2008

Automatic Generation Of Supply Chain Simulation Models From Scor Based Ontologies

Dayana Cope
University of Central Florida

AUTOMATIC GENERATION OF SUPPLY CHAIN SIMULATION MODELS FROM SCOR BASED ONTOLOGIES

by

DAYANA COPE
B.S. University of Central Florida, 2000
M.S. University of Central Florida, 2002

A dissertation submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy
in the Department of Industrial Engineering and Management Systems
in the College of Engineering and Computer Science
at the University of Central Florida
Orlando, Florida

Spring Term
2008

Major Professor: Jose Sepulveda

ABSTRACT

In today's economy of global markets, supply chain networks, supplier/customer relationship management and intense competition; decision makers are faced with a need to perform decision making using tools that do not accommodate the nature of the changing market. This research focuses on developing a methodology that addresses this need. The developed methodology provides supply chain decision makers with a tool to perform efficient decision making in stochastic, dynamic and distributed supply chain environments. The integrated methodology allows for informed decision making in a fast, sharable and easy to use format. The methodology was implemented by developing a stand alone tool that allows users to define a supply chain simulation model using SCOR based ontologies. The ontology includes the supply chain knowledge and the knowledge required to build a simulation model of the supply chain system. A simulation model is generated automatically from the ontology to provide the flexibility to model at various levels of details changing the model structure on the fly. The methodology implementation is demonstrated and evaluated through a retail oriented case study. When comparing the implementation using the developed methodology vs. a "traditional" simulation methodology approach, a significant reduction in definition and execution time was observed.

I dedicate this dissertation to my father, *Nicanor Espinal*, my greatest example of hard work and dedication.

ACKNOWLEDGMENTS

I would like to deeply thank my family for all the support and encouragement that they have provided. I would especially like to thank my husband, Delbert Cope, who provided me with the strength to finish this research.

I would also like to thank my committee for all the guidance that they provided throughout this research, especially my advisor, Jose Sepulveda. I would also like to thank my friend and resident expert in Supply Chain, Dr. Mohamed Fayez, for his constant encouragement and guidance.

I would also like to express my gratitude to Dr. Mansooreh Mollaghasemi for always believing in me, guiding me and encouraging me throughout this entire process.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER ONE: INTRODUCTION

In today's highly competitive marketplace, companies are faced with the need to meet or exceed increasing customer expectations while cutting costs to stay competitive in a fierce global market. In order to cut costs, most companies focus on their core competencies by streamlining core operations and outsourcing out-of- core operations. According to the SMMT Industry Forum (SMMT, 2004), "in the automobile industry, 70% of a vehicle (by cost) is outsourced to first tier suppliers, first tier suppliers outsource 60–70% to second tier suppliers, second tier suppliers outsource 40-60%". However, companies cannot lose sight of the other side of the balance, meeting or exceeding customer expectations. In order to exceed customer expectations, companies must meet changes in customer demand in the least amount of time while providing a reliable product. Successful companies find their competitive advantage when they are able to make informed decisions that optimize this balance. In order to make these informed decisions, decision makers must have a holistic view of all the elements that affect the planning, design, production and delivery of their product. They must be able to understand, estimate, and project their business supply chain performance.

A supply chain is a network of facilities that perform the functions of sourcing of materials, transformation of these materials into intermediate and finished products, distribution of these finished products to customers and the return of defective or excess products. Similarly, Supply Chain Management is the science of managing the supply chain. In a study published in 2000, AMR Research identified that upwards of $400B of opportunities exist in North America for trading partners that fully integrate their supply chains (AMR, 2004). By analyzing a company's supply chain as a single, interconnected structure, companies can make decisions that will minimize costs while maximizing customer satisfaction. Williams and Gunal (2003) state that supply chain improvement has gained importance to many businesses due to rapid globalization, intensifying competition, attractive benefit-to cost ratios, and the trend toward long-term relationships with trusted suppliers.

A variety of methodologies exist to aid decision makers when analyzing their supply chains. A high level breakdown of these methodologies can be observed in Figure 1.

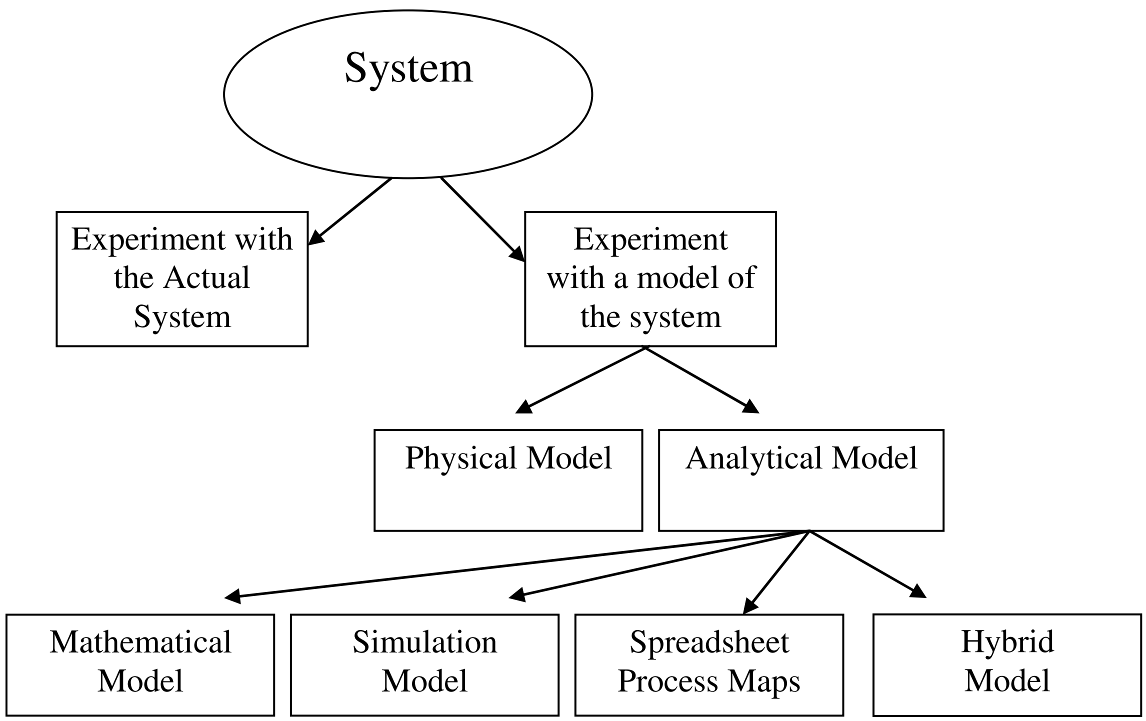


Figure 1: Methods for Studying a System

Most decision makers choose to experiment with a model of a system since experimenting with the real system may be impractical, impossible and/or come at a high risk. Analytical models are widely used when analyzing supply chains. The following are some examples of analytical models:

- Mathematical Models

Mathematical models are an equation or set of equations, which attempt to give a mathematical description of some real phenomenon. Mathematical modeling presents the easiest and fastest solutions for simple problems, giving exact and optimum solutions. However, mathematical models are not dynamic (static), cannot account for changes in the system over time and cannot model variability.

- Spreadsheet Models and Process Maps

Spreadsheets models are fast, easy to use, and widely available. Any number of parameters and formulas with varying degrees of complexity can be included; at the same time these parameters and formulas can be updated quickly to test several scenarios. Process maps represent a common understanding of systems operations. They are easy to use, widely available, and do not require prior mathematics or programming knowledge. Process maps can be used to map an end-to-end business process in greater details, mainly to convey a common understanding of the "as is" process and map alternative "to be" processes. Similar to Mathematical models, spreadsheets and process models are static, deterministic tools that do not account for changes in the system over time and neglect variability.

- Simulation Modeling

System simulation can be defined as "the practice of building models to represent existing real-world systems, or hypothetical future systems, and of experimenting with these models to explain system behavior, improve system performance, or design new systems with desirable performances."(Khoshnevis, 1994). Simulation modeling provides the flexibility to model processes and events to the desired level of complexity, in a risk free, dynamic and stochastic environment.

Furthermore, when considering supply chains, certain characteristics of supply chain environments should be addressed when selecting a methodology to aid supply chain decision makers:

- Uncertain and High Variability Environment

Like any real world environment, supply chain environments are governed by uncertainty. However, uncertainty is extremely critical in a supply chain environment due to the integrated nature of supply chains. Since supply chains are composed of different elements (i.e. suppliers, supplier's supplier, customer, etc) integrated and interrelated, each element's uncertainty interacts with one another greatly affecting supply chain activities. In order to deal with this issue, managers must identify and understand the causes of uncertainty and determine how it affects other activities up and down the supply chain. Then they can formulate ways to reduce or eliminate it (Schunk & Plott, 2000). An example of this is the Bullwhip effect. The bullwhip effect is the phenomena of increasing demand variation as the demand information is passed upstream through the supply chain. This amplification has direct impacts on costs due to the increased safety stock requirements (Chatfield, 2001). The bullwhip effect will propagate to the entire supply chain areas producing backlogs, poor forecasts, unbalanced capacities, poor customer service, uncertain production plans, and high backlog costs (Chang & Makatsoris, 2000). Simulation modeling is a perfect candidate to model a stochastic system such as this one.

- Dynamic Environment

According to Fayez (2005), the dynamism in supply chains is encountered at different levels, which are the supply chain level, the enterprise level, or enterprises' elements level. The dynamic behavior at the supply chain level is encountered when enterprises that constitute the supply chain change over time, e.g. enterprises leave the chain or new enterprises join the chain. Dynamism is encountered at the enterprise level when the elements in the enterprise are changing over time, e.g. new functional units such as a factory or a new information resource or enterprise application system may be added. The dynamism at the enterprise element level is encountered when the specification or the definition of the element changes over time, e.g. a change in the workflow, a change in the schema of an information resource, or a change in the semantics. Dynamic environments are dictated by change. Therefore, decision makers must count on a methodology that would allow for timely and efficient updating to reflect changes in the environment. However, traditional analytical analysis methodologies like simulation modeling require lengthy design and development times. This procedure would have to be repeated every time the supply chain system changes. Steele, Mollaghasemi, Rabadi and Cates (2002) discuss this issue as it applies to simulation modeling. In their paper they state that the development of multiple system-specific models can become problematic due to time and budget constraints. In some cases, the steps involved in simulating multiple systems can be shared if they share common objectives; however, many of the most time consuming steps would be unique to each system modeled. Consequently, the time for modeling and studying each individual system becomes additive to the overall effort. Enterprises are usually not willing to wait for lengthy analyses, since the opportunity to influence the design of a system with respect to the operational impacts on a particular design decision is eliminated if the analysis becomes too lengthy (Steele et al., 2002). The design and development of simulation models for dynamic systems such as supply chains should be minimal to encourage decision makers to make timely decisions.

- Distributed Environment

Since supply chains are physically distributed, the information that makes up the supply chains is also distributed. The information in any supply chain is originated and owned by different entities, i.e. supply chain partners. Consequently, pieces of information are distributed along the supply chain in different systems and, therefore, in different formats. This has a great implication when decision makers attempt to make decisions regarding the supply chain as a unit. Often data is available but the knowledge required for decision-making is hard to come by since a great effort has to precede any analysis in order to obtain the data and format the available data into a common body of knowledge that is universal to all elements of the supply chain. This issue is further complicated when supply chain partners are hesitant to provide this data. According to Gupta, Whitman, and Agarwal (2001), "Supply chain decisions are improved with access to global information. However, supply chain partners are frequently hesitant to provide full access to all the information within an enterprise. A mechanism to make decisions based on global information without complete access to that information is required for improved supply chain decision making" (Gupta et al., 2001).

Clearly, supply chain environments are complex environments requiring a comprehensive methodology or combination of methodologies for analysis. This research is directed towards developing a comprehensive methodology to allow users to perform efficient decision making in supply chain environments. Furthermore, the methodology should adapt to a distributed environment where pieces of information are distributed along the different supply chain elements. In order to accomplish this, the methodology should include the automatic generation of simulation models to adapt to the dynamic stochastic environment prevalent in supply chains. Moreover, the simulation model should be driven from a shared, common definition of the supply chain being modeled to encourage a thorough and common model of the system under study. In order to facilitate the automatic development of the models, an integrated tool should be developed that would automatically generate a simulation model of the system with minimal input from the user in a fast, easy to use, scalable format. Fayez (2005) developed a methodology to "define supply chain systems in a comprehensive, automated, customizable, extensible format". In his research, Fayez used ontologies to represent the definition of the supply chain in a common and sharable format. An ontology is "a formal and explicit specification of a shared conceptualization" (Chandrasekaran, Stephenson, & Benjamin, 1999).

Furthermore, to facilitate the distribution of the supply chain definitions across multiple supply chain partners, Fayez developed his methodology based on the Supply Chain Operations Reference model (SCOR model). The SCOR model is the most widely used tool for defining Supply Chains. In his research, he extended the SCOR model to include a more comprehensive definition of supply chains. This reach will extend the work done by Fayez (2005) to include simulation-modeling constructs within the common definition of the supply chains.

Statement of Problem

The problem statement that this research will address is:

There is a need for the development of a comprehensive methodology that provides supply chain decision makers with a tool to perform efficient decision making in stochastic, dynamic and distributed supply chain environments. The tool should allow for automatic, sharable and scalable analysis of supply chains.

Research Objectives

The Objective of this research is to develop an integrated methodology to allow supply chain decision makers to support informed decision making in a fast, sharable and easy to use format. This methodology should allow for

- Development of simulation models to address and capture the stochastic nature of supply chain environments in a timely manner and at varying levels of fidelity.
- Automatic generation of supply chain models to aid non-simulation experts during decision making in a dynamic environment.
- The use of a common and comprehensive supply chain definition (developed by Fayez, 2005) to encourage knowledge sharing and knowledge acquisition in a distributed environment.

Research Contributions

The anticipated contributions of this research are:

- An automatic generator of simulation models from a common, cross-industry, comprehensive supply chain definition.

- A supply chain simulation ontology that extends the Supply Chain ontology developed by Fayez (2005).
- A user-friendly tool that allows supply chain decision makers to design, develop and experiment with simulation models using their own domain language in a fast and comprehensive manner.

Chapter Layout

This dissertation will be organized as follows. Chapter 2 presents a summary of the current literature relevant to the research topic. Chapter 3 will describe the research methodology. Chapter 4 will depict the implementation of the methodology. Chapter 5 will illustrate a case study that implements the methodology developed. Chapter 6 will summarize the findings, contributions, draw conclusions, and suggest further extensions to this research.

CHAPTER TWO: LITERATURE REVIEW

The purpose of this literature review is to identify the state of the art research that currently dictates the way in which decision-making is conducted in supply chain environments. Specifically, this literature research will focus on identifying the current research in the following areas:

1. Modeling applications in Supply Chain environments: This section presents the current state of modeling in supply chain applications.

   The research efforts can be classified by the type of modeling utilized. The following methodologies were researched:

   - Discrete Event and Object Oriented Simulation
   - System Dynamics
   - Agent Based Simulation
   - Mathematical Modeling
   - Spreadsheet Modeling and Process Maps

2. Simulation, modeling and the SCOR model: This section explores the SCOR model and presents the latest research involving the development of modeling efforts using the SCOR model.
3. Automatic generation of simulation models: This section explores the latest research in the development of automatic generators for discrete event simulation models.
4. Validation of simulation models: This section explores the available research in the process of validating simulation models to ensure the models accurately mimic the real system.

5. Simulation modeling ontologies: This section presents the current research performed in the development of ontologies for simulation modeling.

Based on these key areas of research, a classification matrix was developed to systematically represent the current research as it applies to the specific research areas. This matrix is presented in Table 1. The matrix presents the key research areas listed above and the respective papers that address it. Additionally, in order to perform a thorough literature review, a multi-dimensional matrix (see Table 2) was developed consisting of some research questions designed to identify gaps in current research efforts. The questions are mapped to the equivalent research areas that are anticipated to answer these questions.

Table 1: Current Research Classifications

Papers	Modeling and Supply Chain					Automatic Genration of Simulation Models	Simualtion Modeling and Supply Chain Ontologies	Simulation, Modeling and SCOR
	Discrete Event and Object Oriented Simulation	System Dynamics	Agent Based Simulation	Mathematical Modeling	Spreadsheet Modeling and Process Maps			
Barnett and Miller(2000)								■
Pundoor (2004)								■
Son, Wysk and Jones (2000)						■		
Arief and Speirs (2000)						■		
Bruschi, Santana, Santana and Aiza (2004)						■		
Morgan (1994)						■		
Chatfield, 2001	■					■		
Miller and Fishwick (2004)							■	
Miller, Baramidze, Sheth and Fishwick (2004)							■	
Miller and Baramidze (2005)							■	
Lacy (2004)							■	
Fox and Gruninger (1993)							■	
Fayez (2005)							■	■
Armbruster, Marthaler, Ringhofer (2002)	■							
Bagchi, Buckley, Ettl and Lin (1998)	■							
Banks, Jain, Buckley, Lendermann and Manivannan (2002)	■							
Bansal (2002)	■							
Byrne and Heavey (2004)	■							
Chang and Makatsoris (2000)	■							
Chatfield,Harrison and Hayya (2004)	■							
Siprelle, Parsons and Clark (2003)	■							
Chwif, Barretto and Saliby (2002)	■							
Ding, Benyoucef, Xie, Hans and Schumacher (2004)	■							
Ritchie-Dunham, Morrice, Scott and Anderson (2004)	■							
Enns and Suwanruji (2003)	■							
Gan, Liu, Jain, Turner, Cai and Hsu (2000)	■							
Ganapathy, Narayanan and Srinivasan (2003)	■							
Hamoen and Moens (2002)	■							
Herrmann, Lin and Pundoor(2003)	■							
Ingalls and Kasales (1999)	■							
Jain, Collins, Workman, Ervin and Lathrop (2001)	■							
Liu, Wang, Chai and Liu (2004)	■							
Munoz (2003)	■							
Parsons, Clark, Payette (2004)	■							
Pathak, Dilts, and Biswas (2003)	■							
Phelps, Parsons and Siprelle (2001)	■							
Pundoor (2002)	■							
Rossetti and Chan (2003)	■							
Schunk and Plott (2000)	■							
Sudra, Taylor and Janahan (2000)	■							
Tan, Zhao and Taylor (2003)	■							
Truong and Azadivar (2003)	■							
Umeda and lee (2004)	■							
Vieira (2004)	■							
Wartha, Peev, Borshchev and Filippov (2002)	■							
Williams and Gunal (2003)	■							
Xi, Cao, Berman and Jensen (2003)	■							
Fu and Piplani (2000)	■							
Biswas and Narahari(2004)	■							
Lee, Ramakrishnan and Wysk (2002)	■							
Van der Vorst, Beulens and Beek (2000)	■							
Angerhofer and Angelides (2000)		■						
Barbuceanu, Teigen, and Fox (1997)			■					
Spitter, Hurkens, Kok, Lenstra and Negenmanal (2005)				■				
Hicks (1999)				■				
Hwang (2002)				■				
Alonso-Ayuoso, Escudero, Garin, Ortuno and Perez(2003)				■				
Hicks (1999)				■				
Truong and Azadivar (2003)				■				
Dudek and Stadtler (2005)				■				
Perona and Miragliotta (2004)					■			
Kulp, Lee, and Ofek (2004)					■			
van Donk and van der Vaart (2005)					■			
Ryu and Lee (2003)					■			
Mukhopadhyay and Setoputro (2005)					■			

Table 2: Literature Review Matrix

Questions	**Modeling in Supply Chain**	**Automatic Generation of Simulation Models**	**Simulation Modeling and Supply Chain Ontologies**	**Simulation, Modeling and SCOR**
Why should simulation modeling be used as a decision support tool for supply chain analysis?				
What are the current applications of modeling for analyzing supply chains?				
What simulation modeling tools have been developed to analyze supply chains?				
What methodologies have been developed to address the issues associated with modeling supply chain dynamic environments?				
What is the state of the art in automatic generation of supply chain simulation models?				
What approaches have been developed to support the distributed nurture of supply chain systems?				
What are the advantages of using Ontologies when defining distributed systems?				
Has there been any simulation ontology development effort?				
Has there been any supply chain ontology development effort?				
Has there been any supply chain simulation ontology effort?				
What is the advantage of using Ontologies over XML?				
What is the advantage of defining a supply chain from a common model, such as SCOR?				
What is the state of the art in development of simulation models from the SCOR model?				

Modeling in Supply Chain environments

Discrete Event and Object Oriented Simulation

Since the advent of supply chain and the realization of the advantages of using simulation in supply chain environments, there have been many efforts aiming to apply these benefits within their supply chains for specific supply chain problems (i.e. inventory planning, supply chain design, etc.) The literature in supply chain simulation applications modeling is vast and it can be divided into descriptive papers and case studies, and tools. The papers can be classified as:

- Descriptive papers and case studies: papers describing the application of simulation to a specific supply chain problem (i.e. inventory planning)
- Tools: papers describing the development of a supply chain simulation-modeling tools.

Descriptive Papers and Case Studies

Banks, Buckley, Jain, Lendermann and Manivannan (2002) held a panel session were they discussed the opportunities for simulation modeling in supply chain. Their paper presents opportunities and challenges in the area. The topics of discussion were: the use of simulation in process control, decision support, and proactive planning; simulation use through the supply chain life cycle; the characteristics of firms for which simulation is feasible for SCM; and opportunities for simulation in SCM. They present the following ten opportunities for simulation in SCM (Banks et al., 2002):

- Identify the shortcomings and opportunities for redesign
- Measure impact of changes in demand on supply chain components.
- Measure impact of new ways of setting up and operating a large supply chain.
- Investigate the impact of eliminating an existing or adding a new infrastructure component to an existing supply chain.
- Investigate the impact of changing operational strategies within a supply chain
- Investigate the impact of making in house, outsourcing, developing a new supply base and the combination of these.
- Investigate the impact of merging two supply chains or impact of separating a portion of the existing components of a supply chain.
- Investigate the relationships between suppliers and other critical components of a supply chain.
- Investigate the opportunities for postponement and standardization.
- Investigate the impact of current inventory strategies on the overall performance of a supply chain.

Many authors (Bansal, 2002; Byrne & Heavey, 2004; Chang & Makatsoris, 2000; Chwif, Barretto, & Saliby, 2002; Siprelle, Parsons, & Clark, 2003) discuss the promise, issues and requirements associated with using simulation in a supply chain domain. Similarly, many efforts have been conducted to develop simulation models and simulation-modeling tools to address different needs within supply chain domains. Ritchie-Dunham, Morrice, Scott and Anderson (2000), present the results from a simulation effort designed to quantify the benefits of an enterprise resource planning system coupled with the balanced scorecard framework in an extended enterprise.

