see Barnett and Miller, 2000, and Phelps, Parsons, and Spirelle, 2000).

One of the major issues in the creation of supply chain simulation is the level of detail at which each of the links in the chain should be modeled. In any simulation study, the level of detail modeled depends on the purpose of the effort. With the focus on supply chain performance, the level of detail for the manufacturing stages varies among different efforts. Heita (1998) models manufacturing stages as having constant capacity and a fixed throughput time in supply chain simulation. Umeda and Jones (1998) model manufacturing facilities in detail down to cell level with associated control logic simulations in a test-bed system for supply chain management. Multiple manufacturing cells, buffers, and material handling operations are modeled. Jain et al (1999) highlight the criticality of modeling the detail in semiconductor supply chain simulation for planning.

The level of detail, or fidelity of the model, has to be carefully defined based on the objectives of the effort. The process of selection of factors to be modeled and the level of detail for each of them to be modeled is the abstraction process. The goal of the abstraction process is to capture the essence of the behavior of the real-life system. Correct execution of the abstraction process enables generation of directionally correct results with the right level of effort.

The abstraction method is usually based on the modeler's heuristics and experience. In some cases, a sensitivity analysis is used to determine the key parameters for inclusion in a meta model. McGraw and MacDonald (2000) present algorithms for identifying "insignificant" component input variables in engineering and engagement level simulations. Davis (2000) points out that even with availability of high-resolution models, the need for abstraction still exists due to the curse of dimensionality. With a large number of variables in a model, it is not possible to run a full factorial model for answering the questions. A building block methodology is presented to describe phenomena at different levels of resolution. It was concluded that personal computers are not up to the challenge of making the approach rigorous and reproducible.

Many business situations do not allow enough time or access to large computing platforms for more formalized methodologies. The modeling team has to rely on its collective experience and heuristics. The process can be helped by sharing of experiences and approaches through literature.

3 CONTEXT AND SCOPE

The subject organization for this study is a large logistics and distribution operation that provides logistics services for a large customer base distributed across all 50 states and about 27 countries, at over 500 sites located close to, and partnered with, customers and suppliers. It maintains two main channels for meeting customer demand. A majority of parts are maintained in inventory at its own distribution centers and supplied to customers from these centers on demand. Another channel is based on vendor-managed inventories with the vendor shipping the products directly to customers based on the orders communicated to them through the organization.

The purpose of the analysis was to compare a new operating vision ("To-be") to the "as-is" legacy IT systems and business processes in order to determine value benefit, operational impact, and sensitivities. The value benefit and operational impacts were captured in terms of changes to the following key performance indicators (KPIs):

1. Service levels
2. Inventory Turns
3. Order to delivery lead time

To meet the above objectives, the processes included in the analysis were selected based on their relevance to the customer order to delivery process and included:

1. Order Fulfillment
2. Procurement
3. Demand and Supply Planning

The organization supplies millions of part numbers to its customers. A representative set of products from the wide population was selected for use in the model. The products were selected to provide a representation of the cross-section of the product population across all major business units.

The methodology for this effort is based on use of simulation models to compare the As-Is and the To-Be systems. The major steps in this methodology are:

1. Development of an As-Is Process Model
2. Development of the As-Is Simulation Model
3. Development of a To-Be Process Model
4. Development of the To-Be Simulation Model

5. Comparative analysis of As-Is and To-Be Scenario

At the first stage, a high level As-Is process model was developed to capture a static representation of the business processes in the customer order to delivery chain. Next, subject matter experts were interviewed for adding details to the process flow models and capturing the time distributions for activities. A product segmentation effort led to the development of the representative broad based set of products for including in the model. The process model was then developed into a dynamic simulation model using the discrete event simulation software ARENA (Bapat and Swets, 2000). The dynamics of real life are represented through modeling of order arrivals and their processing through all activities until the delivery of products to customers. The As-Is simulation model results were validated through detailed comparisons with real life numbers and discussions with subject matter experts. The To-Be Simulation model has been developed as a representation of relevant sub-processes based on the To-Be process designs. A number of experiments have been carried out to capture the impact of change from As-Is to To-Be and to understand the sensitivities of the KPIs to changes in major factors.

The comparative analysis of the two models is based on the same set of input data for dynamic entities passing through the model, that is, orders, procurements and product shipments. Figure 1 summarizes the methodology for this effort.

4 ABSTRACTION APPROACH

In any simulation study the abstraction process is the most important step. Abstraction is the process of determining what part of the real-life process will be modeled and at what level of detail. This step is the "art" in the science of simulation. If time and effort were not constraints, the choice will be to model everything in the real-life process. However, in reality the time and effort are constrained, and a simulation practitioner has to carefully judge each aspect of the real-life process and its impact on the performance measures of interest. The aspects that have a direct or indirect appreciable influence on the performance measures need to be included in the model.

The importance of the abstraction process is heightened in modeling complex systems such as large supply chains. It is easy to get lost in modeling all the details, as it is to take a very high level view and miss out influences of critical factors. In this effort, the inclusion of aspects of the real life process was guided by their influence on the selected performance measures. The abstraction level of each aspect selected for inclusion was determined based on the objective of the model, i.e., development of a business case for implementing a new process and new supply chain software.

The performance measures of interest in this effort were service levels, inventory (as a surrogate for cost) and order-to-delivery lead time. These measures guided the scope of the model to include all processes from receipt of customer order to delivery of products to the customer, and

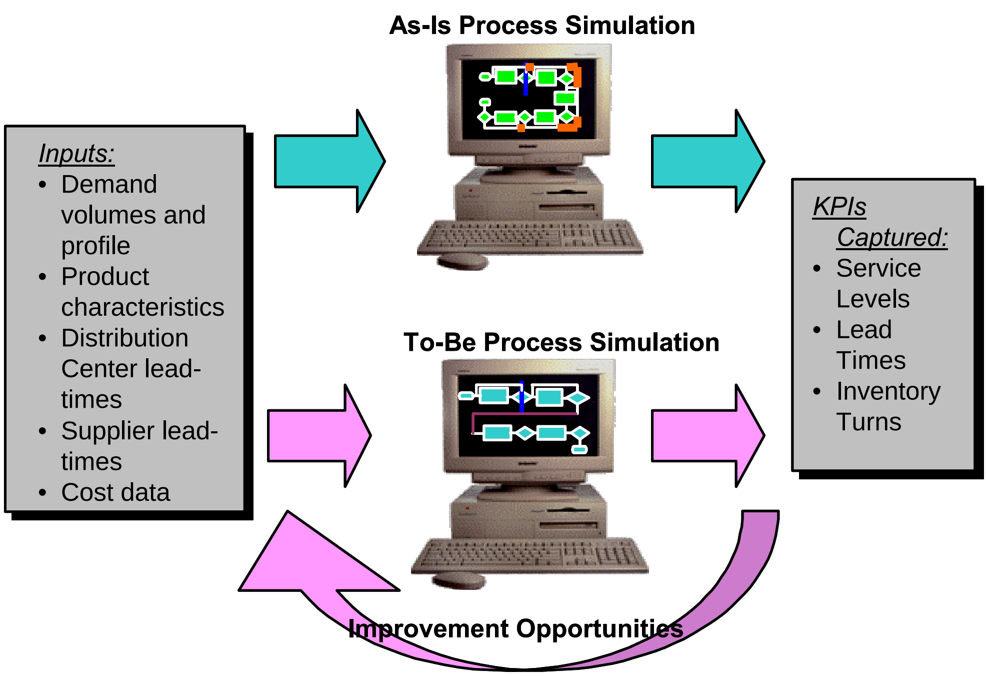

Figure 1: Summary of Approach

all the supporting processes to ensure the availability of products. The supporting processes included demand and supply planning and procurement. The material flow included the flow from suppliers to the DCs, DCs to the customers and the direct flow from suppliers to the customers. The information flows included the interactions between customers, the major functions of the subject organization, the DCs and the suppliers.