Enns and Suwanruji (2003) developed an environment consisting of a planning module and a simulator module. The simulation module was developed in Rockwell Software's ARENA simulation modeling language and the planning module is a spreadsheet-based module with an interface to ARENA through VBA. Using their methodology, they compared different planning and control strategies within a supply chain. It was also used to develop algorithms for updating tactical parameters in MRP systems.

Pathak, Dilts and Biswas (2003), developed a simulation modeling methodology to model dynamic, adaptive supply chain systems. The simulator is implemented using a software agent technology, where individual agents represent firms in a supply chain network. In their paper, the authors present a sample scenario run with results.

Phelps, Parsons and Siprelle (2001), developed the SDI Supply Chain Builder Product Suite. The tool contains four elements for enterprise modeling: SDI Supply Chain Builder for supply/ distribution chains, SDI Plant Builder for multi-stage plants driven by schedules, Extend+Industry for high-speed, high-volume production line modeling, and the SDI Data-Framework for high-speed data import and export.

In their research, Rossetti and Chan (2003) discuss the design, development and testing of an object oriented framework for supply chains using Java.

In their paper, Schunk and Plott (2000) discuss Supply Solver a tool developed to provide supply chain solutions using simulation as the foundation.

Sudra, Taylor and Janahan (2000); Tan, Zhao and Taylor (2003) developed distributed simulation models for different supply chain applications that use GRIDS, a Generic Runtime Infrastructure for Distributed Simulation. "The advantages of transparently connecting the distributed components of a supply chain simulation allow the construction of a conceptual simulation while releasing the modeler from the complexities of the underlying network" (Sudra et al., 2000).

In his paper, Vieira (2004) gives a detail description of the methodology that he followed while developing a supply chain simulation model using Rockwell Software's ARENA simulation modeling language. He used sub-models to represent specific elements in a traditional supply chain (i.e. suppliers, manufactures, distributors (or wholesalers), retailers and customers).

Xi, Cao, Berman, and Jensen (2003), present a generic distributed job running framework for supply chain simulation. In their research they extend the Supply Chain Analyzer (SCA), a supply chain-modeling tool developed by IBM by adding a distributed simulation capability to the tool.

Tools

In their paper, Bagchi, Buckley, Ettl and Lin (1998), present the IBM Supply Chain Simulator (SCS). SCS was developed by IBM Research to improve IBM's internal supply chain. The tool is also used by the IBM Industry Solution Units to help its clients improve their supply chains. SCS uses "simulation and optimization to model and analyze supply chain issues such as site location, replenishment policies, manufacturing policies, transportation policies, stocking levels, lead times, and customer service"(Bagchi et al., 1998). In their paper, they review the capabilities of the tool and present experience from practical studies.

Biswas and Narahari (2004) developed DESSCOM, an object oriented supply chain simulation modeling methodology. In their research, they use their prototype tool to model a liquid petroleum gas supply chain.

Ding, Benyoucef, Xie, Hans and Schumacher (2004) developed "ONE" a simulation and optimization tool to support decision during assessment, design and improvement of supply chain networks. The tool is composed of a data miner, a simulation modeling engine, scenario manager and an optimization module that uses mathematical programming (MP) and genetic algorithms.

Gan, Liu, Jain, Turner, Cai and Hsu (2000) discuss a methodology developed to address the issue of sharing simulation models over a distributed supply chain environment.

"Traditionally, a supply chain involves only a single enterprise with multiple facilities and distribution centers. Hence, sharing of detailed simulation models is not a problem in this scenario. But in recent years, the scope of SCM has evolved to cross the enterprise boundaries. Applying simulation in designing, evaluating, and optimizing the supply chain becomes more difficult since the participating corporations might not be willing to share their simulation models with partners" (Gan et al., 2000). In their research, the authors compare building a distributed simulation model on top of the Runtime Infrastructure of the High Level Architecture or building the simulation on top of a customized distributed discrete event simulation protocol. These alternative approaches are compared in terms of their performance and interoperability. They found that HLA offers an advantage over a DES protocol when considering interoperability. However, when considering performance, the DES protocol outperforms the HLA RTI. "With this split of advantages, the choice of approach for distributed simulation will then be determined by the primary concern of the application" (Gan et al., 2000).

(Gan et al., 2000), Narayanan and Srinivasan (2003), developed a decision support system consisting of a user interface and an object oriented simulation model. In their research they compared the performance of their system when building a supply chain model to building a supply chain model without the tool.

Hamoen and Moens (2002) developed a simulation tool to simulate steel plants. The tool was built using the Enterprise Dynamics package.

Ingalls and Kasales (1999) describe CSCAT, an internal supply chain simulation analysis tool. CSCAT is based on Rockwell Software's ARENA. CSCAT has been used in Compaq to address strategic supply chain issues and certain product-specific supply chain issues.

Jain and Workman (2001), describe their effort developing a generic simulation tool to model supply chains. The tool is composed of a data and experimentation interface, a generic simulation model and an animation feature.

Liu, Wang, Chai and Liu (2004) discuss the development of Easy-SC, a Java-based simulation tool. Easy-SC is a modeling tool for assessing the pros and cons of new facility locations, resource allocations and different combinations of policies.

Umeda and Lee (2004) describe a design specification for a generic, supply-chain-simulation system. The generic simulation is based on schedule-driven and stock-driven control methods to support the supply chain management.

Wartha, Peev, Borshchev and Filippov (2002) developed Decision Support Tool - Supply Chain (DST-SC). DST-SC is a domain-oriented tool, which is an extension of the UML-RT Hybrid Simulation kernel of AnyLogic by XJ Technologies. They list the benefits of the tool as having high interoperability with third party software, being platform-independence as well as having a potential for concurrent use by a geographically distributed group.

In their paper Williams and Gunal (2003) present an overview and tutorial of SimFlex. SimFlex is a supply-chain simulation software package that uses Excel and MS Access for data management.

Another supply chain simulation modeling tool is Supply Chain Guru. Supply Chain Guru uses the ProModel discrete event simulation language as its simulation engine (ProModel Corporation, 2002).

System Dynamics

In their paper, Angerhofer and Angelides (2000) provide an overview of recent research work that has been performed in the areas of Supply Chain modeling using System Dynamics. They identified several areas for future research to be addressed when using System Dynamics to analyze supply chain systems. They recommend that a taxonomy of a particular area within System Dynamics in supply chain management could be developed to show the relations between partnerships in supply chains, problems addressed and the conditions for success or failure. They also recommend future research to improve the modeling approach in areas related to inventory management.

Agent Based Simulation

Barbuceanu, Teigen, and Fox (1997) discuss the advantages of using agent and coordination technology to model, design and simulate global, distributed supply chains. In their paper, they demonstrate how supply chains can be naturally modeled, simulated and improved using this paradigm "within a short development time and with reduced human resources" (Barbuceanu, Teigen, and Fox, 1997). Using agent technology the simulation models can be reused with minor modifications when analyzing distributed supply chains. "In this way, the presented agent technology gives us a powerful approach to life-cycle support of supply-chain information architectures" (Barbuceanu, Teigen, and Fox, 1997).

Mathematical Models

Research efforts in supply chain modeling have been documented using different types of mathematical models. Spitter, Hurkens, Kok, Lenstra and Negenmanal (2005) and Hicks (1999) used linear programming; Hwang (2002) and Alonso-Ayuoso, Escudero, Garin, Ortuno and Perez (2003) used integer programming; Hicks (1999), Truong and Azadivar (2003) and Dudek and Stadtler (2005) used mixed integer programming.

Spreadsheet Models and Process Maps

Supply Chain modeling efforts can be found in the literature that use spreadsheet and/or process mapping to model their supply chain systems. Perona and Miragliotta (2004) developed a conceptual model to represent the complexities in a manufacturing environment and how these complexities affect the supply chain performance. Kulp, Lee, and Ofek (2004) developed a conceptual framework that relates information integration initiatives to manufacturer profitability. van Donk and van der Vaart (2005) developed a framework to investigate the level and scope of integration that can be achieved in a supply chain dominated by shared resources. In their research, Ryu and Lee (2003) developed a model to analyze the effects of investment strategies to control lead times. Mukhopadhyay and Setoputro (2005) developed a profit maximization model to obtain polices for return policy in terms of certain market reaction parameters.

Simulation, Modeling and SCOR Model

The Supply Chain Council developed and endorsed the Supply Chain Operations Reference (SCOR) model. The SCOR model integrated the concepts of business process reengineering, benchmarking, and process measurement into a cross-functional framework.

The SCOR model describes the business activities associated with all phases of satisfying a customer's demand. The model is organized around five management processes: Plan, Source, Make, Deliver, and Return. By describing supply chains using these processes, the model can be used to describe supply chains that are very simple or very complex using a common set of definitions. "As a result, disparate industries can be linked to describe the depth and breadth of virtually any supply chain. The SCOR model has been able to successfully describe and provide a basis for supply chain improvement for global projects as well as site-specific projects" (SCC, 2003).

In order to facilitate a common description of the supply chain, researchers have performed simulation-modeling efforts that utilize the SCOR model as the building block to define the model structure.

In their research, Barnett and Miller (2000) developed architectural components to implement a distributed supply chain-modeling tool based on e-SCOR. e-SCOR is a supply chain modeling tool developed by Gensym that is based on the SCOR model.

Pundoor (2002) and Herrmann, Lin and Pundoor (2003) developed a supply chain simulation framework that follows the Supply Chain Operations Reference (SCOR) model. They use Rockwell Software's ARENA as the simulation engine. They developed sub models in ARENA that represent the processes within SCOR. "The SCOR framework provides a basis for defining the level of detail in a way as to include as many features as possible, while not making them industry specific" (Herrmann et al., 2003). The paper describes the implementation of the simulation models and how the sub models interact during execution.

Automatic Generation of Simulation Models

Simulation modeling is a versatile and powerful tool that has grown in popularity due to its ability to deal with complicated models of corresponding complicated system (Kelton, Sadowski, & Sadowski, 2002; Wartha et al., 2002). Nevertheless, simulation models can be time consuming to build, requiring substantial development time, effort and experience. According to Mackulak, Lawrence & Colvin (1998), simulation development time takes about 45% of the total simulation project effort. Furthermore, simulation-modeling efforts often have to be modified to accommodate the development of what if scenarios and constantly changing requirements.

These modifications also take time to model. An alternative to creating a unique simulation model is to reuse an existing generic model that can be reconfigured for individual projects.

Mackulak et al (1998) define a generic model as a model that is applicable over some large set of systems, yet sufficiently accurate to distinguish between critical performance criteria. The model becomes specific when the data for a particular system is loaded. "Their primary advantages are that they eliminate major portions of the upfront model design process, they are bug free, they have been code optimized for fast run times, and they can be consistently applied throughout the corporation" (Mackulak & Lawrence, 1998). In their research, Mackulak et al (1998) state that there exists a need for generic/reusable models that are properly structured to provide sufficient accuracy and computer assistance. In order to respond to this need and to evaluate the advantages of generic simulation models in terms of design turnaround time, they created a model of an automated material handling system. In their study, they demonstrate that a generic model can be constructed to meet the needs of reuse for a situation with a reasonably small set of unique components and that when properly constructed a special purpose reusable model can be more accurate and efficient than new models individually constructed for each application scenario. Simulation reusability resulted in an order of magnitude improvement in design project turnaround time with model building and analysis time being reduced from over six weeks to less than one week.

GEM-FLO is a generic modeling environment developed by Productivity Apex, Inc and designed to aid in the rapid development of simulation models that can predict the operational characteristics of future space transportation systems during the entire project lifecycle. GEM-FLO was developed using Visual Basic and Rockwell Software ARENA simulation language.

GEM-FLO accepts any reusable launch vehicle design characteristics and operational inputs (such as processing times, event probabilities, required resources, and transportation times) and automatically generates a simulation model of the system. Once the simulation model is executed, it will provide multiple measures of performance including operations turnaround time, expected flight rate, and resource utilizations, thus enabling users to assess multiple future vehicle designs using the same generic tool (Steele et al., 2002).

Nasereddin, Mullens and Cope (2002), developed a generic simulation model for the modular housing manufacturing industry. The model involves the use of Excel spreadsheets/Visual Basic capabilities for data input and post processing report generation. Following user specification of system specific details, such as processes and process cycle times, ProModel code is automatically generated using Visual Basic. Nasereddin et al (2002), found that with the use of generic simulation, a significant reduction in model design and model maintenance times can be achieved. Moreover, models can be rapidly modified to reflect different possible scenarios changes. In addition, an improvement in knowledge transfer was also achieved, since modelers can now decrease the time required to get proficient in modeling using the generic simulation.

Brown and Powers (2000) generated a generic maintenance simulation model design to support a model of Air Force Wing operations and the maintenance functions associated with them. The model was also designed to be generic enough to be used in military applications as well as the commercial world. The simulation tool used was Arena by Rockwell Software and Excel/VBA for model input/output data. In addition, a Visual Basic Input Form also feeds into the model providing additional values (specified by the user) that control the timing of simulation events and the length of the simulation run. As some of the lessons learned, they found that the generic nature of the model required large quantities of input leading to a substantial amount of time consumed in setting up the model and manipulating the data.

Generic simulation models can be complicated to design and set up in order to obtain a truly generic simulation model. Furthermore, they may require great amounts of user inputs and knowledge on the specific simulation platform. Automatic discrete event model generation facilitates the development of a valid simulation model strictly from operational information, without the need for the user to build the model. The need from user inputs can be minimized through the combined used of technologies such as ontologies, artificial intelligence and computing.

Automatic generation of simulation models involves the development of the structure and parameters of a simulation model automatically. In 1994, Morgan (1994) developed an automatic DES model using Visual Basic and QUEST. In his study, Morgan (1994) uses Microsoft Visual Basic as the model generation engine and the integrated graphical user interface. Through this interface users maintained process, products, and production data in external data files (Microsoft Excel spreadsheet). After following an iterative process, the system reads the data files and a library of QUEST models. A QUEST simulation model is then generated of a reconfigurable production facility that meets production requirements. In order to develop this automated model, they required an open system to allow for external (non-interactive) manipulation of the model. This requirement was met by QUEST, a commercial off the shelf discrete event simulation engine. A genetic algorithm was used to discover the heuristic rules required to generate a schedule that maximized profit based on revenue on products sold and a variety of costs.

Son, Jones, and Wysk (2000), expressed the difficulty of building, running, and analyzing simulation models due to the dramatically different simulation analysis tools capabilities and characteristics. To address the model building issue, researchers at the National Institute of Standards and Technology (NIST) proposed the development of neutral libraries of simulation components and model templates. The library of simulation objects became a basic building block to model systems of interest. Then a translator generated a simulation model for a specific commercial package from the neutral descriptions of the components. In this paper, the authors present the use of the neutral libraries to generate a model in ProModel. The library of objects consists of header information, experiment information, shop floor information, product process information, production information and output information. The information objects were developed using EXPRESS. These objects are then used to generate a collection of database tables in MS Access. The model builder or translator, implemented in Visual Basic, then builds the platform specific model (in this case ProModel).

Arief and Speirs (2000; 2004; Wartha et al., 2002) identified simulation components that are applicable to many simulation scenarios along with the actions that can be performed by them. Based on these components, they developed a simulation framework called Simulation modeling Language (SimML) to bring the transformation from the design to a simulation program. A UML tool that supports this framework was constructed in Java using the JCF/Swing package. The simulation programs are generated in JAVA using JavaSim. XML is used for storing the design and the simulation data. XML was used because of its ease of manipulation and its ability to store information in a structured format by defining a Document Type Definition (DTD).

In their research Bruschi, Santana, Santana and Aiza (2004), present a tool developed to automatically generate distributed simulation environments. They named their tool, ASDA, an automatic distributed simulation environment. In their research they state that "the automatic word can be understood in three different ways: the environment automatically generates a distributed simulation program code; the environment can automatically choose one distributed simulation approach; and the environment can automatically convert a sequential simulation program into a distributed simulation program using the MRIP (Multiple Replication in Parallel) approach"(Chatfield, 2001). In their research they developed a user interface, a code generator, a replication and a software interface module. The user interface module was developed in Java. The Replication module implements communication and analysis functions.

The Software Interface Module defines an interface between the developed simulation program and the replication module.

In his PhD dissertation, Dean C. Chatfield (2001), addressed the difficulty of creating simulation models of supply chain systems due to the need for the modeler to describe the logic of the component processes within the simulation language in order to represent the various parts of the supply-chain (such as warehousing, manufacturing, and transportation). "This is required because the processes and actions that occur in a supply-chain are not standard, built-in events of the simulation languages offered by the major vendors. As a result, the user must create the supply-chain event procedures. Unfortunately, this work is specific to the specific supply-chain being modeled. If the modeler wishes to develop a simulation model for a different supply-chain, most of the work will have to be performed again" (Chatfield, 2001). As part of his research, Chatfield (2001), develop the Supply Chain Modeling Language (SCML) to address the information sharing difficulties affecting supply-chain researchers and practitioners. SCML is a platform-independent, methodology-independent, XML-based markup language that provides a generic framework for storing supply-chain structural and managerial information. In addition, a Visual Supply Chain Editor (VSCE) was developed as a dedicated SCML editor. This allows users to create SCML-formatted supply-chain descriptions without directly editing any SCML markup. Additionally, a Simulator for Integrated Supply Chain Operations (SISCO) was developed as part of his research to address supply chain modeling difficulties. SISCO is a GUI based, Object Oriented, Java-based tool combining visual model construction, integrated SCML compatibility for easy information sharing, and future Internet capabilities. Chatfield's research addresses the three characteristics of a supply chain system (Stochastic, Dynamism and Distributed). As part of his research, Chatfield uses SISCO to analyze the bullwhip effect and demonstrates the benefits of his methodology (a visual supply-chain simulation tool coupled with an information-sharing standard).

Validation of Simulation Models

Model Validation is defined as the "substantiation that a computerized model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model" (Schlesinger et al. 1979). In his paper, Sargent (1998) discusses model validation, different techniques of validating simulation models and how model validation relates to the model development process. "A model should be developed for a specific purpose (or application) and its validity determined with respect to that purpose. If the purpose of a model is to answer a variety of questions, the validity of the model needs to be determined with respect to each question" (Sargent, 1998). Model validity is acquired when the accuracy of a set of experimental conditions is within an acceptable range. In his paper, Sargent (1998) specifies, that before a model can be validated the model's output variables of interest must be identified along with their required amount of accuracy. He also states that it is time consuming and costly to deem a model absolutely valid over an entire domain, therefore, test and evaluations are conducted until sufficient confidence is obtained that a model can be considered valid for its intended application. In his paper, he also discusses the following validation techniques (Sargent, 1998):

- Animation
- Comparison to Other Models: Comparing the results of the model in question to the results of other valid models
- Degenerate Tests: The degeneracy of the model's behavior is tested by appropriate selection of values of the input and internal parameters.
- Event Validity: The simulation events are compared to the events of the real system
- Extreme Condition Tests: The model structure and output should be reasonable when tested with extreme and unlikely combinations of factors
- Face Validity: Obtaining approval from Subject Matter Experts regarding the behavior of the model
- Fixed Values: Using fixed values as inputs to check the model results against calculated values

- Historical Data Validation: Using part of the collected historical data to build the model and the reminder to test the whether the model behaves as the system does.
- Internal Validity: Several replications of the model are run to determine the amount of variability. If variability is high this might indicate a problem with the model's validity.
- Multistage Validation: Consists of (1) developing the model's assumptions on theory, observations, general knowledge, and function, (2) validating the model's assumptions where possible by empirically testing them, and (3) comparing (testing) the input-output relationships of the model to the real system.
- Operational Graphics: The values of performance measures are displayed graphically as the model runs.
- Parameter Variability: Performing Sensitivity Analysis. Those parameters that are sensitive should be made sufficiently accurate prior to using the model.
- Predictive Validation: The model is used to forecast the system behavior, and then the system's behavior is compared to the model's behavior.
- Traces: The behavior of different entities in the model is traced to determine if the model's logic is correct and if the necessary accuracy is obtained.
- Turing Tests: People who are knowledgeable about the operations of a system are asked if they can discriminate between system and model outputs.

Saregent (1998) distinguishes between the different steps that make up a simulation study and the validation steps that may be observed within the different steps. For each steps he gives the following recommendations for validation tests:

- Data validity: Develop good procedures for collecting and maintaining data, test the collected data using techniques such as internal consistency checks, and screen for outliers and determine if they are correct.
- Conceptual model validation: Use Face Validation test and Traces
- Operational validity: Use any of the tests listed above.

Kleijnen (1999) discusses the different statistical techniques for validation of simulation models depending on the amount of available data. In his paper, he covers three situations: no real data, only real output data and both real input and real output data.

In their paper, Nayani and Mollaghasemi (1998) discuss the application of formal validation for a semiconductor manufacturing simulation model. In their paper they discuss the different techniques (Turing tests, extreme condition tests, face validity test, etc.) that were used to ensure operational validity of their simulation model.

When considering, generic simulation model the literature has some mention of the procedures used to validate these models. Steele, Mollaghasemi, Rabadi and Cates discuss the validation procedures that were followed to validate GEM-FLO, a generic environment for modeling future launch operations. A measure of validation used was to take the data from a previous simulation model of Space Shuttle processing and use it as input to GEM FLO. However, in their paper they state that when comparing specific models to generic models, generic models are much harder to validate due a higher degree of abstraction.

In their paper, Mackulak, Lawrence and Colvin (1998) discuss the validation of generic models and stress the importance of validation in generic models since these models are reused and if they have been incorrectly validated the error will be amplified through reuse. In their study they validated their generic model of material handling systems by assuring that the model performs identically to the control logic of an actual material handling system. They compare model output to actual implementations to ensure that the model outputs identically mimic the real system.

Pidd (2002) discuss validation with model reusability. In his paper, Pidd states that simulation models should only be reused for the same purpose for which they were originally constructed to remain valid for that domain. "This is possible when a model is used on a routine basis to support tactical decision making within known and defined limits. It is not possible to be sure that reuse is valid when a model is used for a purpose different form that for which it is built or is used in combination with other models that might be based on different sets of assumptions" (Pidd, 2002). If the reusable model is to be reused for a different purpose, then it must pass additional validation tests that would make the model credible in its new use. "Proper credibility assessment does not come free and its cost must be built into any estimates of the value of model reuse" (Pidd, 2002).