The high-level business case development objective guided the abstraction of the processes to one that captures their impact on inventory and lead time. The subject organization provides a few million products to its customers. A segmentation analysis was used to select a set of products representing a cross section across business units, ordering frequency (regular consumption fast moving items to slow moving service parts), and channels (maintained in own inventory and vendor managed inventory). The demand for these products was captured as summary distributions based on historical data. Major inventory control policies were included to capture the current practice in the organization. The inventory control parameters changes with the demand variations were modeled using correlations with forecast parameters.

Major processes were modeled to capture their impact on lead time. This included the steps within the order fulfillment, procurement and demand and supply planning processes. Any steps that impact the lead time to an appreciable level were included. For example, the occurrence of order entry errors, that required going back to the customer for correction thus adding to the lead time, was included. The activity of supplying products through own DC and through suppliers was modeled using lead time distributions. Transportation activity was represented similarly through time distributions based on historical data.

The requirements of the effort motivated the use of a general-purpose simulation software rather than supply chain simulation tools that have recently become commercially available. The objective of the effort required development of a model with integrated representation of information and material flows. The abstraction level was also designed independent of software features and constraints. Ideally, the model should be built such that as the objective of the model changes from high-level analysis to detailed design, successive levels of detail can be added to the same model. Selection of a general-purpose simulation software allowed complete flexibility in determining the scope and abstraction level for different aspects of the model.

5 PROCESS MODEL DEVELOPMENT

In preparation for developing the simulation model, the business processes were captured and documented. After interviewing Subject Matter Experts (SMEs) in the organization, data was collected to document the current processes within the system. Using this information, flow diagrams were built using Visio to represent Order Fulfillment, Procurement, and Supply and Demand Planning.

5.1 Order Fulfillment

Order fulfillment is the process covering the period from generation of the order by a customer to the time they receive the requested product. The process begins when an order is accepted in the front-end customer center and ends with the generation of a receipt by the customer upon delivery. Most of the activities in Order fulfillment are automated processes as determined by encrypted information in the order number. This data determines the method of support, supplier type, and transportation requirements. Human intervention is required if an order is invalid, or if item is not available (backorders). A priority level is associated with each order based on a number of factors. All orders are edited and validated. If an order is for a product supplied from vendor-managed inventory, it is passed to the vendor. If the order is for a product supplied from own inventory, the order is released to the DC. The order is then shipped to the customer completing the order fulfillment process.

5.2 Procurement

Procurement includes processes responsible for acquiring and maintaining all type of contracts with vendors and suppliers. Most contracts are long term contracts that last for years. It is more desirable to have this type of relationship with the vendors because service levels and delivery agreements are upheld to specifications within the contracts. A purchase request will enter Procurement if it is a new item, an urgent order with no inventory at the DC or a normal replenishment order for products maintained in inventory at DCs. The process for establishing contracts for a new item is long extending into months while other procurements are within days.

5.3 Demand and Supply Planning

Demand Planning is the process of planning the demand based on the current inventory level, and committed and forecasted demands. Reorder quantity is determined based on current inventory policy and using the defined re-order points and lead times for the products in the data set. Inventories that have fallen below their re-order point are flagged, and a forecast of future demand is developed. This action leads to a demand plan, which feeds into Supply Planning.

Supply Planning deals with developing a plan to replenish inventory. Using customer order data and procurement lead time information, a supply position is determined. The next process is to determine replenishment quantity, which is determined automatically with some human intervention some of the time.

6 SIMULATION MODEL DEVELOPMENT

The static process model was transitioned into a dynamic simulation model with addition of distributions to represent entity flow and the logic within the process steps. Limitations of current information systems, as well as policies that limit control of the flow information or materiel through the process model are included to better represent real life flows. Features are added for statistics collection. These statistics are used to capture the performance measures of interest, their various components and for validation of the model. The simulation animation helps individuals unfamiliar with simulation models better understand the dynamic nature of simulation, in addition to helping those unfamiliar with detail of the study better understand the business processes represented in the simulation. Major aspects of the simulation model development are described below.