In their research, Malak and Paredis (2004) developed a conceptual framework for validating reusable behavioral models. Their framework addressed the challenges associated with collaboration among specialist during validation in engineering design. Their framework decomposes validation into three processes: validity characterization, compatibility assessment and adequacy assessment. This allows validation knowledge to be acquired, transferred and used efficiently and enables effective validation of reusable behavioral models.

The literature does not address validation of automatic generated simulation models.

Simulation Modeling Ontologies

"Ontologies provide a way to establish common vocabularies and capture knowledge for organizing the domain with a community wide agreement or with the context of agreement between leading domain experts. They can be used to deliver significantly improved search and browsing, integration of heterogeneous information sources, and improved analytics and knowledge discovery capabilities"(Miller, Baramidze, Sheth, & Fishwick, 2004). Ontologies provide explicit semantics. This allows software to perform more sophisticated interpretations of data.

In their paper, the researchers discuss the characteristic that an ontology for a specific domain should possess. They state that unlike schemas or data models, which are application or data access oriented, ontologies define a domain to be shared and used by many. "In a way, it provides semantics by agreement. Most useful ontologies are therefore created by expert groups" (Lacy & Gerber, 2004).

The focus of their paper is to address the creation of ontologies for specific domains as a contribution of the semantic web. They overview OWL (Web Ontology Language), they briefly describe prior taxonomy efforts in modeling and simulation and they discuss the use and development of ontologies for modeling and simulation. In their research, they present strategies and issues that came up as they developed a prototype simulation ontology called DeMO.

The Web Ontology Language is an ontology/knowledge modeling language. OWL was developed to address the need to have a more decidable language to be more appropriate for the Semantic Web since limiting the languages expressivity will improve its computability/tractability. The Web Ontology Language (OWL) was designed with a limited expressivity to improve its computability/tracability. "OWL overcomes the weaknesses associated with XML-only approaches by defining standard methods for representing classes, properties, and individuals. It provides a consistent XML syntax using the Resource Description

Framework (RDF) and predefined constructs with standard semantics" (Miller et al., 2004).

OWL comes in three flavors: OWL Lite, OWL DL and OWL Full. OWL Lite and OWL DL are decidable. However, some simple expressions are beyond the capabilities of OWL. To address this gap, the Semantic Web Rule Language (SWRL) is being proposed. By combining OWL with SWRL, a semi-decidable language can be achieved. The researchers recommend that complex ontologies suitable for modeling and simulation will need the capabilities of OWL+SWRL (Fishwick & Miller, 2004).

For the prototype simulation ontology (DeMO), the authors represented the ontology using OWL DL and developed it using Protoge 2000. Protoge is an ontology-editing tool.

In a similar paper, Fishwick and Miller (2004) describe the use of ontologies in two projects at the University of Florida and at the University of Georgia. At the University of Florida, a project called "RUBE" uses ontologies for schema definitions, XML files for model types and model files, and an OWL representation of a sample air reconnaissance scene. In RUBE users build a scene to be simulated and then build a dynamic model of the scene. The dynamic models are translated into MXL and a model is generated from these files.

At the University of Georgia, work is currently undergoing to extend DeMO.

Similar DeMO efforts are ongoing in modeling and simulation. For example, the Simulation Reference Markup Language (SRML) (Reichenthal, 2002) and the Extensible

Modeling and Simulation Framework (XMSF) (Brutzman, 2004). SRML defines tags/elements such as Script, Link, Item, EventClass, EventSink and Simulation. SRML provides DTD and XSD schemas.

In his paper, Lacy (2004) emphasizes the impact of ontologies in simulation modeling. In this paper, he states that when a simulation is designed using a web-based application: "Software agents could scour the web for available web services to compose a simulation model. Domain descriptions and parametric data could be harvested from authoritative sources to support the composed simulation. An existing scenario could be found that could be tailored to meet the requirements. All of these activities are possible if simulation web services are described and information is represented using Semantic Web technology" (Lacy & Gerber, 2004).

Lacy (2004) discussed modeling and simulation challenges that can be addressed with the semantic web (like sharing data and scenarios). He also discusses the strength and weakness of using OWL to represent M&S ontologies. He states the strength of OWL as its object oriented facets, web readiness, open vendor policy, etc. However, OWL may not be efficiently applied in real time applications due to OWL performance issues.

In his PhD Dissertation Lacy (2006) developed a Discrete Event Simulation Ontology using OWL. The ontology facilitates open interchange of models without attachment to vendor specific software. In his research, he also developed a translator to translate models developed in Arena, Process Model, ProModel and AnyLogic to OWL and vice versa.

Literature Review Conclusions

The literature is rich with research and development efforts that use modeling to aid decision makers in supply chain systems. These efforts address certain aspects of supply chain environments (stochastic, distributed and dynamic system) independently or a combination of these. However, no effort currently exists that addresses all of these aspects comprehensively. Modeling tools are common (Gan et al., 2000; Sudra et al., 2000); tools like the Supply Chain Guru, IBM Supply Chain Simulator, DESSCOM, ONE, EasySC, Supply Chain DST-SC, CSCAT and SimFlex allow users to design simulation scenarios for supply chains. Some of these tools address the distributed nature of supply chains by incorporating a distributed methodology by using HLA or tools like GRID. However, these tools require an extensive upfront effort since the analyst will need to define the system from scratch without a structured supply chain (and supply chain modeling) definition methodology that is common and accepted by the diverse partners of the supply chain. Furthermore, during the design process, supply chain partners are not encouraged to collaborate during the model definition since most of these tools do not support data sharing through the use of XML or OWL. In addition, when defining the level of detail of simulation models these tools don't always provide analyst with a flexible environment to model their supply chain systems at varying levels of details. Currently, the research conducted by Chatfield (2001) provides the most comprehensive methodology to address these supply chain-modeling needs. However, the following shortcomings were encountered when desiring to develop a truly stochastic, distributed and dynamic supply chain environment:

- SCML may be hard to implement as a common, industry wide standard, since it is not based on any of the current supply chain standards, such as the SCOR model. Supply

Chain partners may object to providing information regarding their processes since this would require a major effort on their part.

- The methodology proposed may requires a massive upfront effort, to define the supply chain in terms of its processes, information, performance measures, objects and interactions. Therefore, users would define the structure of the model (i.e. supply chain definition), supply chain parameter data (i.e. resources, time, inventory policy, etc.) and simulation parameters.
- The methodology implemented does not account for variable levels of fidelity across the multiple supply chain partners. Users cannot model supply chain partners at varying levels of detail. In general, users cannot define the sub-processes within a process and choose to simulate at the sub-process level or at the aggregate, parent level.
- XML does not provide enough flexibility to contain the knowledge required to define the supply chain at varying levels of detail. XML documents carry some semantics (through the use of meaningful tags); xml alone does not provide enough semantics to achieve the goals of discovery interoperability, integration and reuse.

This research will address these shortcomings by developing an integrated methodology that will allow supply chain decision makers to analyze the performance of their supply chain in a fast, sharable and easy to use format. The tool will allow users to define a supply chain simulation model using SCOR based ontologies. The ontology will include supply chain knowledge (supply chain elements, functional units, processes, information, etc) and the knowledge required to build a simulation model of the supply chain system. The simulation model will then be generated automatically from the ontology to provide the flexibility to model at various levels of details changing the model structure on the fly.

CHAPTER THREE: METHODOLOGY

Based on the conclusions obtained after conducting the literature review presented in Chapter 2, the following research opportunities can be observed:

- *Development of an enhanced supply chain simulation ontology*: The ontology will define the supply chain in a thorough and explicit way that will allow for the development of simulation models by capturing the processes, process characteristics (times, units, etc), resources, information/information flow, materials/materials flow, objects/objects flow, resources, interdependencies, networks, multi-tier processes, functional units, and all their complex interactions. Specifically, the ontology will be used to define the structure of the simulation model. The knowledge within the ontology will be used to define the simulation processes logic, decision logic, routing, resource allocation, entity definitions and interactions such as: process with process, process with resource, entity with process and entity with entity.
- *Development of a simulation modeling methodolog*y: The simulation modeling methodology will accommodate the characteristics present in supply chain environments; namely stochastic, dynamic, and distributed environments; to allow supply chain decision makers to make informed decisions in a fast, sharable and easy to use format. The modeling methodology will be flexible, scalable and expandable to allow for modeling systems in diverse fields at varying levels of fidelity.

- *Development of an automatic generator*: The automatic generator will serve as a link between the supply chain simulation ontology and the modeling engine. The automatic generator's main objectives are to parse the ontology knowledge to automatically generate a simulation model of the system of interest and to populate the simulation model with the required instances of data that will drive the simulation scenarios. Furthermore, the automatic generator will allow for the storing of ontology and scenario files in a sharable, platform independent format.

In order to ensure that the developed methodology will allow supply chain decision makers to support informed decision making in a fast, shareable and easy to use format, the methodology will be evaluated against the following criteria:

- Realism: The methodology should allow for modeling supply chain systems with the highest degree of realism. Uncertainty is extremely critical in a supply chain environment due to the integrated nature of supply chains. Since supply chains are composed of different elements (i.e. suppliers, supplier's supplier, customer, etc) integrated and interrelated, each element's uncertainty interacts with one another greatly affecting supply chain activities. A realistic modeling methodology should account for this uncertainty. Simulation modeling is a perfect candidate to model a stochastic system such as this one. "Simulation models provide an added level of realism over deterministic models by accounting for the natural variations that occur in the various processes within the supply-chain" (Chatfield, 2001). In addition, a methodology with a high degree of realism allows for modeling entire supply chain systems including their entire processes, interactions, information flow, object and material flow for the different supply chain partners. “Simulation modeling provides added realism over other stochastic modeling methods since they generally restrict modelers to small systems because such models quickly become mathematically intractable. By allowing larger systems to be analyzed, simulation models afford a greater degree of realism” (Chatfield, 2001). Therefore, this research should address the following research question: How well does the developed methodology produce realistic models that address uncertainty and allow for modeling entire supply chains?

- Usefulness: The methodology should be useful to decision makers by providing a means to analyze the entire supply chain under different conditions. The methodology will allow for the development of different scenarios that examine the behavior of the system by monitoring certain performance measures. One such scenario would be to describe the “status quo” or study the system “as is”. Following, decision makers might wish to implement new initiatives and observe how these changes affect the “to be” system. “The utility of simulation models is derived from their ability to describe the performance of a system under various conditions or scenarios. The ability to evaluate a supply-chain under many conditions, such as "best case," "worst case," or other environmental situations is generally not possible with deterministic modeling, but is a common use of simulation models (Chatfield, 2001). Therefore, this research should address the following research question: How well does the developed methodology produce useful models that can aid decision making under different conditions or scenarios?
- Flexibility: Due to the high degree of dynamism present at all levels of supply chain environments, the methodology will be flexible to allow for change. The methodology

will allow for changing model parameters fast and easily to facilitate the decision making process and allow decision makers the opportunity to make informed decision when the need arises not being delayed by a lengthy modeling process. Enterprises are usually not willing to wait for lengthy analyses, since the opportunity to influence the system with respect to the operational impacts on a particular decision is eliminated if the analysis becomes too lengthy (Steele et al., 2002). Therefore, this research should address the following research question: How flexible is the developed methodology to produce models in short time frames with minimal effort?

- Scalability: Supply chains are distributed systems with multiple partners; the methodology should be scalable to allow for dynamically changing the scope and the level of detail within the model. This provides decision makers with the ability to analyze the entire supply chain or different sub models focusing on specific or a combination of functional units. Therefore, this research should address the following research question: How scalable is the developed methodology to produce models at varying levels of detail?
- Extensibility: Similarly, due to the variety of problems that can be addressed in supply chain environments (i.e. strategic and tactical decision making like supply chain design and analyzing/implementing inventory strategies; operational decision making like safety stock and inventory quantities, etc..) the methodology will be extensible to address different problems with minimal change in the methodology. Furthermore, the modeling methodology will allow for the addition of new processes as supply chain environments evolve (i.e. transportation and training process). Therefore, this research should address

the following research question: How extensive is the developed methodology to produce models that can aid varying decision making for supply chain systems?

- Adoptability: Like any methodology, the methodology will be easily adopted by practitioners to encourage it use. This is achieved by a methodology that is easily understood, simple to implement/maintain and can lend itself to provide results fast. Furthermore, the methodology will be more easily adopted if the users are familiar with the methodology and can communicate the results easily to other stake holders. Therefore, this research should address the following research question: How adaptable is the developed methodology to produce models that are easy to understand, implement and maintain?

In order to evaluate the methodology, a series of scenarios will be developed using the methodology. The scenarios developed were designed to address the shortcomings in Supply Chain Modeling (Banks, 2002) and to demonstrate the ability of the methodology to provide models that follow the criteria above. ABC Supermarket Supermarket's Supply Chain will be used as a Case Study to develop the following scenarios:

- Scenario A: Add a Warehouse or Distribution Center
- Scenario B: Vary Demand, Add/Remove Customer
- Scenario C: Modify Supplier to include more detail
- Scenario D: Adding a new supplier.
- Scenario E: Vary Inventory strategy

Table 3 presents the various shortcomings identified by Banks (2002) and which scenario addresses the shortcomings.

Table 3: Scenarios vs. Shortcomings

Identified Shortcomings	Scenario				
	A	B	C	D	E
Identify the shortcomings and opportunities for redesign	x	x		x	x
Measure impact of changes in demand on supply chain components.		x			
Measure impact of new ways of setting up and operating a large supply chain.	x			x	x
Investigate the impact of eliminating an existing or adding a new infrastructure component to an existing supply chain.	x				
Investigate the impact of changing operational strategies within a supply chain					x
Investigate the impact of making in house, outsourcing, developing a new supply base and the combination of these.		x			
Investigate the impact of merging two supply chains or impact of separating a portion of the existing components of a supply chain.			x		
Investigate the relationships between suppliers and other critical components of a supply chain.			x	x	
Investigate the opportunities for postponement and standardization.					
Investigate the impact of current inventory strategies on the overall performance of a supply chain.					x

Table 4 presents the research questions and how each question relates to the evaluation criteria.

Table 4: Evaluation Questions

Questions	***Criteria***					
	Realism	***Usefulness***	***Flexibility***	***Scalability***	***Extensibility***	***Adoptability***
Does the resulting model take into account uncertainty?	x	x				x
Does the resulting model represents the entire supply chain including the supply chain processes, their interactions, information flow, object and material flow for the different supply chain partners?	x	x		x		
Is the resulting model easily and quickly modifiable to examine different conditions or scenarios?		x	x	x	x	x
Is the model easily reconfigurable to represent a "to be" state from an "as is" state?		x	x	x	x	x
Does the model allow for quickly varying parameters without requiring a lengthy modeling process?		x	x	x	x	x
Can models be easily developed that represent varying levels of detail? At Enterprise Level? At Functional Unit Level? At Facility Level?		x	x	x	x	x
Can the models developed address decision making for Supply Chain design?		x			x	x
Analyzing/Implementing Inventory Strategies? Effect of varying Safety Stock?		x	x		x	x
Can the models be easily shared to enhance communication among stake holders?		x				x

The models developed will also be compared against comparable models modified using a “traditional modeling approach” to determine the effect of scenario implementation on model definition and execution.

The Development Methodology

In order to develop a sound methodology that adheres to the criteria outlined above, a detailed research methodology must be defined. In the literature, there is a clear understanding of the steps required to complete a sound simulation study. Many authors (Banks, Hohn S. Carson, & Nelson, 1996; Hoover & Perry, 1990; Law & Kelton) have discussed these steps in detail. Figure 7 presents a comprehensive illustration of these steps. This simulation methodology will be used as a framework to define the research methodology used in this study. However, this methodology will be enhanced to accommodate for the criteria outlined above.

Defining the System

The first step in the traditional simulation methodology is a planning phase where the objectives, constraints, scope and level of details of the study are defined. The traditional simulation methodology, presented in Figure 7, assumes that there is an implicit definition of the system. However, if the methodology is going to be truly generic, this can not be assumed. Therefore, the proposed methodology has the system definition as its first step. The system definition involves the definition of the system in terms of its processes, material flow, information flow, and object flow. The output of a system definition is usually a conceptual diagram that dictates the structure of the system under study. However, a conceptual diagram as it is traditionally represented (i.e. flow charts) in simulation studies may not be sufficient when meeting the criteria above. A comprehensive and explicit definition is required to accommodate for a dynamically and flexible methodology such as this one. Therefore, a SCOR-based simulation ontology will be used to allow for the definition and planning of the system and to serve as the conceptual model from which simulation models may be automatically generated. The ontology will capture the processes, process characteristics (times, units, etc), information/information flow, materials/materials flow, objects/objects flow, resources, interdependencies, networks, multi-tier processes, functional units, and all their complex interactions. Once the system is defined in the ontology, a simulation model of the system can be developed. However, this simulation model will only hold the elements that define the structure of the model (i.e. process modules, resources, and routings). The content, or data, that will drive the model (i.e. resource capacities, times, etc…) still needs to be defined in the data collection phase.

The second phase in the proposed methodology is the planning phase. If the proposed methodology is to be truly generic, this step should be specific to individual studies. The ability of the methodology to accommodate varying values and levels of objectives, scope and detail will dictate the tool's scalability and extensibility. Model objectives are measured in terms of performance measures. Since simulation modeling is a descriptive tool, the result of a study that uses simulation as a methodology will be the value of a performance measure. Decision makers can then use these results to optimize the system as they see fit. The specification of performance measures will be done through the ontology since a comprehensive system definition usually includes the definition of performance measures (Fayez, 2005). However, this definition will provide a complete set of performance measures that apply to the system under study. It would be unfeasible and erroneous to include all performance measure of interest in a single simulation scenario analysis. Therefore, the use of a graphical user interface (GUI) that will allow the user to create different analysis scenarios ("as is" or "to be") based on the definition ontology is required. The GUI will take as input the system definition (ontology). Users can then plan the study using the GUI. Using the GUI the user will be able to define the following elements:

1. **Performance Measures:**

The SCOR based ontology developed by (Fayez, 2005) includes SCOR Model Performance Measures. The SCOR model categorizes the performance measures into five categories. These five categories are Reliability, Responsiveness, Flexibility, Cost, and Asset Management. These categories are defined as (SCC, 2003):

- Supply Chain Delivery Reliability (%): represents the delivery performance of the Supply Chain. The highest delivery will be achieved if the Supply Chain always delivers the right quantity of the right products or materials to the right destination, with the highest quality and packaging with the right documents.
- Supply Chain Responsiveness (Time Units): represents the speed of a Supply Chain to fulfill a customer's order.
- Supply Chain Flexibility (Time Units): represents the flexibility and agility of the Supply Chain to respond to any changes upstream or downstream.

- Supply Chain Costs (Currency Units): represents the costs of operating a Supply Chain.
- Supply Chain Assets Management Efficiency (Time Units or Number of Turns): represents the efficiency of managing the assets that support the Supply Chain, either fixed assets or working capital assets.

The SCOR model defines a set of Level One performance measures that allow quantitative and qualitative measurement of the categories defined above at a high level (see Figure 2). The Level 1 Metrics may cross multiple SCOR processes and do not necessarily relate to a SCOR Level 1 process.

Level 1 Metrics	Performance Attributes				
	Customer-Facing			Internal-Facing	
	Reliability	Responsiveness	Flexibility	Costs	Assets
Perfect Order Fulfillment	X				
Order Fulfillment Cycle Time		X			
Upside Supply Chain Flexibility			X		
Upside Supply Chain Adaptability			X		
Downside Supply Chain Adaptability			X		
Supply Chain Management Cost				X	
Cost of Goods Sold				X	
Cash-To-Cash Cycle Time					X
Return on Supply Chain Fixed Assets					X

Figure 2: SCOR Level One Metrics and Categories (SCC, 2003).

The simulation methodology will be designed to collect the metrics at a SCOR process Level Three. These measures will then be aggregated to Level One Performance Metrics. An example of how this will be achieved can be illustrated by considering Order Fulfillment Cycle Time. Order Fulfillment Cycle time is defined as “the average actual cycle time consistently achieved to fulfill customer orders. For each individual order, order fulfillment cycle time starts from the order receipt and ends with customer acceptance of the order" (SCC, 2003). This perfromance measure crosses multiple Level Three proceeses from source, make to deliver. Figure 3 presents the aggregation processes for Order fulfillment cycle time from Level two processes to Level One.

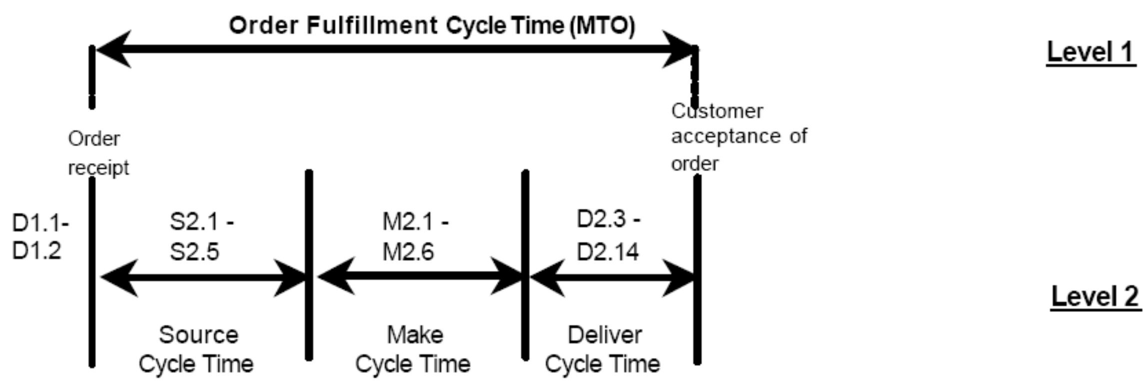


Figure 3: Aggregate Performance Measures from Performance Measures Level Two to Level One. (SCC, 2003)

The user will define the performance measures that apply to the system at Level One. Not all of the defined performance measures will be modeled, since some qualitative measures may not be accurately modeled. Furthermore, users may not wish to model all applicable performance measure in each analysis scenarios. The user will be able to select the performance measures of interest per analysis scenario.

2. **Scope of the Study:**

The scope of the study defines what functional units, processes, materials, objects, and/or information will be modeled. The user will be able to specify which of these elements will be included in the simulation scenario. When considering large systems, modeling the whole system is infeasible. Therefore, having the ability to limit the scope provides many advantages in terms of time and money.

3. <u>Level of Detail:</u>

The SCOR model based ontology, is based on a multiple level of detail definition (see Figure 4). When developing the SCOR model, the Supply Chain Council focused on three process levels with a generic Level 4 that should be defined using organization-specific processes, systems, and practice. Therefore, when defining a system using this ontology, users can define their system to a low level of detail (i.e. level 4). However, similar to varying the scope of a model, modeling a system to a very low level of detail may be unfeasible in some instances. The user will be able to define the level of detail for specific scenarios.