6.1 Assumptions

The major assumptions made in development of the simulation model include:

1. The activity times modeled are representative of the system operating with the current level of manpower. Manpower constraints are not explicitly modeled.
2. The distribution & transportation activity times modeled are representative of the system operating with the current distribution center and transportation capacities. Distribution and transportation constraints are not explicitly modeled.
3. For activities where detail data is available, activity times are represented using the best-fit statistical distribution.
4. For activities where summary statistics are used, activity times are represented using the exponential, normal, beta or discrete distribution that best represents the process.
5. For activities where subject matter expert estimations are used, activity times or re-work percentages are represented using triangular or discrete distributions. The representation captures different variations of activity where applicable.
6. Inventory is explicitly modeled as a constraint. Time on backorder is dependent on replenishment policies and the timelines and accuracy of data.
7. Demand profiles and product attributes for individual items are accurately represented in the data provided to this study.

Handling of entities (orders, purchases or other units of work for the system) is defined by distinct classification for each type; any “gray areas” are not modeled.

6.2 Process Flow Representation

The static process flows captured in Visio as described in previous section are modeled using a discrete event simulation tool, ARENA, to create a dynamic representation of the real life process. The inputs and outputs of each activity represent the potential paths an entity can take through the system. For activities that are resource or flow constrained, entities build up in queues until the resource either becomes available or until flow is released (for example, order queue builds up until an information system’s batch run). The model contains business rules so entities can be processed uniquely by type or certain conditions in the environment. Each activity is defined as a process in the simulation model with associated statistical distributions for the activity times. Similarly, decision blocks are coded with logic to implement the decisions or provided distributions to represent the percentage of entities that will flow through the respective output paths of the block. Source blocks are created to model the arrival of entities, for example, requisitions for the order fulfillment sub-model, to initiate the dynamic occurrences in the model. The flow of requisitions through the order fulfillment sub-model is linked by processes and decision logics to other parts of the model. For example, the assignment and release of inventory will trigger the shipment of the materiel to the customer. It will also update the inventory levels that in turn may result in inventory falling below the reorder point and trigger generation of purchase request entities in the demand planning and supply-planning model. The purchase requests may result in a procurement request flowing through the procurement sub-model, triggering a replenishment shipment from the supplier to the DC.

The act of building the representation of the process flow, associated time parameters and decision logic provides for the transition of the static process flow charts into a dynamic simulation model.

6.3 Demand Volumes

The simulation of individual order arrivals and order quantities to represent demand for various products in this study uses a robust approach that gives the capability to closely mimic three years of time series data available for each item.

A key consideration in the modeling of demand was the ability to create orders for the simulation with the same range of frequency and variation as viewed in the three years of historical data for each of the several thousand products that comprised the representative sample for this study. The end result is an algorithm that uses a non-stationary Poisson process generating an order pattern that closely resembles the actual time series. The statistical distribution used to generate demand introduces orders into the simulation in a non-constant, random arrival pattern. This random pattern on average generates a similar order volume as viewed in the historical data for the same time period and resembles "real operations" by creating orders that sometimes arrive shortly after one another, and by creating outlying events where an unusual amount of time passes between orders. For highly variable items, typical spikes and troughs in demand occur with the same frequency over the simulation run.

Another key consideration in modeling demand was the variation and average size of order quantities. The approach the simulation uses to generate order quantities was tailored to the data available. In the absence of transactional data to fit statistical distributions for order size, the methodology uses quarter by quarter summary statistics to fit a unique Beta distribution for each product, for each quarter. The net result of this approach is a simulation that generates order quantities that closely mirror the skewed nature of the data (for example, a case where the average order quantity for a quarter is close to the minimum, but not the maximum) and the average nature of the data (the average order size is what was observed in the data). This technique enables the generation over order quantities close to the average, as well as, "outliers" for small or large orders that are present in the historical data.

The described approach to model order arrivals and order size generates overall demand patterns that are consistent with those seen in the historical data (within +/-2%). For most experiments, the volumes generated mimicked closely the demand volume experienced in the three years of historical data used in this study.

6.4 Forecasting

The objective with forecasting component of the model was to simulate the unique forecasting behavior for each item in the study. The forecasting software generates a forecast based on a single and double smoothing algorithm. This forecast may then be modified using other models or may be modified by managers. The adjusted forecast is ultimately used for determining replenishment parameters, and the simulation captures the behavior associated with the modified forecast. A statistical analysis of the three-year time series for each product helped derive a methodology for modeling the forecast quantity and forecast error. The model uses several parameters to forecast a demand quantity for each quarter. For each product, the mean absolute deviation, the mean deviation and the maximum deviation are used in combination to determine the forecast quantity for each quarter of the time series. The outcome of this approach is an algorithm that generates a unique forecast for each product with the same absolute average forecast error that is consistently as positive or negative as viewed in the historical data set and is not greater than the maximum error viewed in the historical data set.

6.5 Replenishment

This order-to-delivery simulation uses inventory as a constraint to positively or negatively impact the business process performance under the new process. Specifically, the goal is to show how a backorder will act as a limiting factor despite having more accurate, timelier data and a more automated business process. To enable modeling inventory as a constraint, the simulation methodology incorporates the behaviors and policies associated with the replenishment of all products ranging from fast moving consumption items to slow moving service parts.

For determining the standard replenishment quantity, a statistical analysis revealed a relatively high correlation between the modified forecast quantity and standard replenishment quantity for the same time period. This helped define a mathematical relationship between the forecast quantity of a given period to the standard replenishment quantity for the same period. This allows standard replenishment quantity to move up and down with the forecast quantity for highly correlated items. In cases where the product manager did not move standard replenishment quantity with the forecast, the simulation model also reflects this behavior. A mathematical relationship was similarly established to model the changes in reorder point.

6.6 Statistics Collection

A number of customized features have been built in the model for collection of the required KPIs and other measures of interest for validation. These include:

1. Service levels
2. Inventory Turns
3. Order to delivery lead times with associated determination of 50, 75 and 95 percentiles

The statistics collection was done using the tally features in ARENA. These KPIs were collected in the model for the whole organization and with different breakdowns – by operating units, by different kind of inventories, etc. In addition to the above KPIs, a number of other measures were collected. To ensure model accuracy, other tallies were used in the model solely for the purpose of validation during the model build phase.

6.7 Interface to Input Data Sources

Several interfaces have been built using Visual Basic Applications to read the input data to the simulation model from MS Excel files and text files. Text formats were particularly used for large files to reduce the model initialization time. The input files were in the following major classes:

- **Process data** – describing the flow that the customer orders and corresponding entities such as purchase requests, material, etc, go through for the processes in the scope. The times for activities and branching percentages for nodes with multiple output nodes were entered to mimic the real-life execution of the processes.
- **Product profile** – describing the characteristics of the products such as its classification, unit of issue, volume, purchase prices, and lead times.
- **Demand profile** – describing the demand parameters for the products such as forecasted and actual demand quantity, order inter-arrival times, and the associated inventory management parameters such as standard order quantity and reorder point. The demand data was collected for a period of 3 years.
- **Distribution and Transportation** – describing the times taken for processing and shipment of orders from the DCs and suppliers to customers. These were modeled at a high level.

In addition to the data files, an Excel file was used to control the experiment parameters. Use of Excel and text files allowed experimenting with a wide range of scenarios without changing the model code.

6.8 Animation Screens

"Logicians may reason about abstractions. But the great mass of men must have images." – Thomas Babington Macaulay.

The above quote used by Rohrer (2000) is rather appropriate beginning for this section. Rohrer highlights the importance of visualization in manufacturing simulation and suggests that it is critical for communicating results to a non-technical audience. Supply chain simulations can similarly gain from use of animation to help the customers visualize the operation of the model.

Figures 2 and 3 show examples of animation screens in the model that helped explain the simulation process to the client management. The screens have been captured early in the simulation run and hence the numbers appearing in these figures are not representative of the long-term performance predicted by the model.