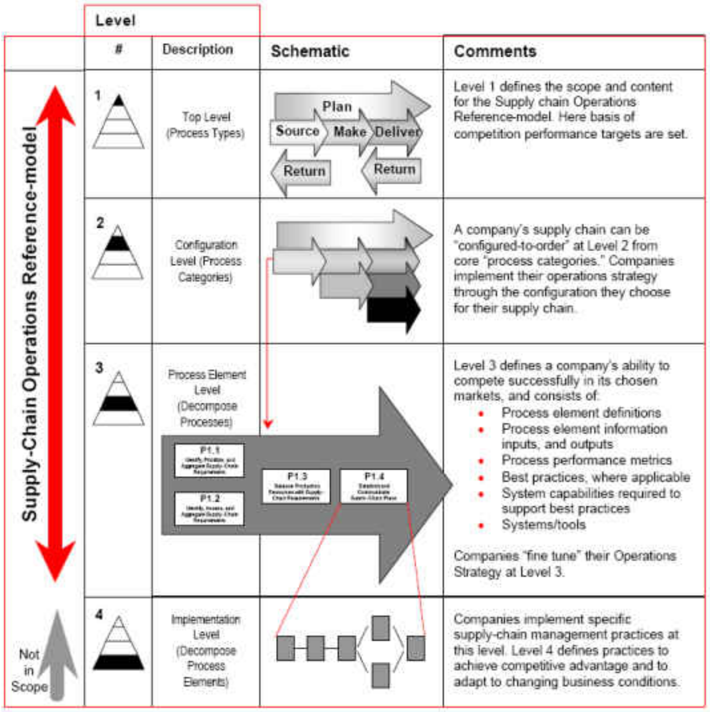


Figure 4: SCOR model Level of Detail (SCC, 2003) .

4. Data Definition (Content):

Since the SCOR based ontology provides a means by which the structure (conceptual model) of the system can be defined, there is still a need to define the content of the models. The content (or data) will be used to populate the core structure of the model with information such as resource capacities and times. The Graphical User Interface will allow the user to input the content by guiding the user through a series of questions.

Model Translation

The Model Translation Phase defined in a traditional simulation study involves the transformation of conceptual models into simulation language. This is usually done with the help of special purpose simulation software such as ARENA, AutoMod, WITNESS, ProModel, AnyLogic, etc. This transformation can be seen in Figure 5.

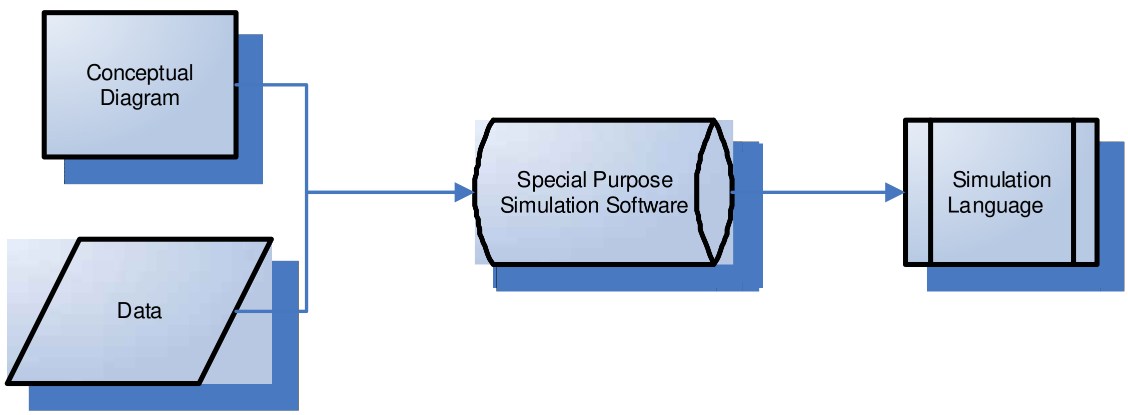


Figure 5: Traditional Model Translation

However, this translation does not allow for the automatic generation of simulation models (simulation language) from ontologies and user defined data. Therefore, the following translation is proposed (see Figure 6):

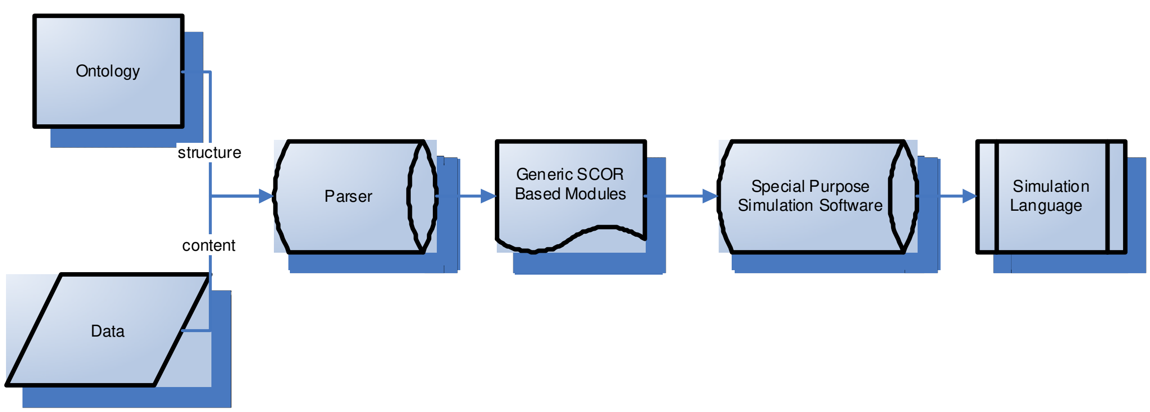


Figure 6: Proposed Methodology for Translation Phase

The conceptual model and data in a common format (xml and/or owl) will be inputted into a parser tool. The parser will transform this information into a format that is compatible with pre-defined SCOR based generic modules. The output of the parser will be a file containing the parsed data in a common format (xml). The file will then be used to automatically drop and populate pre-defined generic SCOR modules into a blank model. The module's content will also be populated using the same file. The modules will be pre-developed and compiled using special purpose simulation software which will then translate the model into simulation language.

Validation and Verification

From the literature review presented in Chapter 2, various authors address the validation of generic or reusable simulation models (Steele et al (2002), Mackulak et al (1998), Pidd (2002) and Malak (2004)). In their studies, they validated the generic models developed by generating scenarios and validating those scenarios using different validation techniques. These validation techniques should also apply in automatic generation of models if the methodology is used to generate models within the Supply Chain domain as defined using the SCOR (vs. 6.1) model. Furthermore, the development of simulation models automatically adds an additional level of abstraction (when compared to generic models) since the data and the flow of the simulation are changing simultaneously.

Due to the high degree of abstraction present in the development of automatic models, validation and verification will be achieved by focusing on the verification and validity of the methodology itself. This validation methodology has been successfully applied in the literature. The proposed methodology will be verified/validated by generating a series of scenarios (or models) and verifying/validating theses models using a variety of techniques such as degenerate tests, event validity, and fixed values. If the methodology is proven valid, valid simulation models will be created.

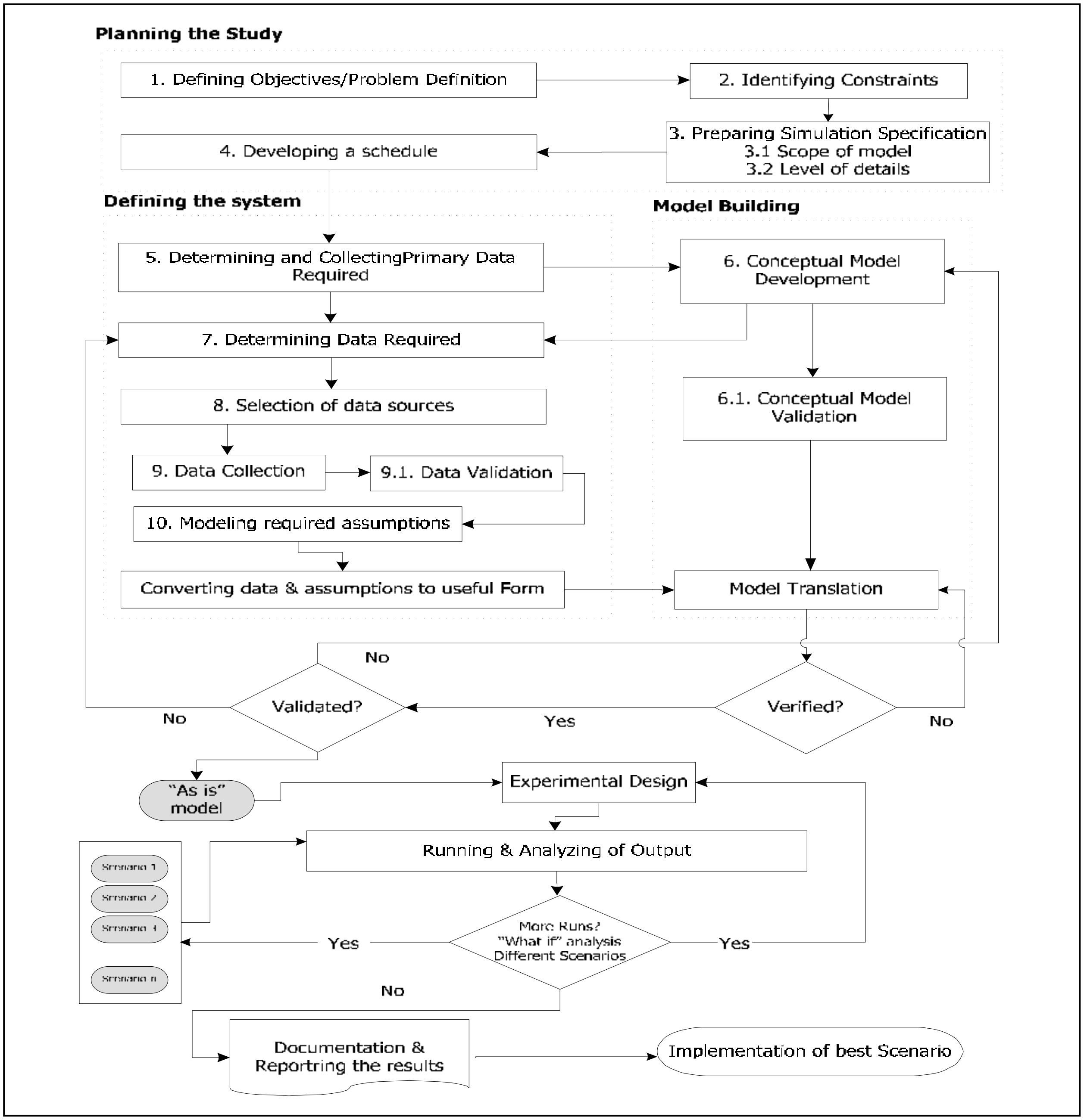


Figure 7: Modeling Methodology

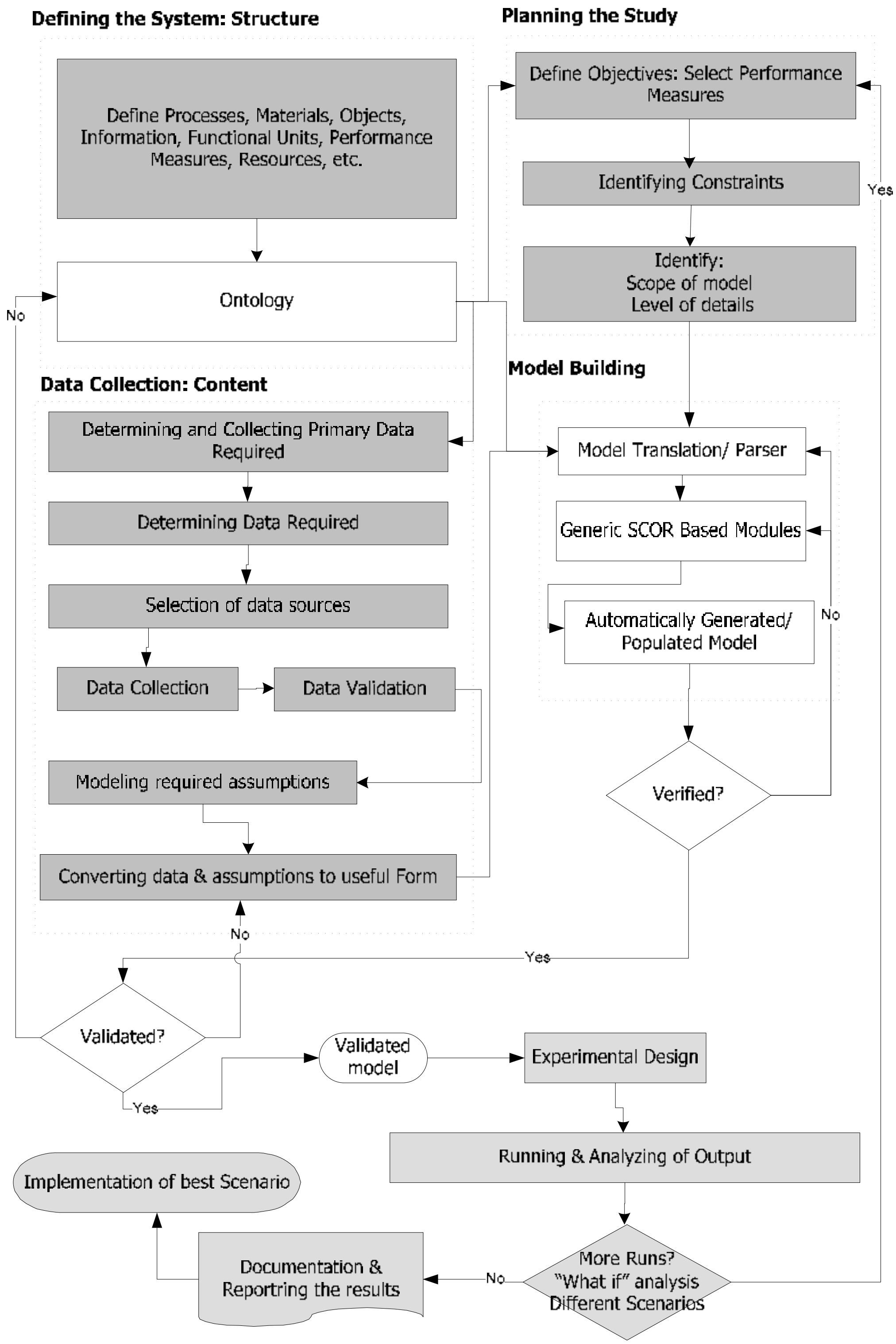


Figure 8: Proposed Simulation Methodology for Automatically Generated Models

Figure 8 presents the modified methodology. The grey shaded items indicate the user input and/or user processes. Figure 8 illustrates the three major areas of development:

1. Development of a Simulation Ontology
2. Development of a Simulation Methodology
3. Development of Automatic Generator

Development in these areas will be discussed in detail in the next chapter.

CHAPTER FOUR: IMPLEMENTATION

This Chapter describes the implementation of the research methodology (described in the previous chapter) into a prototype tool. The chapter discusses the development of the simulation ontology, the development of the simulation modeling methodology and finally the automatic generator. In addition, the chapter briefly describes the graphical user interface that will integrate these sections into a final usable tool. Figure 9 presents the prototype's architecture.

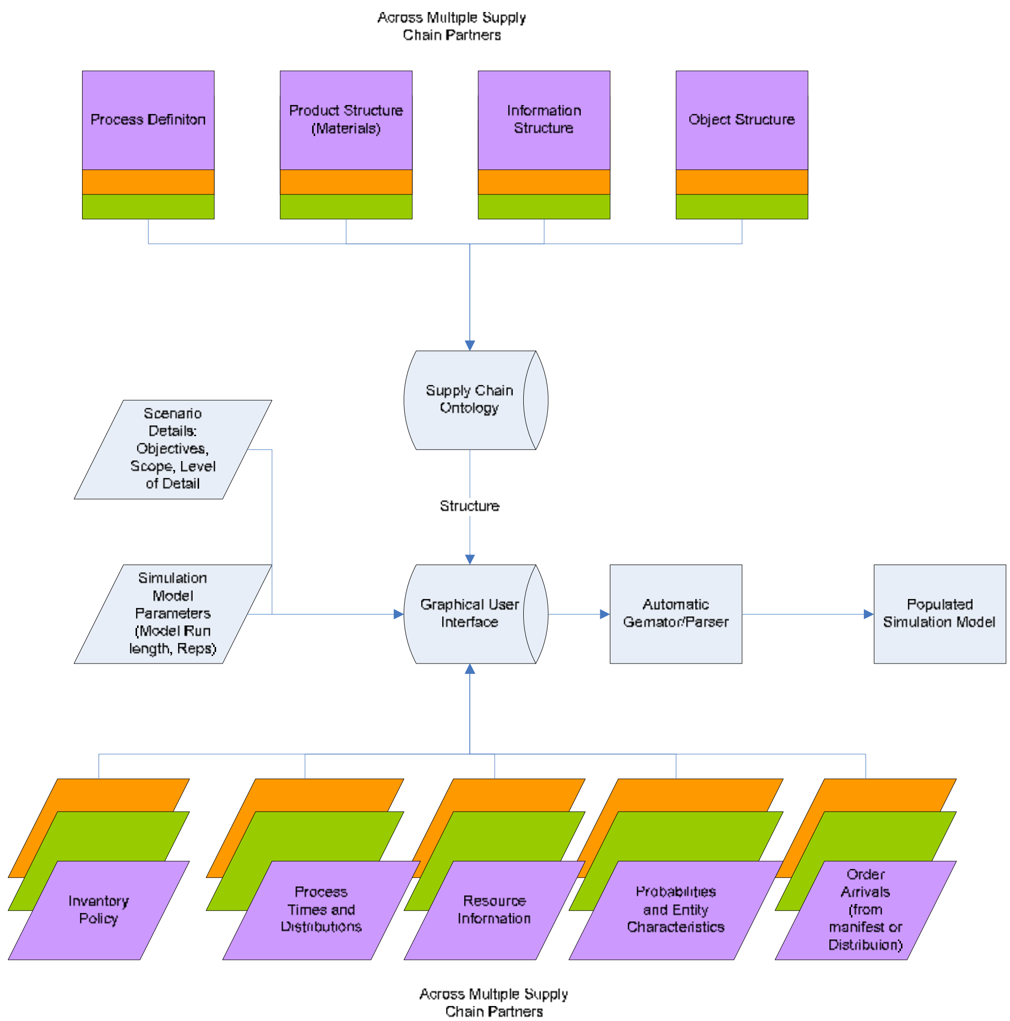


Figure 9: Architecture

Development of a Simulation Ontology

The purpose of the ontology is to hold the definition (the structure) of the supply chain system. According to Fayez (2005) the first and the most important step in modeling and analyzing a Supply Chain is to define the Supply Chain, not in an abstract way but in a way that will capture and define generically all the constituent parts. In his study, Fayez (2005) developed a methodology to define supply chain systems in a comprehensive, automated, customizable, extensible format. He used ontologies to represent the definition of the supply chain in a common and sharable format. To facilitate the distribution of the supply chain definitions across multiple supply chain partners, Fayez developed his methodology based on the SCOR model. The SCOR model is the most widely used tool for defining Supply Chains. In his research, he extended the SCOR model to include a more comprehensive definition of supply chains. This research will extend the work done by Fayez (2005) to include simulation-modeling constructs within the common definition of the supply chains.

The ontology was developed using OWL (Web Ontology Language) and XML (eXtensible Markup Language), as they are the semantic web standard languages. In order to include the simulation constructs within the Supply Chain Ontology already developed, the following required simulation construct classes were defined:

1. Resources: The Resource class defines the resources that will be seized and released to perform the processes. Each resource can be associated with a functional unit and with processes within a functional unit. The following fields were defined:
    a. Type of Resource: Specifies the type or resource as Human, Equipment, Facility, Inbound Transportation and Outbound Transportation.

b. Resources Available: Specifies the number of resources that are available for this type of resource.
c. Resources Required: Specifies the number of resources that are required to perform a task at a process level.
d. Direct or Indirect: Specifies the resource relationship with the material, information, or both.
e. Schedule: Specifies the schedule of the resource

2. Processing Duration: Specifies the processing duration at a process level of detail. The following fields were defined:
    a. Value: Specifies the value of the processing duration. Can take the value of a constant or distribution.
    b. Units: Specifies the time units for the processing duration.

The ontology will then be modified using a GUI that allows the user to create different session files to reflect the modified scenarios. The GUI will take as input the system definition (ontology) and the user provided input (outlined in Chapter 3) and output an xml session file that will later be used by the parser to generate a simulation model. The GUI will allow a user to:

1. Define a supply chain. This function will guide the user through populating the ontology framework developed by Fayez (2005) and modified in this research. The user will define:
    a. The Functional Units: Define the facilities to be included in the model for the focus company, suppliers, supplier's suppliers, customers, etc...

b. The Products: Define the physical material that will move through the system. Includes final products, raw materials, and components.
c. The Bill of Materials: Define the structure of the products defined above in terms of its components and subcomponents.
d. Functional Unit and Product Relationships: Define the transformation of sourced products into finished and delivered products by functional unit.
e. Sourcing Policy: Define the policies used to source the products defined above. Includes supplier determination and supplier lead time.
f. Inventory Policy: Define the policies used to inventory the products defined above. Includes specification of replenishment policies, reorder points and quantities.
g. Production Policy: Define the policies used to produce the products defined above. Includes specification of make policy and production lead time.
h. Delivery Policy: Define the policies used to deliver the products defined above to the customer. Includes specification of product destination and transportation mode used.
i. Return Policy: Define the policies used to return the products defined above. Includes specification of the return destination, transportation mode used and type of return.
j. Resources: Define the resources available at each functional unit.
k. Objects: Define the objects that (similarly to products) flow through the system.

l. Performance Measures: Define the performance measures that will be used to assess the supply chain performance. The performance measures will be used from the SCOR model.

The baseline session file will be generated by saving the defined supply chain in an XML file. A simulation model will then be generated based on the session file and the underlying supply chain defined contained in the session file.

2) Develop supply chain operational scenarios: The scenarios will be generated by modifying the baseline session file and the underlying defined supply chain. The scenario generation procedure includes opening the baseline session file, editing the file, and saving the file under a new file name. Simulation models can then be generated for the operational scenarios defined.
3) Run simulation experiments for the baseline and the scenarios developed. Performance Measures of interest will be selected before running the simulation experiments.
4) Generate output reports that will illustrate the simulation results in terms of the Performance Measures selected for the baseline and the selected operational scenarios.