7 CONCLUSIONS

This paper described the development of a high-level simulation model for a complex supply chain. The abstraction process for determining the processes and the level of detail was discussed. The level of abstraction used for all the major aspects was described. The processes to be modeled and the level of detail for each process were captured in a process model. The simulation model was developed based on the flows captured in the process model and the abstraction of decision policy and logic for major activities. The input mechanisms were described indicating their use for experimental runs without modifying the model. The importance of animation as the communication medium for scope and functionality of the model was highlighted and some examples were provided.

Design and development of a simulation model for such a complex scenario as a supply chain requires careful thinking. The level of detail included in the model should be appropriate to the objective of the study. Inclusion of more detail than necessary can easily lead to too large an effort for the objective at hand and may lead to the effort not being approved by the parent organization, or adversely impacting the approval of future simulation efforts. The abstraction process is a key phase in a simulation study that determines the level of modeling effort and in turn the success of the overall effort. Abstraction is an "art" and is subjective. The sharing of experiences by simulation practitioners will be helpful to collectively gain and develop the art of abstraction.

REFERENCES

Bapat, V. and Swets, N., 2000. The Arena Product Family: Enterprise Modeling Solutions, In: *Proceedings of the 2000 Winter Simulation Conference*, eds: J.A. Joines, R.R. Barton, K. Kang and P.A. Fishwick, 163-169, Insitute of Electrical and Electronics Engineers, Piscataway, New Jersey.

Barnett, M.W., and C.J. Miller, 2000. Analysis of the Virtual Enterprise Using Distributed Supply Chain Modeling and Simulation: An Application of e-SCOR. In: *Proceedings of the 2000 Winter Simulation Conference*, eds: J.A. Joines, R.R. Barton, K. Kang and P.A. Fishwick, 352-355, Insitute of Electrical and Electronics Engineers, Piscataway, New Jersey.

Chwif, L., Barretto, M.R. and Paul, R.J., 2000. On Simulation Model Complexity, In: *Proceedings of the 2000 Winter Simulation Conference*, eds: J.A. Joines, R.R. Barton, K. Kang and P.A. Fishwick, 449-455, Insitute of Electrical and Electronics Engineers, Piscataway, New Jersey.

Davis, P.K. 2000. Exploratory Analysis Enabled by Multiresolution, Multiperspective Modeling, In: *Proceedings of the 2000 Winter Simulation Conference*, eds: J.A. Joines, R.R. Barton, K. Kang and P.A. Fishwick, 293-302, Institute of Electrical and Electronics Engineers, Piscataway, New Jersey.

Hennessee, M. 1998. Challenges Facing Global Supply-Chains in the 21st Century. In *Proceedings of the 1998 Winter Simulation Conference*, ed. D.J. Medeiros, E.F.