Development of a Simulation Modeling Methodology

"An ideal supply-chain simulation tool is one that simplifies the process of describing the supply-chain and assists the actual simulation construction by providing reusable supply-chain-specific constructs to work with while still providing the flexibility of customization if so desired" (Chatfield, 2001). The simulation modeling tool developed is modular to allow for efficient reuse and flexibility while reducing the development time of the automatic models. The software consists of a series of modules defined using the SCOR model framework. Each of the modules defined can be directly traced to one of the SCOR model processes. Modules are defined up to a SCOR Level 3 (see Figure 4). The modules where developed using Arena 10.0 template development functionality. A total of 27 modules were developed to model the Source, Make, Deliver and Return processes for a make to order product at a Level 3 level of detail (see Figure 4). Figure 10 presents a screenshot of the developed modules.

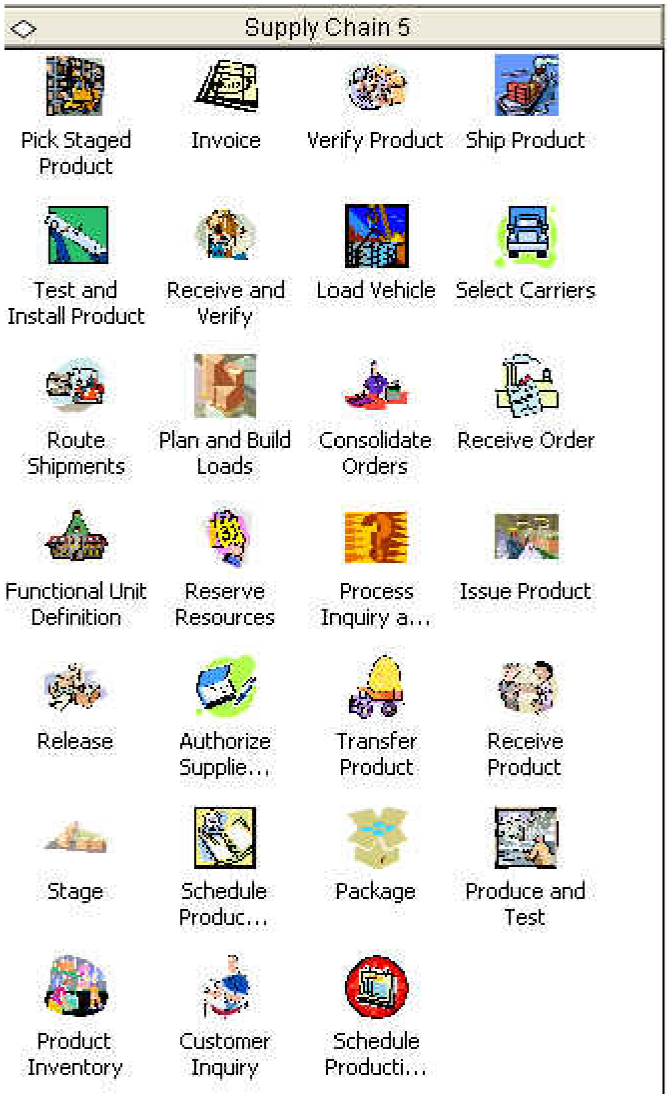


Figure 10: Supply Chain Modules

Each module was developed by first defining each process in a generic flow chart. The flow chart was then used to develop the logic and user inputs for each module. Each module was then compiled, encapsulating this logic and receiving as inputs the user inputs previously defined. Figure 11 presents the flow chart developed to create the Schedule Product Deliveries module.

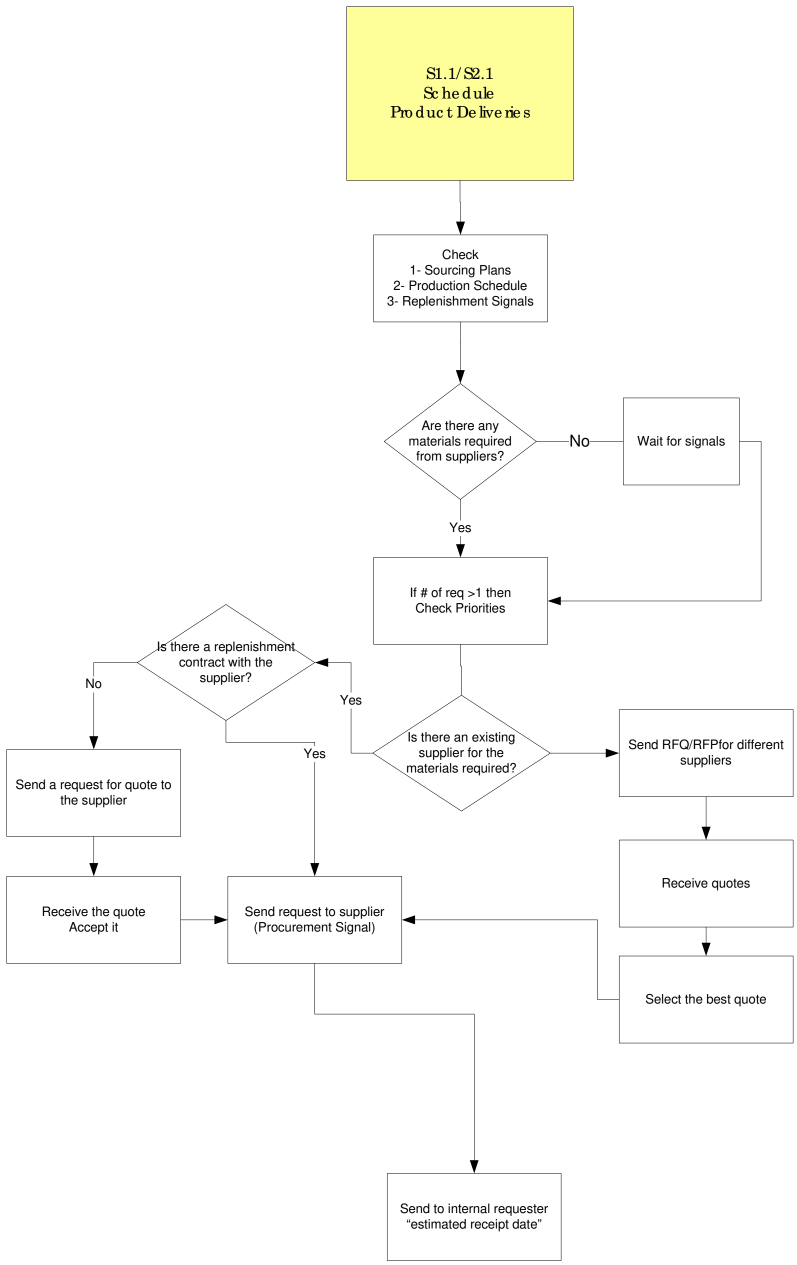


Figure 11: Flow chart developed to create the Schedule Product Deliveries Module

This flow chart was then used to develop the Schedule Deliveries module presented in Figure 12 and Figure 13. The module developed can then be "dragged and dropped" into a model as seen in Figure 12.

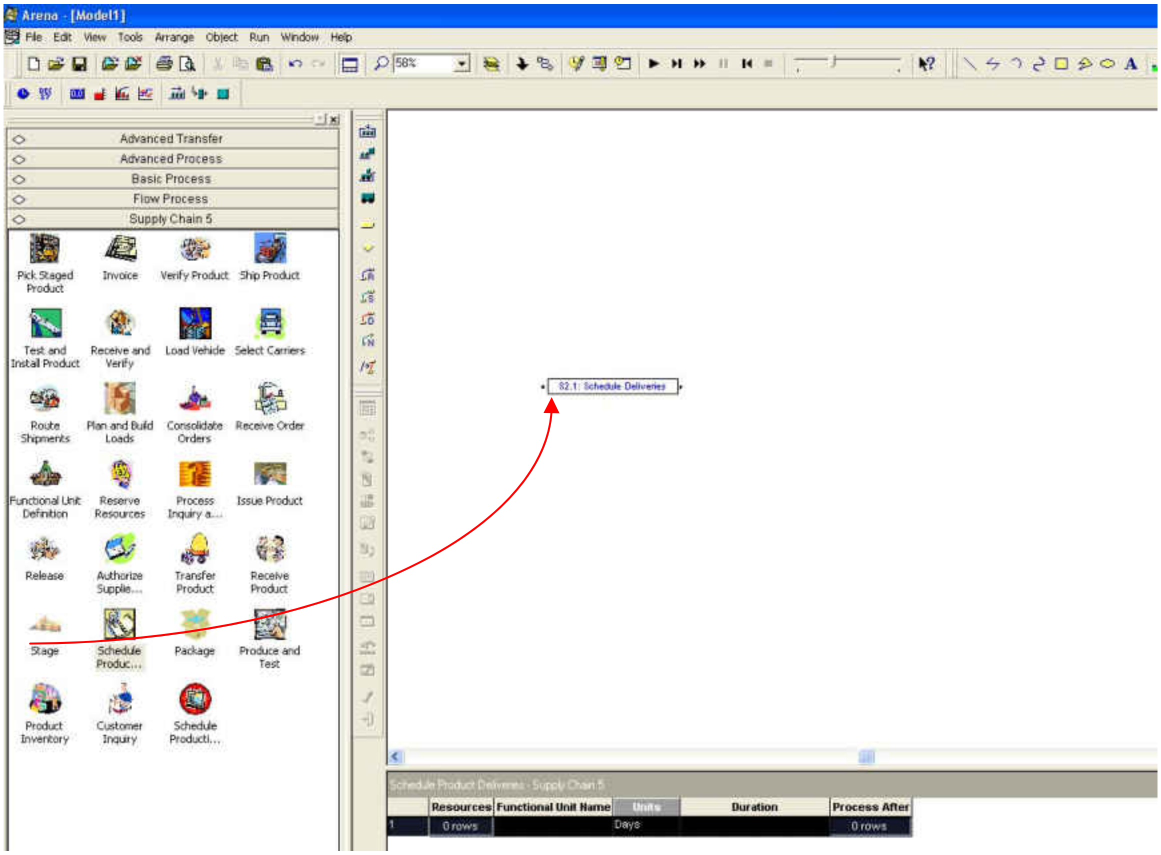


Figure 12: Drop of Schedule Product Delivery Module

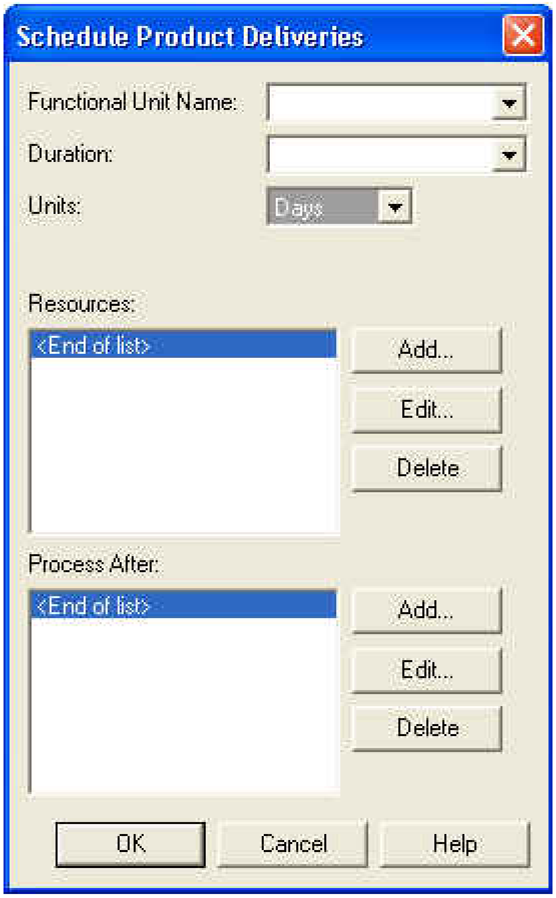


Figure 13: User Input Required for Schedule Product Delivery Module

Development of Automatic Generator

The Automatic model generator parses the conceptual (or structure) model (obtained from the Ontology) and the model logic, parameters and data (obtained from user input through the GUI) to obtain a fully executable simulation model of the scenario described by the user. The parser performs a series of XSLT transformations that provide as an output an xml file. The main objective of the XSLT transformation is to integrate and translate the Ontology and user input data into a common format. This common format is compatible with a set of pre-defined

Generic SCOR based modules developed in a stand alone Arena template. The xml file generated is then used to automatically generate the models.

The Graphical User Interface produces a scenario file in XML. The XML file follows a schema that allows for the definition of Supply Chain systems in an easy and user friendly manner. In order to generate models, this file has to be translated into a list of Arena Modules and parameters that can be easily dropped into blank Arena modules using VB routines. Therefore, the parser will obtain the initial XML file and transform it into a new XML file that follows the schema. This was achieved by developing two Transformation routines using XSLT. "XSLT is an XML application for specifying rules by which one XML document are transformed into another XML document" (Harold and Means, 2002).   An XSLT document contains template rules that are used to specify patterns. An XSLT processor uses these rules to parse an input XML document by comparing the elements and nodes to the template rule patters. When a match is made, the template is written to an output file (Harold and Means, 2002).

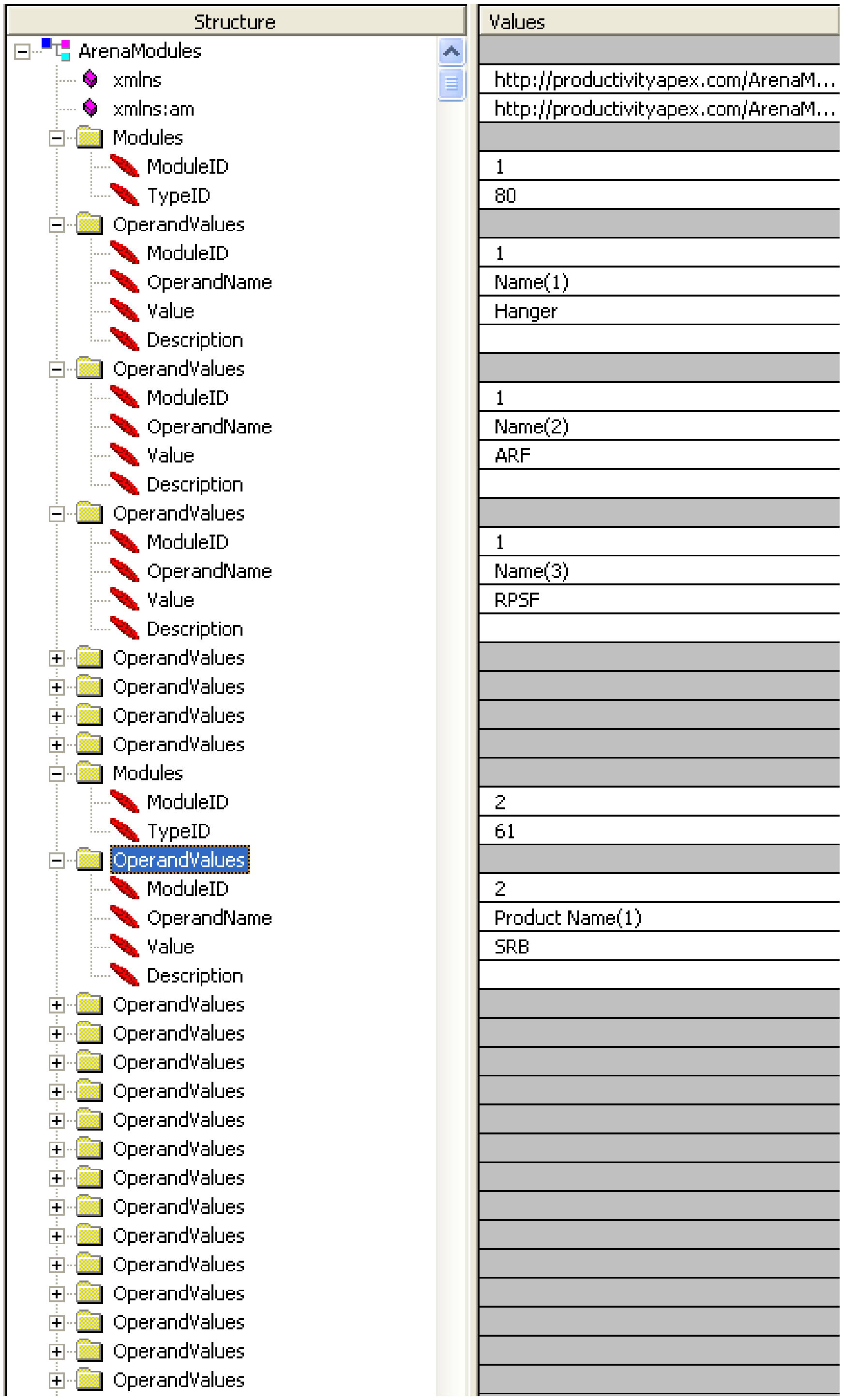


Figure 14: Output XML File

Figure 14 presents a sample Output XML file. The parser will then loop through each "Module" Instance in the Output XML file. Each module is uniquely identified by a "ModuleID" and a "TypeID". The TypeID refers back to "Definition" and "Operand" elements that contain the meaning of each module including what parameters are required per module instance. For each ModuleID defined, a series of "OperandValues" elements are also defined. Each contain an individual parameter value for the module and is uniquely traced to a module instance by a "ModuleID" entry.

A simple Arena Record module example is presented below:

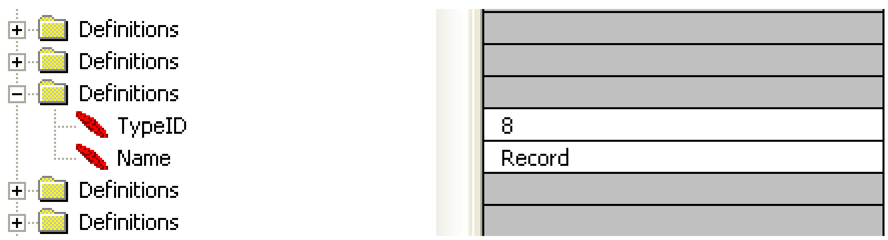


Figure 15: Module Definition

With the following Operand Values or Parameters:

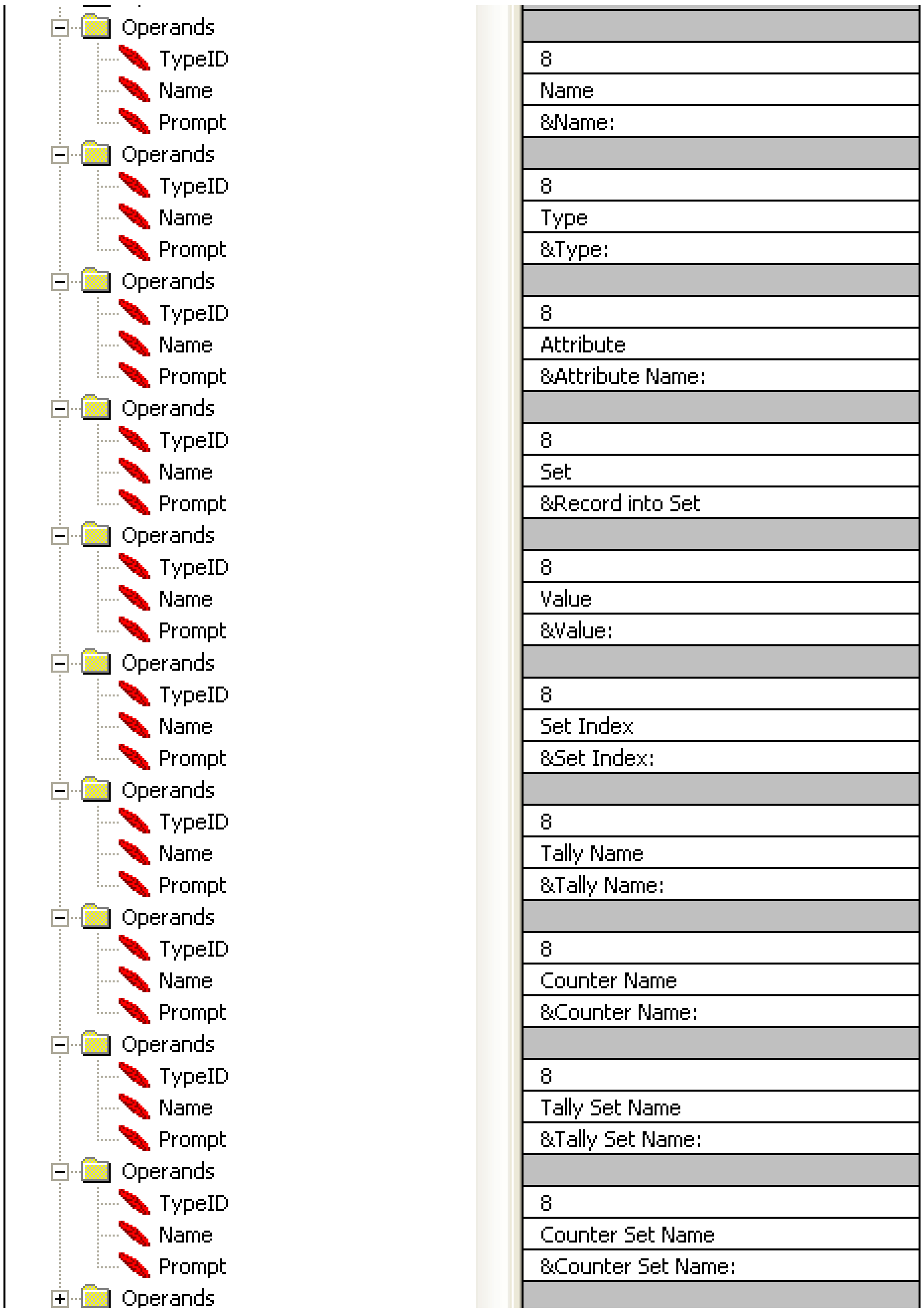


Figure 16: Module's Operand Definitions

A Record Module instance is specified:

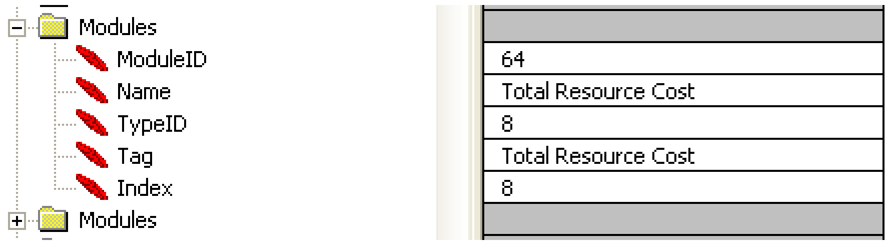


Figure 17: Record Module Instance

With the following parameters:

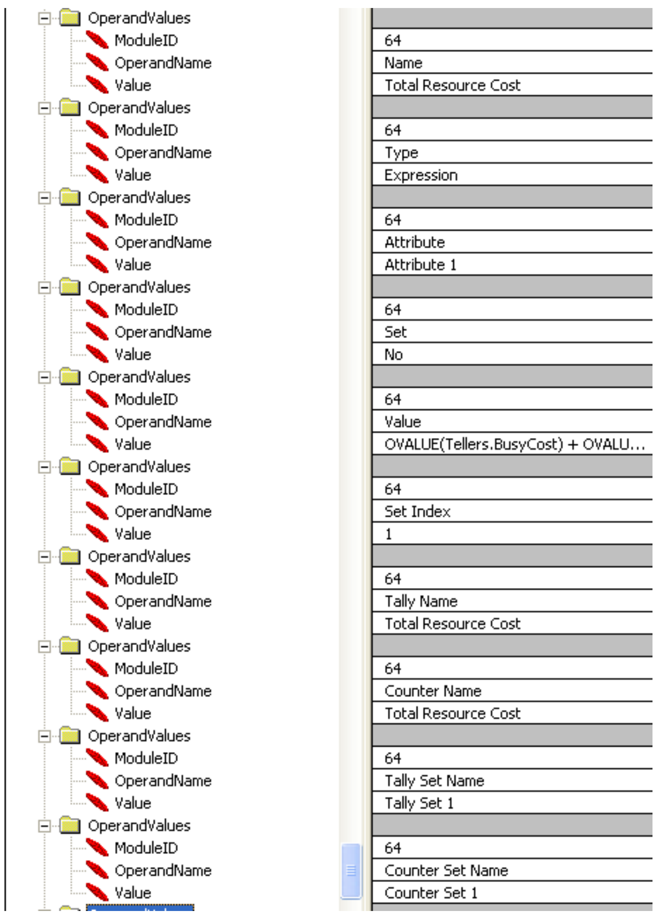


Figure 18: Record's Module Instance Parameters

Verifying/Validating the Methodology

In order to verify and validate the methodology developed, a series of scenarios (or models) were generated. The simulation models developed were verified in the following ways (Nayani *et al*, 1998):

- The model logic was followed for each event type.
- The state of the simulated system was observed in real time and checked for accuracy.
- The model was traced to follow the progress of the simulation models over simulated time
- The outputs of the simulation models were checked to see if they effectively reflected changes in the input parameters. For example, the inter-arrival time of customer orders were varied to observe a change in the number of orders that were completed by the system.

The following techniques were used to validate the simulation models developed (Nayani *et al*, 1998):

- Extreme condition tests: "This method consists of carrying out runs to simulate extreme situations and to verify that the model performs as intended in such situations" ((Nayani *et al*, 1998). For example, the simulation models developed were tested to see how they would react to an extremely high number of customer orders. As expected, the increase in customer orders increased the number in queue and increased the turn of inventory at the different functional units.
- Subject Matter Expert Opinion: The different scenarios developed were run at varying conditions and the results were evaluated and confirmed by subject matter experts.

The results of these tests provide confidence that verified and valid simulation models may be developed using the methodology developed. However, like any simulation model developed using a “traditional” simulation approach, the process of validation should be repeated throughout the life cycle of the methodology. This is understandable, since the proposed methodology can only output a valid simulation model when a correct and “valid” definition of the content (data) and context (Ontology) of system is defined.

In summary, this chapter presented a detail description of the implementation of the methodology. Specifically, the chapter is divided into the three main development efforts outlined below:

- Development of a simulation ontology that enables a common and comprehensive supply chain definition to encourage knowledge sharing and knowledge acquisition in a distributed environment.
- Development of an automatic model generator to aid decision making in a dynamic environment.
- Development of a simulation modeling methodology to address the stochastic nature of supply chain environments in a timely manner and at varying levels of fidelity.

Chapter Five presents a case study developed to demonstrate the use of the methodology in a real life scenario. In addition the models created to represent the case study under different scenarios will be used to evaluate the proposed methodology.

CHAPTER FIVE: CASE STUDY AND METHODOLOGY EVALUATION

The objective of this chapter is to demonstrate the implementation of the methodology developed in a case study and to use the resulting model to evaluate the methodology. The case study used is ABC Supermarket Super Markets.

Background

ABC Supermarket operates retail food supermarkets in Florida, Georgia, South Carolina, Alabama and Tennessee. The company is headquartered in Lakeland and operated 850 supermarkets at the end of 2004. The company's main line of business is to sell groceries, dairy, produce, deli, bakery, meat, seafood, house-wares and health and beauty care items. Many supermarkets also have pharmacy and floral departments. ABC Supermarket's sells a variety of nationally advertised and private label brands, as well as unbranded merchandise such as produce, meat and seafood. Furthermore, the company has a manufacturing division that is in charge of producing private label items. The company manufactures dairy, bakery and deli products. Its dairy plants are located in Lakeland and Deerfield Beach, FL, and Lawrenceville, GA. The bakery plants are located in Lakeland, FL, and Atlanta, GA, and the deli plant is located in Lakeland. The Distribution division of the company is in charge of receiving and distributing the food and nonfood items to the many stores throughout the south east. The company has a wide array of suppliers not being dependent on any single supplier for any of its lines of merchandise. ABC Supermarket success has been attributed to their emphasis on customer service and a family-friendly image rather than price.

ABC Supermarket's ultimate goal in planning and executing their supply chain is different than other companies. ABC Supermarket is a retailer, and as such, it is the last point in the downstream supply chain, in direct closeness to the consumer. Their goal is a "retail focused supply chain". Customer service and satisfaction is of the highest priority to the extent that they strive to be as efficient as they can be without interfering with their level of customer service.

Defining ABC Supermarket's Supply Chain

Company Operations and Functional Units

The company operates stores, processing plants and distribution centers scattered throughout the southeast. The company operates three dairy processing plants in Deerfield Beach and Lakeland, Florida, and Lawrenceville, Georgia and a deli plant and a bakery in Lakeland. ABC Supermarket operates eight distribution centers in Florida (Boynton Beach, Deerfield Beach, Jacksonville, Lakeland, Miami, Orlando, and Sarasota) and Georgia (Lawrenceville).

The following functional units can be observed:

ABC Supermarket Manufacturing

There are eleven manufacturing facilities and three main manufacturing support areas that service/procure for these facilities. The following is a list of the current manufacturing facilities and support areas at ABC Supermarket:

- Bakery Plants
- Dairy Processing Facilities
- Deli Kitchen
- Fresh Foods
- Printing Services
- Corporate Quality Assurance
- Manufacturing Engineers
- Manufacturing/Supply Purchasing

ABC Supermarket Manufacturing consists of 12 facilities: four Fresh Foods operations, three Dairy Plants, two Bakery Plants, the Deli Kitchen, Printing Services, and Corporate Manufacturing.

- **Fresh Foods Manufacturing Operations:** Located in Lakeland, FL, Deerfield Beach, FL, Jacksonville, FL, and Lawrenceville, GA. Here fruits and vegetables are packed into containers.
- **Dairy Manufacturing Operations:** Located in Lakeland, FL, Deerfield Beach, FL, and Lawrenceville, GA. Dairy processes fresh milk and milk products such as ice cream, cheese and sour cream.

- **Bakery Manufacturing Operations:** Located in Lakeland, FL and Atlanta, GA. Production lines include dry mix, frozen sweet goods, frozen rolls, frozen pies, frozen wire-cut cookies and fruit fillings.
- **Deli Manufacturing Operations:** Located in Lakeland. The Deli Plant produces prepared meats and salads
- **Printing Services:** Printing services is responsible for printing forms, labels, signs, and newsletters. This department also produces negatives for ABC Supermarket's weekly newspaper ads, engraves nametags for retail management, and handles corporate photography needs.

ABC Supermarket Distribution Centers

The ABC Supermarket distribution centers' main job is to keep the shelves stocked in over 850 stores throughout the southeast. ABC Supermarket distribution uses over 6 million square feet of warehouse space to receive, store, and ship more than 550 million cases of over 31,000 items each year. "The ABC Supermarket fleet of 552 tractors and 1,635 trailers traveled more than 56.3 million miles in 2004 to make more than one million deliveries to stores in 314 cities. To keep this fleet up and running, our Garage associates change more than 14,000 tires and 114,000 quarts of oil per year" (ABC Supermarket website). ABC Supermarket's eight distribution centers are located in:

- Lakeland, FL
- Miami, FL
- Jacksonville, FL

- Sarasota, FL
- Boynton Beach, FL
- Deerfield Beach, FL
- Lawrenceville, GA, and
- Orlando, FL.

The Distribution Centers can be further classified as:

- **High velocity warehouses:** Currently there are seven HVDC's located in Boynton Beach, Jacksonville, Orlando, Lakeland, Miami, Sarasota, and Lawrenceville, Ga. High Velocity warehouses distribute products that are considered high movers in terms of demand.

- **Low velocity warehouses:** Two LVDC's located in Lakeland and Lawrenceville, Ga. Low Velocity warehouses distribute products that are considered low movers in terms of demand.

- **Dairy/boxed meat warehouses:** Located in Lawrenceville, Ga., Deerfield Beach, Jacksonville, and Lakeland

- **Produce warehouses:** located in Lawrenceville, Ga., Deerfield Beach, Jacksonville, and Lakeland, which shipped 95 million cases to stores in 2004.

- **Frozen food warehouses:** located in Lawrenceville, Ga., Deerfield Beach, Jacksonville, and Lakeland

- **Damage return center:** located in Lakeland. The DRC receives damaged goods (only Grocery Department Items) from the stores and sells them to salvage companies or donates them to food banks.

ABC Supermarket Stores

ABC Supermarket Super Markets operates about 850 (see breakdown in Table 5) grocery stores in Alabama, Florida, Georgia, South Carolina, and Tennessee.

Table 5: Breakdown of ABC Supermarket Stores in 2005

	No.
Florida	626
Georgia	159
South Carolina	37
Alabama	21
Tennessee	7
Total	850

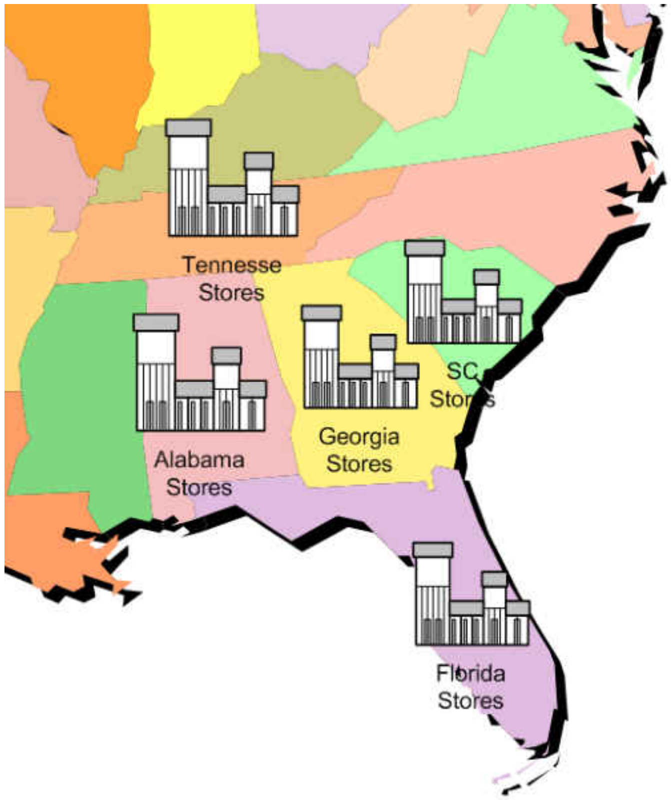


Figure 19: Geographical Map of ABC Supermarket Stores by states

ABC Supermarket Headquarters

ABC Supermarket headquarters (located in Lakeland, FL) manage, plan and enable the supply chain activities. Specifically, the logistics department is divided into different teams with individuals that are in charge of specifics functions that help plan, enable, and manage the end to end supply chain processes. Some of these functions include:

- Category managers: responsible for knowing everything they can about products in their category, including sourcing, promotion, pricing, and profit potential.
- Forecaster: forecasts demand for new items and/or new events.

- Replenisher: is in charge of building loads and planning the transportation of loads from/to the different functional units.
- Buyer: Negotiates costs , sets prices and events

Figure 20 presents a network diagram with ABC Supermarket's supply chain functional units and how these units interrelate. The middle circle represents ABC Supermarket's internal functional units. The outside functional units represent ABC Supermarket's customers, suppliers, supplier's suppliers and so on.

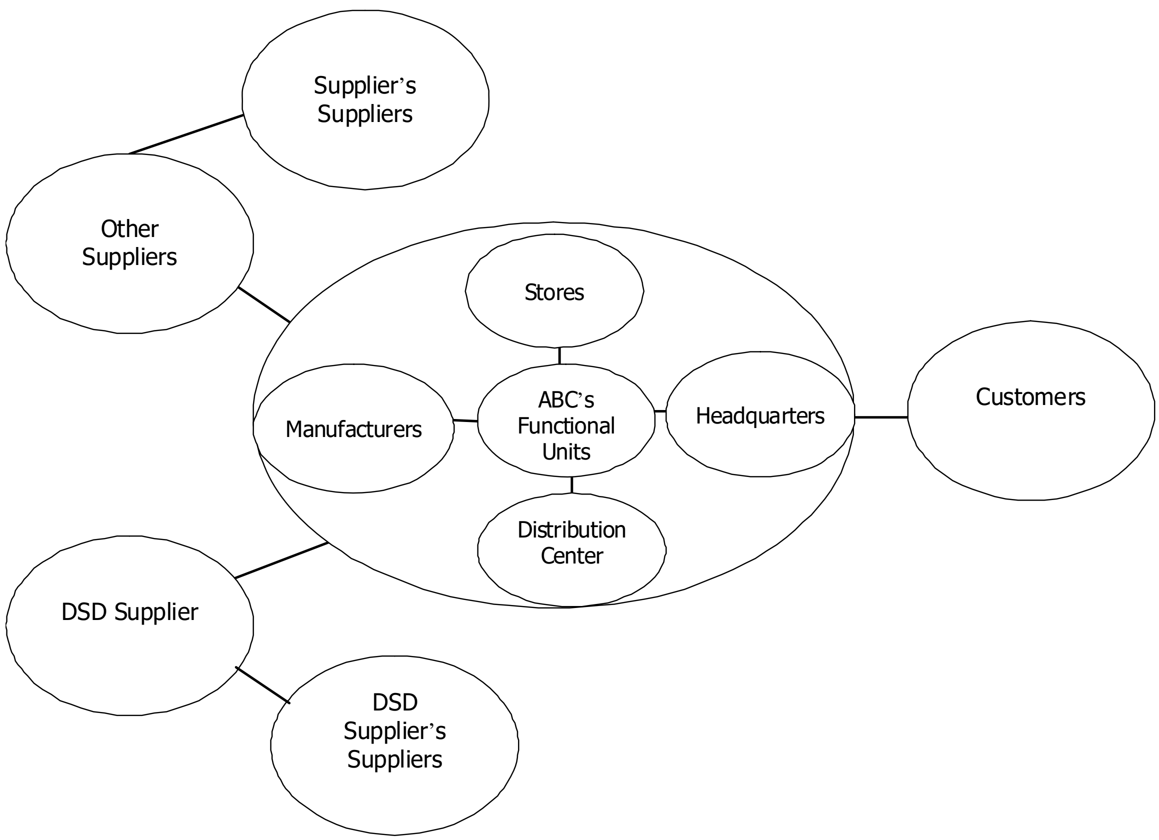


Figure 20: ABC Supermarket Functional Unit Network Diagram

Products

Due to the nature of the supermarket (retail industry), the number of products offered by a supermarket chain such as ABC Supermarket is very extensive. Therefore, the products offered will be classified into departments. The following departments are common throughout ABC Supermarket stores:

- Bakery
- Banking
- Deli
- Ethnic foods
- Floral
- Grocery
    - Frozen Foods
    - House wares
    - Dry Grocery
    - Health and Beauty
    - Dairy
- Meat
- Pharmacy
- Photo processing
- Produce
- Seafood

Further, products can be classified by the supply chain process/rules that are used to manage these product lines. The following classifications can be observed:

- Direct Store Delivery Products: These products are products that are delivered directly to the stores by their suppliers. An example of these is Coca-Cola products.
- High Velocity Products: These are products that are high movers. They are usually shipped from a High Velocity designated Distribution Center to the stores in pallets or (at the very least) in cases.
- Low Velocity Products: These are products that are low movers. They are shipped from a Low Velocity Warehouse in smaller packages or in units.
- Low Shelf Life Products: These products are delivered directly from the manufacturing plants to the stores in a timely fashion.

ABC Supermarket Suppliers

ABC Supermarket has a wide variety of suppliers that are responsible for supplying the products in the departments listed above to the manufacturing plants, distribution centers and sometimes directly to the stores (depending on the product type (see above)). Some examples of suppliers include:

- Del Monte Fresh Produce, N.A., Inc.: Located in Coral Gables, FL,
- Tanimura and Antle, Inc.: Located in Salinas, CA,
- DUDA: Located in Oviedo, FL.

Therefore, when defining this wide array of suppliers, the same classification as in the products above (by Department and/or by supply chain process/rules) will be used.

ABC Supermarket Customers

The final customer at ABC Supermarket is the end consumer. The Customer at ABC Supermarket can be described as the typical consumer that shops at ABC Supermarket for their grocery items on a daily, weekly or even monthly level. Usually, these customers will visit the store and select the desired products from the different departments and then proceed to check out where they will be invoiced. Payment is received and the customer then exits the store with their purchases on hand.

This type of demand is highly seasonal. Stores observe a high peak during after work hours and during weekend. Similarly, during holidays the stores experience a high number of demands. Out of the ordinary events, like hurricanes and other natural phenomenon, also cause changes in the demand.

For specialty items like subs or party trays, orders are sometimes taken ahead of time over the phone. The customer then comes to pick up the items and proceed to check out.

Key Performance Measures

According to ABC Supermarket, the following performance measures are identified with the highest priority:

- Appearance: Minimize the amount of empty shelves
- Efficient Inventory Levels
- Minimize Out of Stocks
- Minimize Lost Sales

- Minimize Holding Costs
- Efficient Inventory Tracking

Defining the Baseline Scenario

Due to the complex nature of the system being considered, the scope of the baseline scenario will be confined to the manufacture of ABC Supermarket Subs at the Deli Department within a specific store. The following steps were followed to define the baseline scenario using the developed methodology:

Step 1: Defining Enterprises, Locations and Functional Units

All operational facilities, suppliers and customers defined above were defined within the Graphical User Interface. However, in order to accommodate the scope defined above only the following functional units were included in the model. Figure 21 illustrates how these functional units were defined using the tool.

- Customer
- An ABC Supermarket Store
- Produce Distribution Center (DC)
- Dairy Boxed Meat DC
- Low Velocity DC
- Dairy Plant
- Produce Supplier

- Meat Supplier
- Bakery Supplier
- Dairy Supplier
- Grocery Supplier

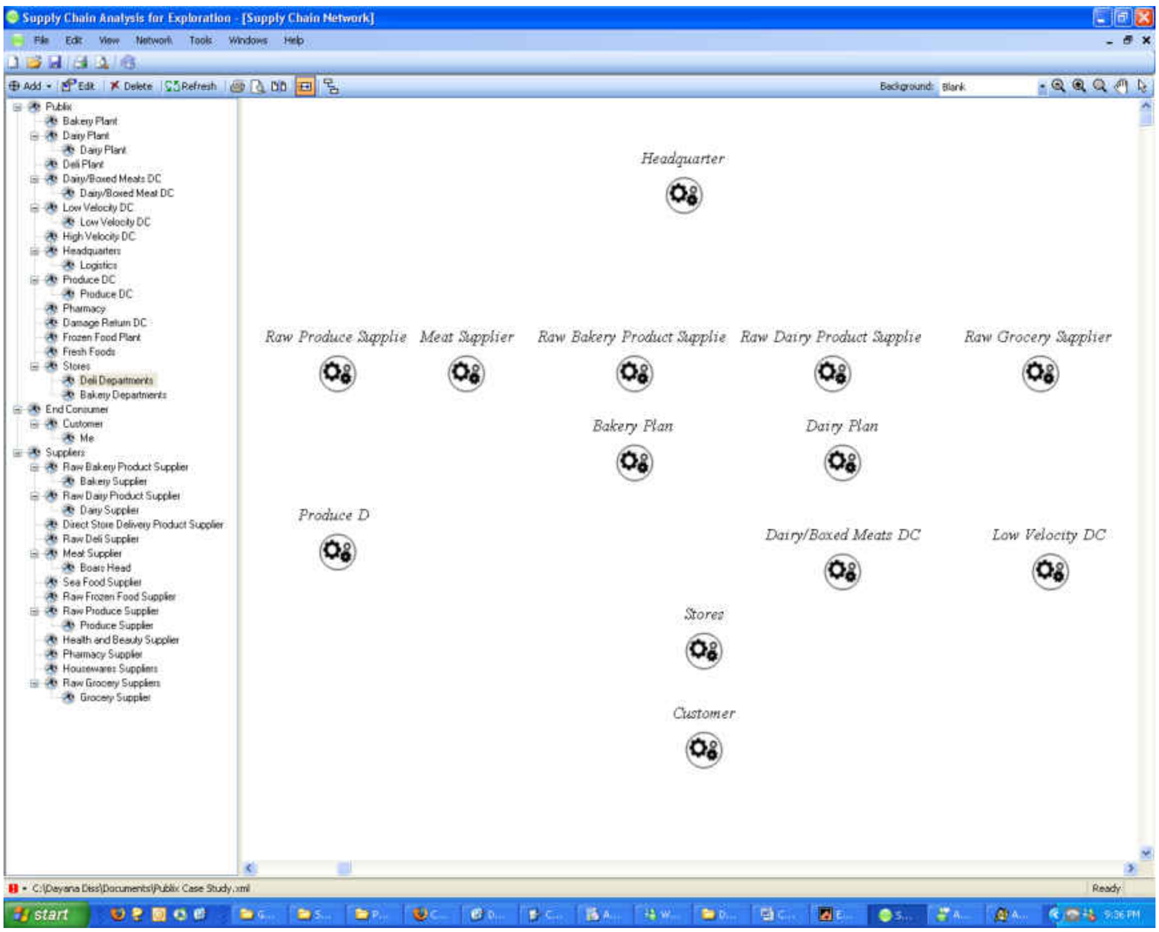
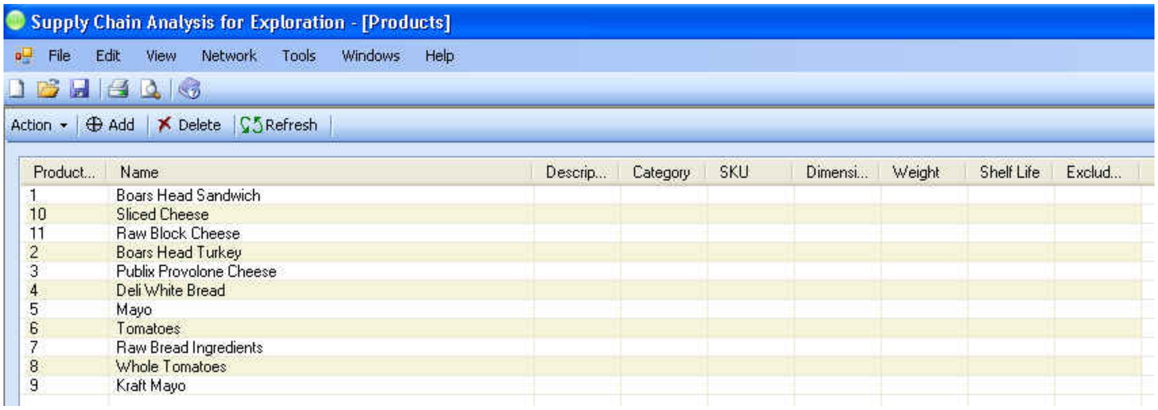


Figure 21: Defining the Functional Units

Step 2: Defining the Products

Figure 22 illustrates the Products as they were inputted in the GUI.