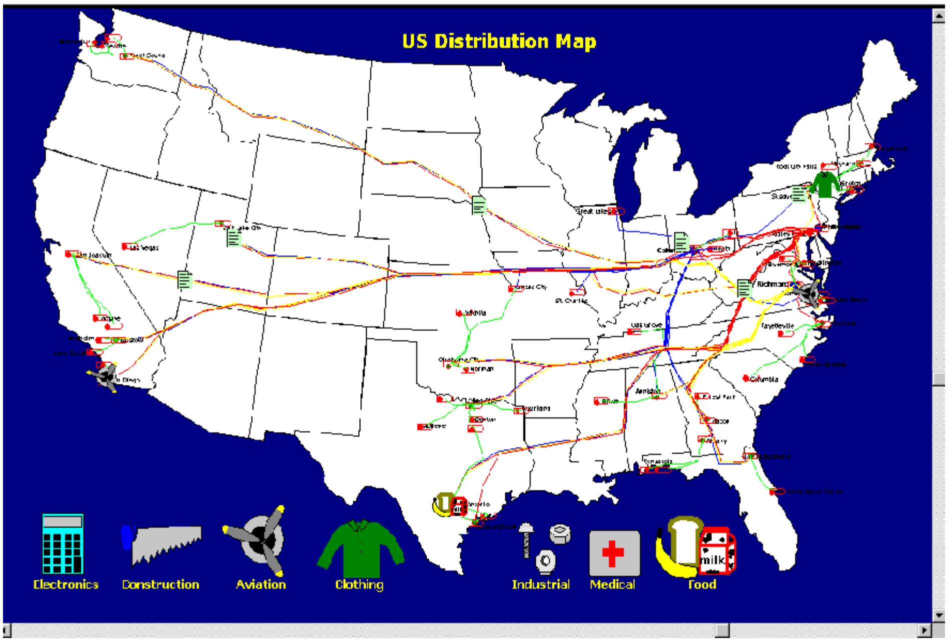

Figure 2: Animation of Material Flow Process in the Supply Chain

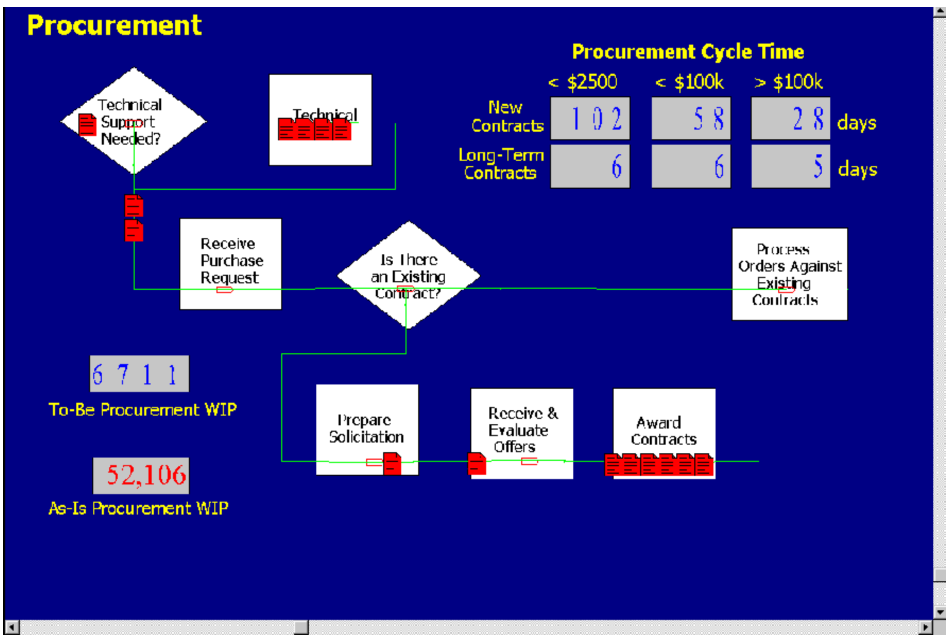

Figure 3: Animation of a Business Process in the Supply Chain

Watson, J.S. Carson and M.S. Manivannan, 3-4. Institute of Electrical and Electronics Engineers, Piscataway, New Jersey.

Hieta, S. 1998. Supply Chain Simulation with LOGSIM-Simulator. In *Proceedings of the 1998 Winter Simulation Conference*, ed. D.J. Medeiros, E.F. Watson, J.S. Carson and M.S. Manivannan, 323-326. Institute of Electrical and Electronics Engineers, Piscataway, New Jersey.

Jain, Sanjay. 1999. Simulation in the Next Millennium. In: *Proceedings of the 1999 Winter Simulation Conference*, ed. P.A. Farrington, H.B. Nembard, D.T. Sturrock, and G. W. Evans, 1480-1487. . Institute of Electrical and Electronics Engineers, Piscataway, New Jersey.

Jain, S., C.C. Lim, B.P. Gan and Y.H. Low. 1999. Criticality of Detailed Modeling in Semiconductor Supply Chain Simulation. In: *Proceedings of the 1999 Winter Simulation Conference*, ed. P.A. Farrington, H.B.

Nembard, D.T. Sturrock, and G. W. Evans, 888-896. Institute of Electrical and Electronics Engineers, Piscataway, New Jersey.

McGraw, R.M. and R.A. MacDonald, 2000. Abstract Modeling for Engineering and Engagement Level Simulations. In: *Proceedings of the 2000 Winter Simulation Conference*, eds: J.A. Joines, R.R. Barton, K. Kang and P.A. Fishwick, 326-334, Institute of Electrical and Electronics Engineers, Piscataway, New Jersey.