Product...	Name	Descrip...	Category	SKU	Dimensi...	Weight	Shelf Life	Exclud...
1	Boars Head Sandwich							
10	Sliced Cheese							
11	Raw Block Cheese							
2	Boars Head Turkey							
3	Publix Provolone Cheese							
4	Deli White Bread							
5	Mayo							
6	Tomatoes							
7	Raw Bread Ingredients							
8	Whole Tomatoes							
9	Kraft Mayo							

Figure 22: Defining the Products

Step 3: Defining the Functional Unit and Product Relationships

After defining all the products and functional units above, these were related by specifying the raw materials and finished products that flow through a specific functional unit. Figure 23 illustrates this relationship for the Deli Department Functional Unit. The final product of the deli department is a "Boars Head Sandwich". The Raw Materials are: Boars Head Turkey, ABC Supermarket Provolone Cheese, Deli White Bread, Mayo and Tomatoes.

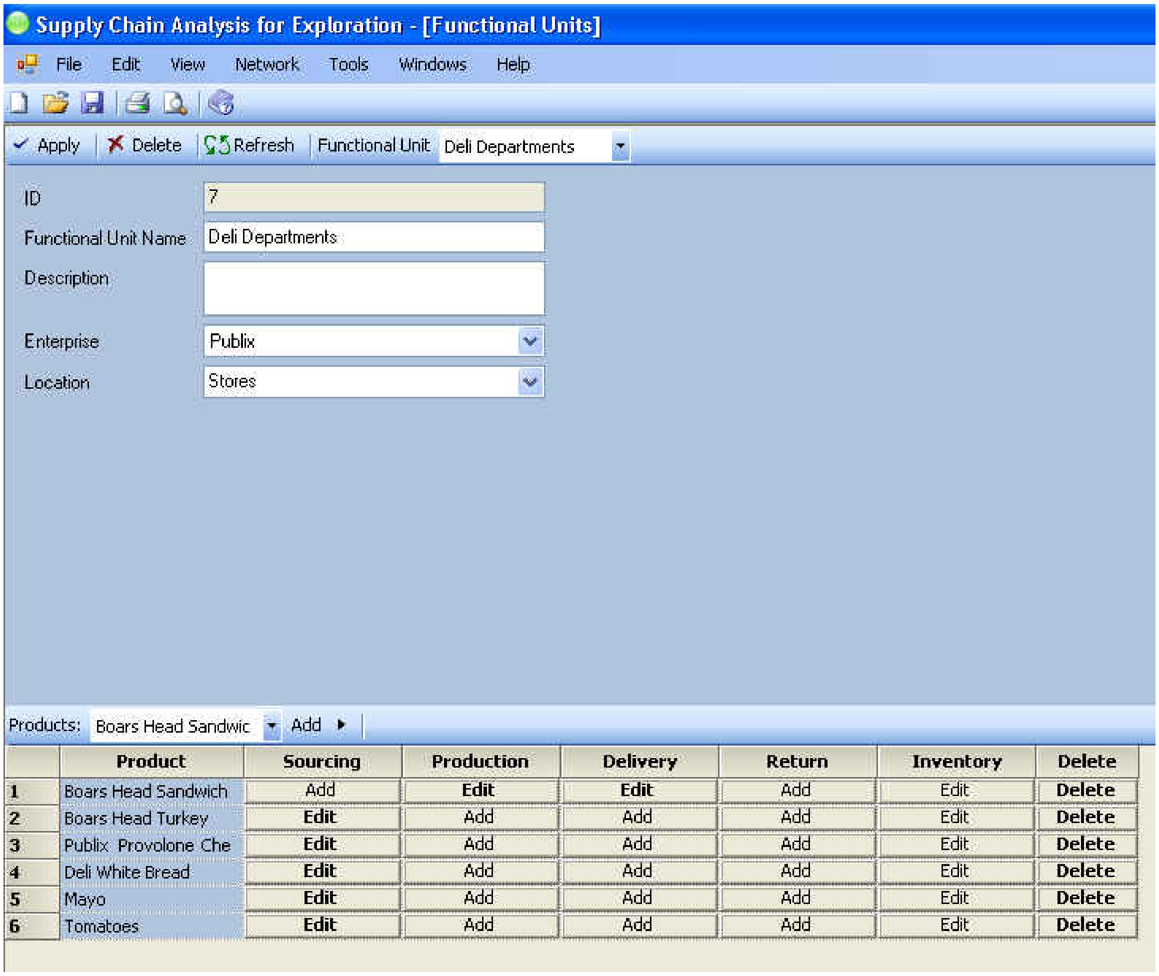


Figure 23: Relating the Deli Department FU with its raw materials and finished product

Step 4: Defining the Sourcing Policies

Figure 24 illustrates defining the sourcing policy for “Boars Head Turkey”.

Figure 24: Sourcing Policy for Boars Head Turkey

Step 5: Defining the Inventory Policies

Figure 25 illustrates defining the inventory policy for “Deli White Bread”.

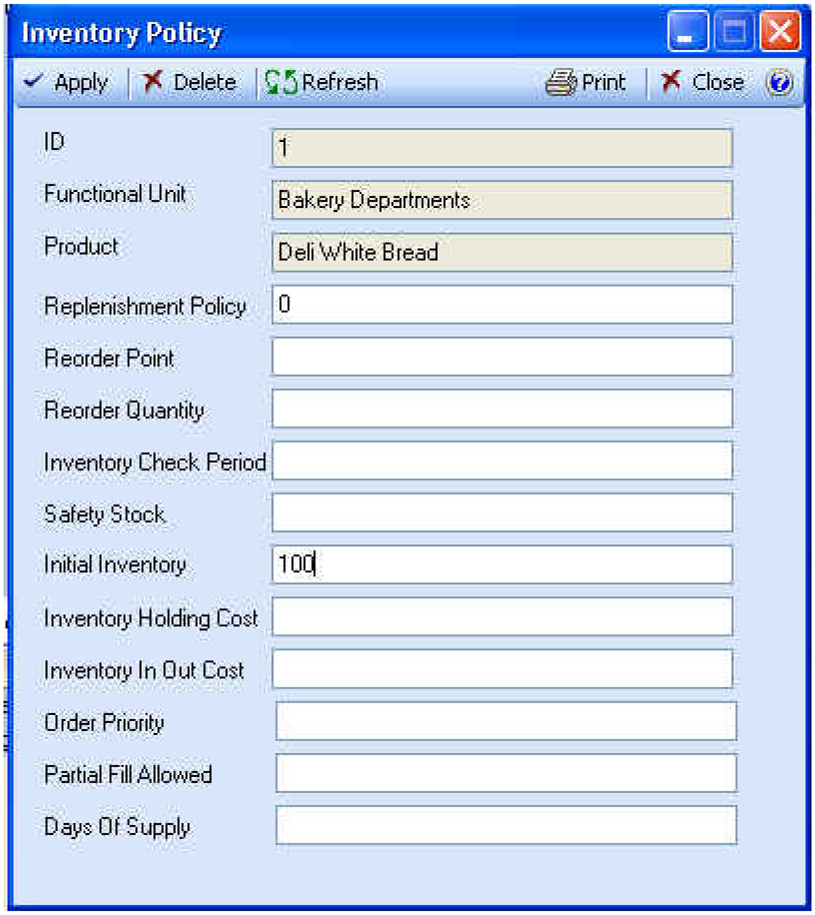


Figure 25: Defining an Inventory Policy

Step 6: Defining the Production Policies

Figure 26 illustrates defining the production policy for "Boars Head Sandwich".

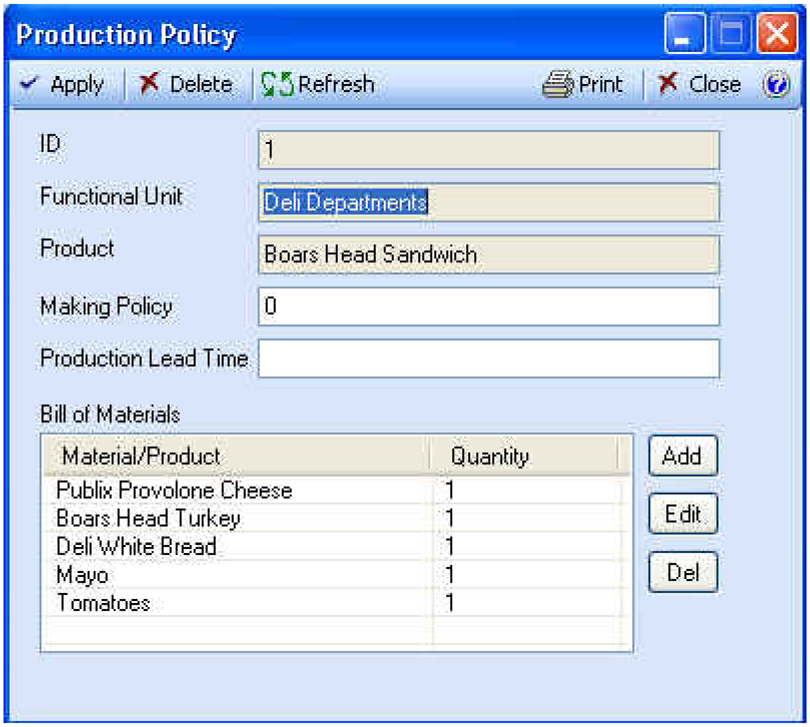


Figure 26: Defining the Production Policy

Step 7: Defining the Delivery Policies

Figure 27 illustrates defining the delivery policy for "Boars Head Sandwich".

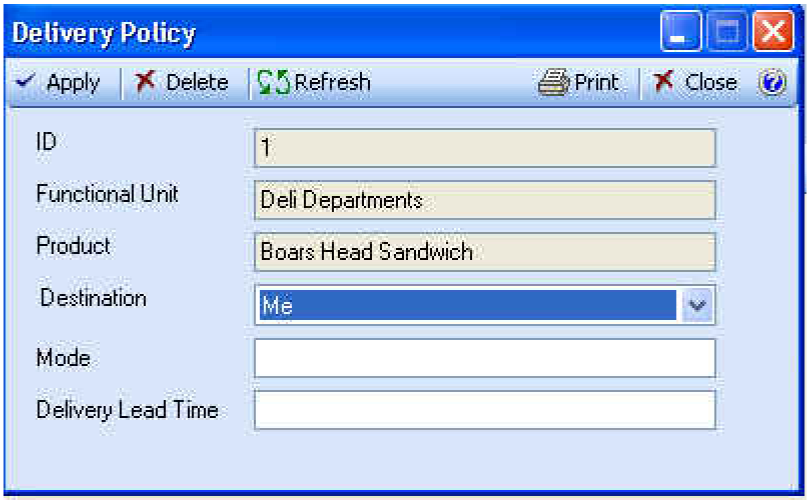


Figure 27: Defining the Delivery Policy

After completing the above steps, an xml file is generated that contains the definition of the supply chain (see Appendix A). This xml file is parsed by the automatic generator (using XSLT transformation logic) and a transformed xml file is generated that contains a list of the Arena Supply Chain modules (from the Supply Chain Template) required and their content (see Appendix B). These modules are then dropped and populated into a blank Arena model (Appendix C). Figure 28, Figure 29 and Figure 30 present screenshots of the modules dropped for supplier, distribution center and store functional units.

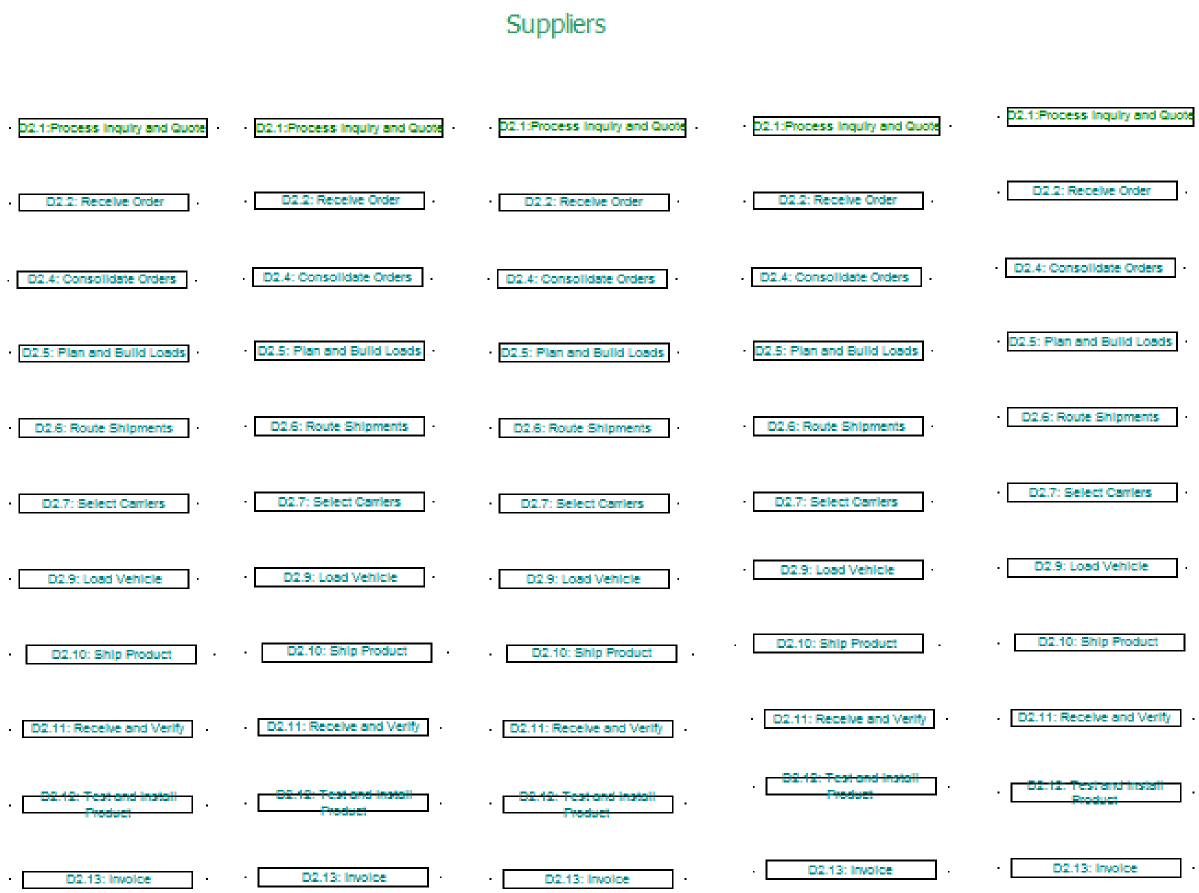


Figure 28: Modules dropped in Model for Suppliers

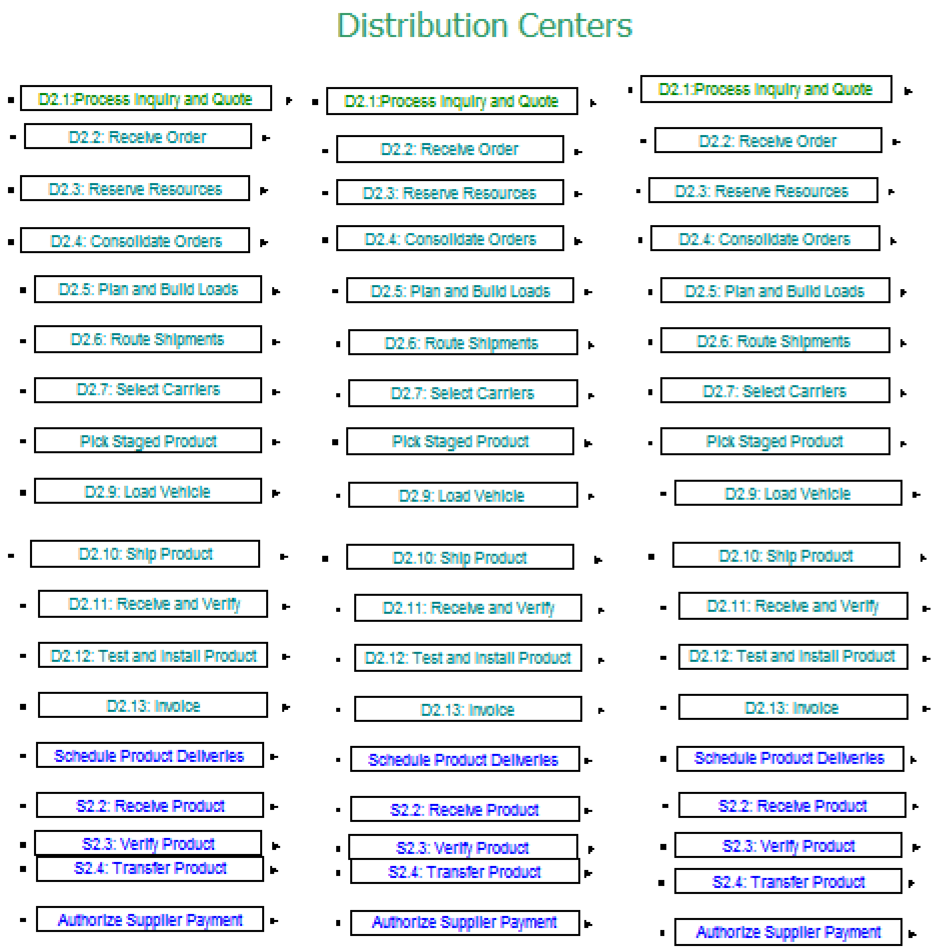


Figure 29: Modules dropped in model for Distribution Centers

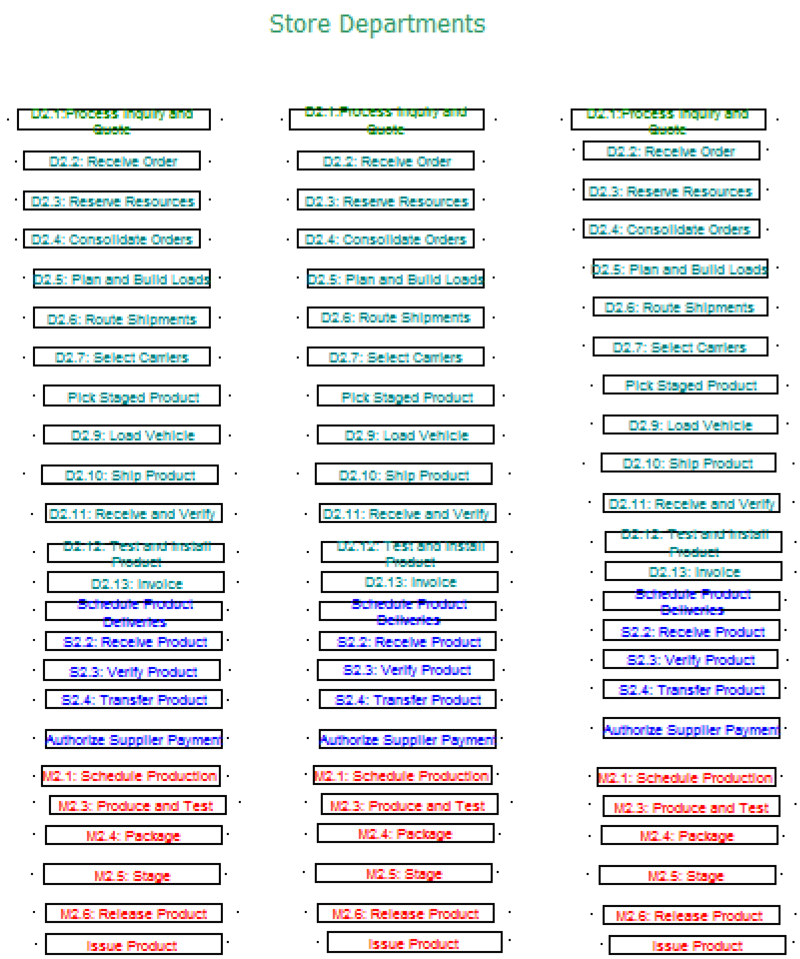


Figure 30: Modules dropped in model for the Store Departments

The resulting model was used as one of the scenarios used for validation/verification of the methodology (from Chapter 4). The model was verified and validated by:

- Following the logic for each event type. This involved following a customer order from creation to delivery to the final customer. This included following all objects and orders generated along the way for raw materials, WIP and final products.

- The state of the simulated system was observed in real time and checked for accuracy. Special attention was placed on the state of the inventory (raw, WIP and final) and resource allocation to assure that they behaved as expected as the simulation progressed.
- The model was traced numerous times to follow the progress of the objects, products and information entities over simulated time.
- The outputs of the simulation models were checked to see if they effectively reflected changes in the input parameters. For example, the inter-arrival time of customer orders were varied to observe a change in the number of orders that were completed by the system.