Phelps, R.A., D.J. Parsons, and A.J. Spirelle, 2000. The SI Industry Product Suite: Simulation from the Production Line to the Supply Chain. In: *Proceedings of the 2000 Winter Simulation Conference*, eds: J.A. Joines, R.R. Barton, K. Kang and P.A. Fishwick, 208-214, Institute of Electrical and Electronics Engineers, Piscataway, New Jersey.

Rohrer, M.W. 2000. Seeing is Believing: The Importance of Visualization in Manufacturing Simulation, In: *Proceedings of the 2000 Winter Simulation Conference*, eds: J.A. Joines, R.R. Barton, K. Kang and P.A. Fishwick, 1211-1216, Institute of Electrical and Electronics Engineers, Piscataway, New Jersey.

Schunk, D. and B. Plott, 2000. Using Simulation to Analyze Supply Chains. In: *Proceedings of the 2000 Winter Simulation Conference*, eds: J.A. Joines, R.R. Barton, K. Kang and P.A. Fishwick, 1211-1216, Institute of Electrical and Electronics Engineers, Piscataway, New Jersey.

Umeda, S., and A. Jones. 1998. An Integration Test-Bed System for Supply Chain Management. In *Proceedings of the 1998 Winter Simulation Conference*, ed. D.J. Medeiros, E.F. Watson, J.S. Carson and M.S. Manivannan, 1377-1385. Institute of Electrical and Electronics Engineers, Piscataway, New Jersey.

AUTHOR BIOGRAPHIES

SANJAY JAIN is a Manager with the Decision Integration group of Accenture, where he leads simulation and optimization projects in supply chain area. Prior to joining Accenture, he has worked at Gintic Institute of Manufacturing Technology, Singapore, and General Motors North American Operations Technical Center in Warren, MI, USA. He received a Bachelors of Engineering from University of Roorkee, India in1982, a Post Graduate Diploma from National Institute for Training in Industrial Engineering, Mumbai, India in 1984, and a PhD in Engineering Science from Rensselaer Polytechnic Institute, Troy, New York in 1988. He is a member of Institute of Industrial Engineers and of the editorial board of *International Journal of Industrial Engineering*. His email address is `<sanjay_jain@hotmail.com>`.

RUSSELL W. WORKMAN is a Manager in Accenture's Decision Integration group. He received a Bachelor of Science in Operations Research from the United States Air Force Academy in 1993, and a Master of Science in Operations Research from Northeastern University in 1997. He is a member of INFORMS. His interests and experience in simulation span a range of industries, including capital markets, pharmaceuticals, information technology, and the defense industry. His email address is: <russell.w.workman@accenture.com>.

LISA M. COLLINS is a Consultant in Accenture's Decision Integration group. She graduated from Georgia Institute of Technology in 1997 with a Bachelor of Science in Industrial Engineering. Her project experience at Accenture include pharmaceuticals, telecommunications, government, supply chain, eCommerce, and call center work. Prior to joining Accenture, she worked as a management engineer at Piedmont Hospital (a 500+ bed facility) in Atlanta. She can be reached at <lisa.m.Collins@accenture.com>.

ERIC C. ERVIN is a Manager in Accenture's Decision Integration group. He received a Bachelor of Science in Industrial Engineering from Iowa State University in 1995. He is member of INFORMS. His interests and experience in simulation span a range of industries and domains including pharmaceuticals, consumer goods, communications, electronics, supply chain and customer relationship management processes. His email address is <eric.c.ervin@accenture.com>.

ANDREW P. LATHROP is a Consultant in Accenture's Decision Integration group. He received a Bachelor of Science in Operations Research from the United States Military Academy in 1993 and a Master of Science in Operations Research from the Colorado School of Mines in 1999. He is a member of INFORMS. Prior to joining Accenture, he worked in the Army as a combat engineer. His e-mail address is <andrew.p.lathrop@accenture.com>.