The following techniques were used to validate the simulation model:

- The model was tested to see how it reacted to an extremely high number of customer orders. As expected, the increase in customer orders increased the number in queue and increased the turn of inventory at the different functional units.

The results of these tests provide confidence that the baseline model developed using the methodology is valid.

Methodology Evaluation

At a high level, the methodology should allow supply chain decision makers to support informed decision making in a **fast**, **shareable** and **easy to use format.** The baseline scenario presented above was defined and executed using the developed methodology in under one day. An identical model, if developed using a traditional methodology, could take weeks to design and execute. This demonstrates a significant reduction in model definition and development time when using the developed methodology. The development of the baseline scenario (as shown in the paragraphs above) allows users to develop scenarios using their domain language using a standardized, fully automated procedure. The design of the methodology allows users to develop simulation models of different scenarios without the need of expertise in simulation methodology. This greatly benefits the ease of use and “share-ability” of the tool when compared to a “traditional” modeling approach.

Furthermore, in order to evaluate the methodology, the following scenarios were developed (with the Baseline scenario as a starting point) to address the shortcomings in Supply Chain Modeling (Banks, 2002) and to demonstrate the ability of the methodology to provide models that follow the defined criteria (see Table 4):

- Scenario A: Add a Warehouse or Distribution Center
- Scenario B: Vary Demand, Add/Remove Customer
- Scenario C: Modify Supplier to include more detail
- Scenario D: Adding a new supplier.
- Scenario E: Vary Inventory strategy

Scenario A: Add a Warehouse or Distribution Center

The process of defining a new warehouse or Distribution Center involves a total of 4 steps that could be accomplished in less than five minutes. The first step consists in adding a new Location and Functional Unit as seen in Figure 31. Figure 31 also reflect the second step which consist of defining the products that will be related to this functional unit. Step three consist of defining the Sourcing policy for the new warehouse (see Figure 32) and Step four consist of defining the Delivery Policy for the new warehouse (see Figure 33)

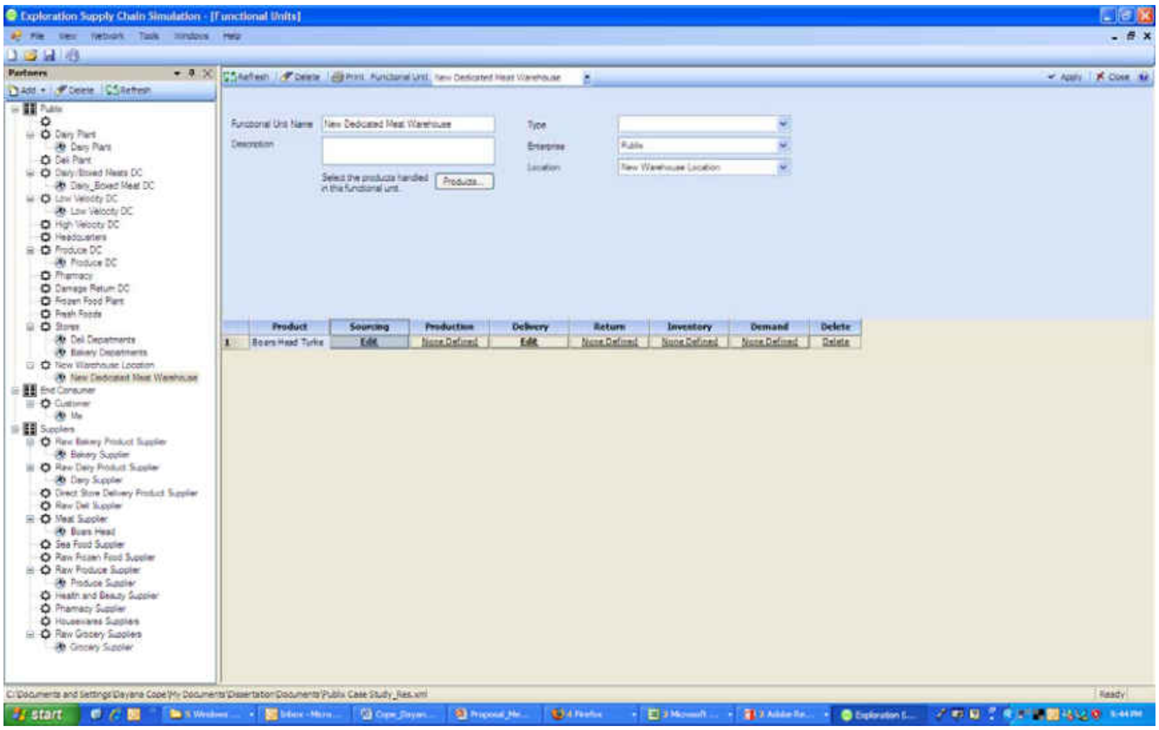


Figure 31: Adding New Warehouse Functional Unit

Figure 32: Define Souring Policy for New Warehouse

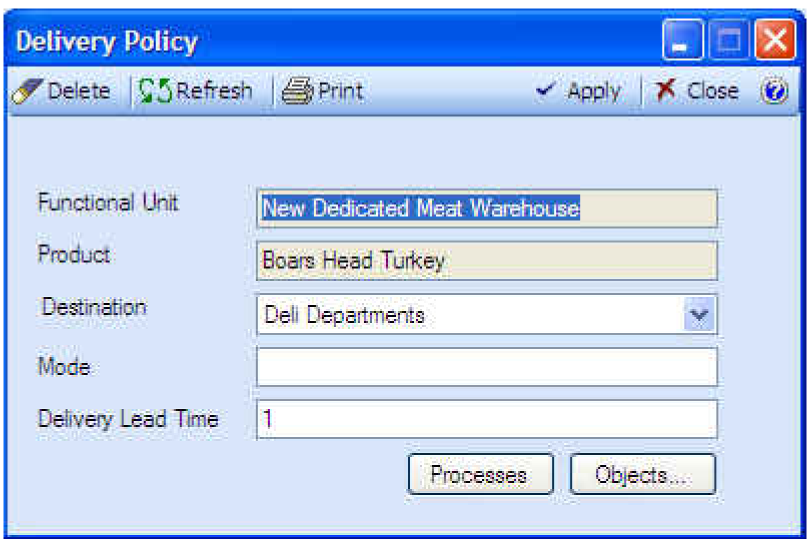


Figure 33: Define Delivery Policy for New Warehouse

The process of automatically developing a simulation model for this scenario can be completed in less than one minute.

Scenario B: Vary Demand, Add/Remove Customer

The process of varying demand by adding or removing a customer involves a total of 6 steps that could be accomplished in less than five minutes. The first step consists in adding a new Location and Functional Unit as seen in Figure 34. Figure 34 also reflect the second step which consist of defining the products that will be related to this functional unit. Step three consists of defining the Sourcing policy for the new customer (see Figure 35), step four consists of defining the Inventory Policy for the new customer (see Figure 36) and step five consists of defining the Demand for the new customer (see Figure 37)

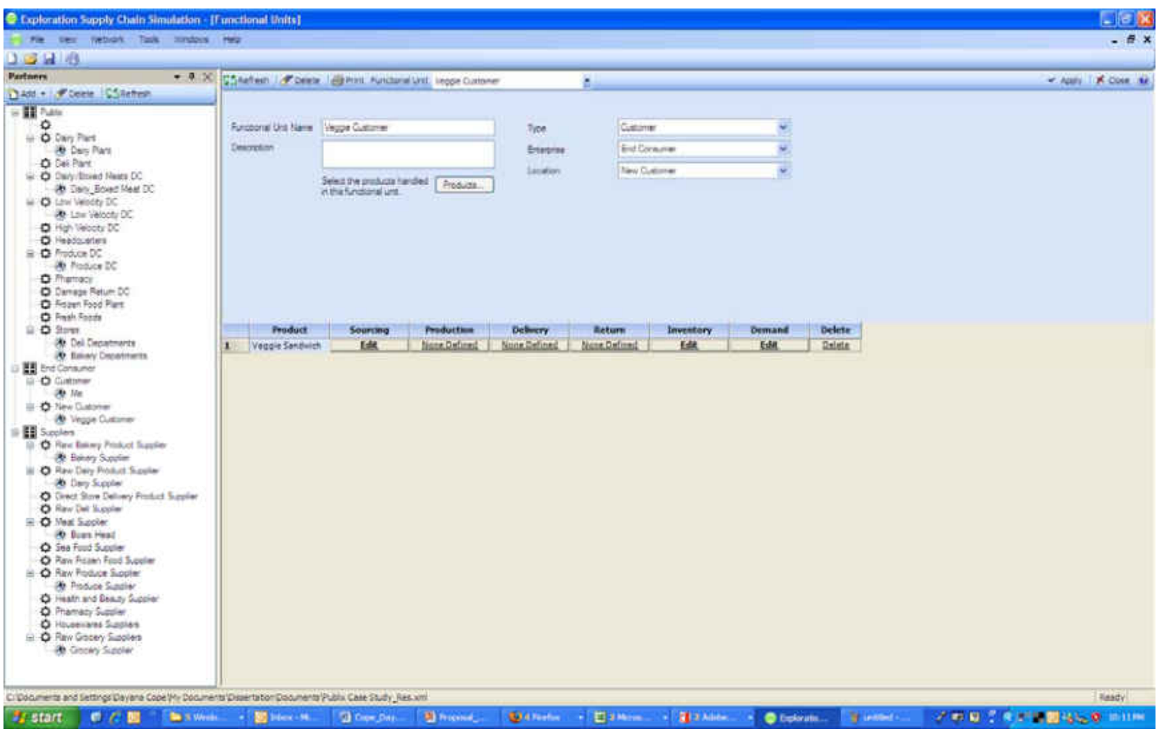


Figure 34: Adding New Customer Functional Unit

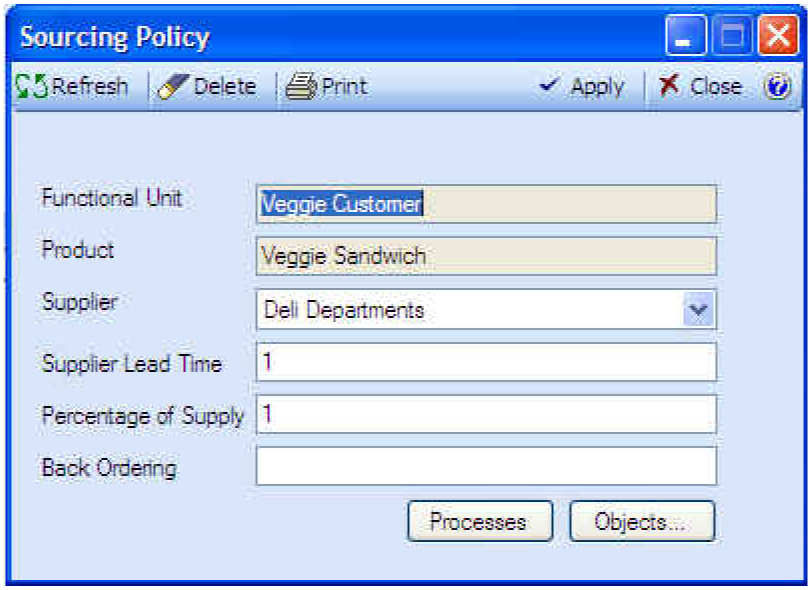


Figure 35: Define Souring Policy for New Customer

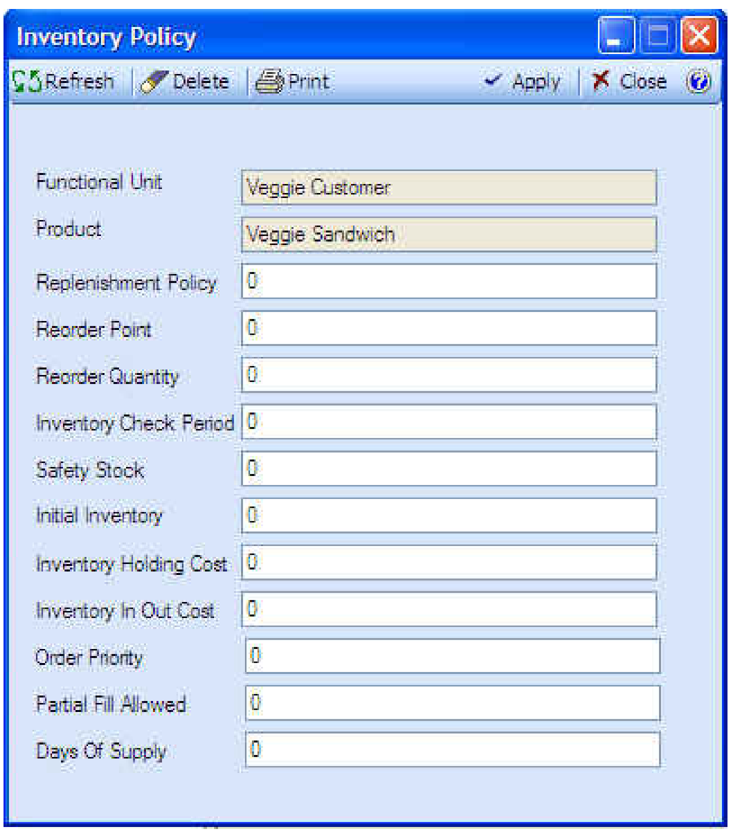


Figure 36: Define Inventory Policy for New Customer

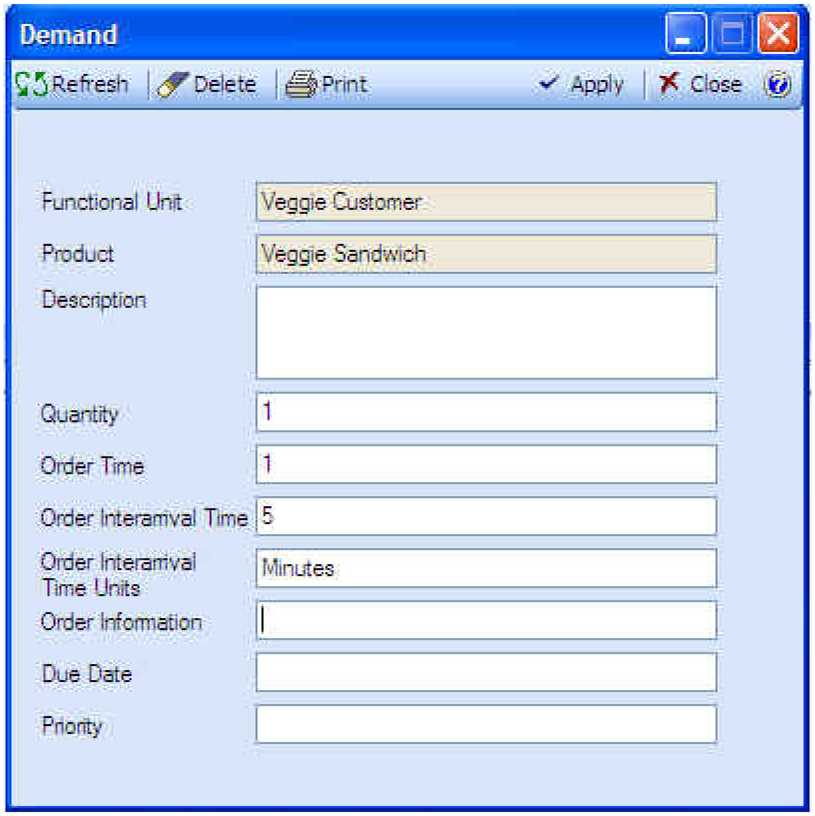


Figure 37: Define Demand for New Customer

The process of automatically developing a simulation model for this scenario can be completed in less than one minute.

Scenario C and D: Modify Supplier to Include More Detail and Add a New Supplier

In order to demonstrate the ability to modify a supplier to include more detail using the methodology, a supplier will be decomposed into a lower level of detail by defining the supplier sub-functional units: the Supplier's Suppliers (New Supplier), Manufacturing Functional Unit and Transportation Units. This process will involve a total of 7 steps that could be accomplished in less than five minutes. The first step consists in adding three new Functional Units to represent the Supplier’s internal supply chain. This can be seen in Figure 38. In this scenario, the Boars Head Supplier was decomposed to three lower level Functional Units: Turkey Supplier (Supplier’s Supplier), Boars Head Manufacturing and Boars Head Transportation. Figure 38 also reflect the second step which consists of defining a new Functional Unit for the new Turkey supplier. The new Functional Unit will require a product definition (step three) and a Delivery Policy Definition (step four). Similarly, the Boars Head Manufacturing and Transportation Departments will require two new Functional Unit definitions; each with Sourcing, Production and Delivery policy definitions (as needed).

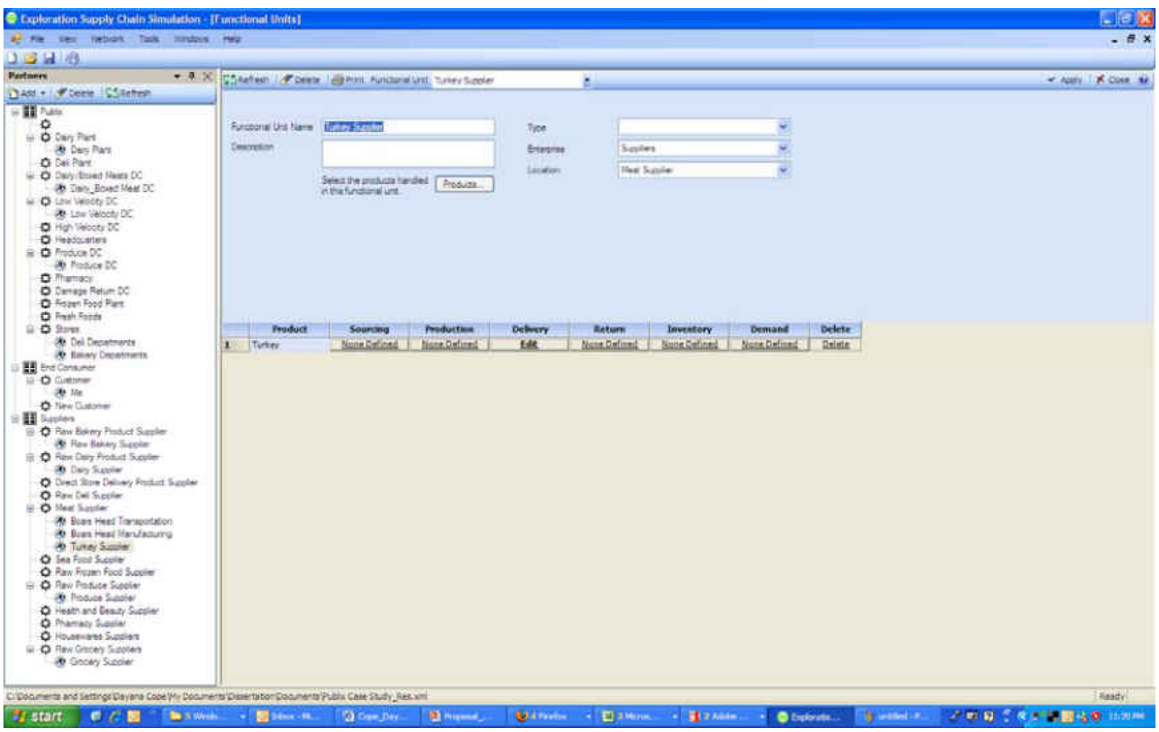


Figure 38: Enhancing Boar’s Head Supplier Level of Detail

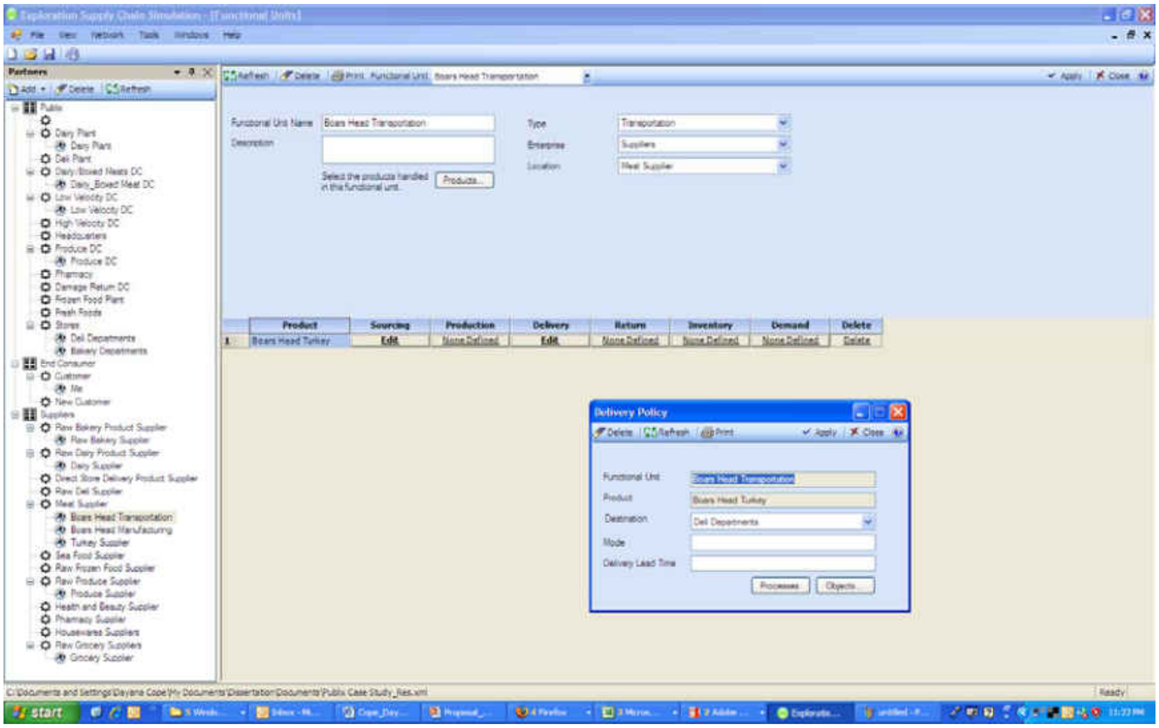


Figure 39: Define Souring Policy for New Boars Head Transportation Functional Unit

The process of automatically developing a simulation model for this scenario can be completed in less than one minute.

Scenario E: Varying Inventory Strategy

The process of varying an inventory strategy can be accomplished in one step. This modification can be accomplished in less than two minutes. This step consists of modifying the inventory policy for a specific functional unit and product. For this scenario, the Deli Department Functional Unit inventory for Boars Head Turkey will be modified (Figure 40). Figure 41 presents the different parameters that can be modified to vary the inventory strategy. In this example, the safety stock was eliminated.

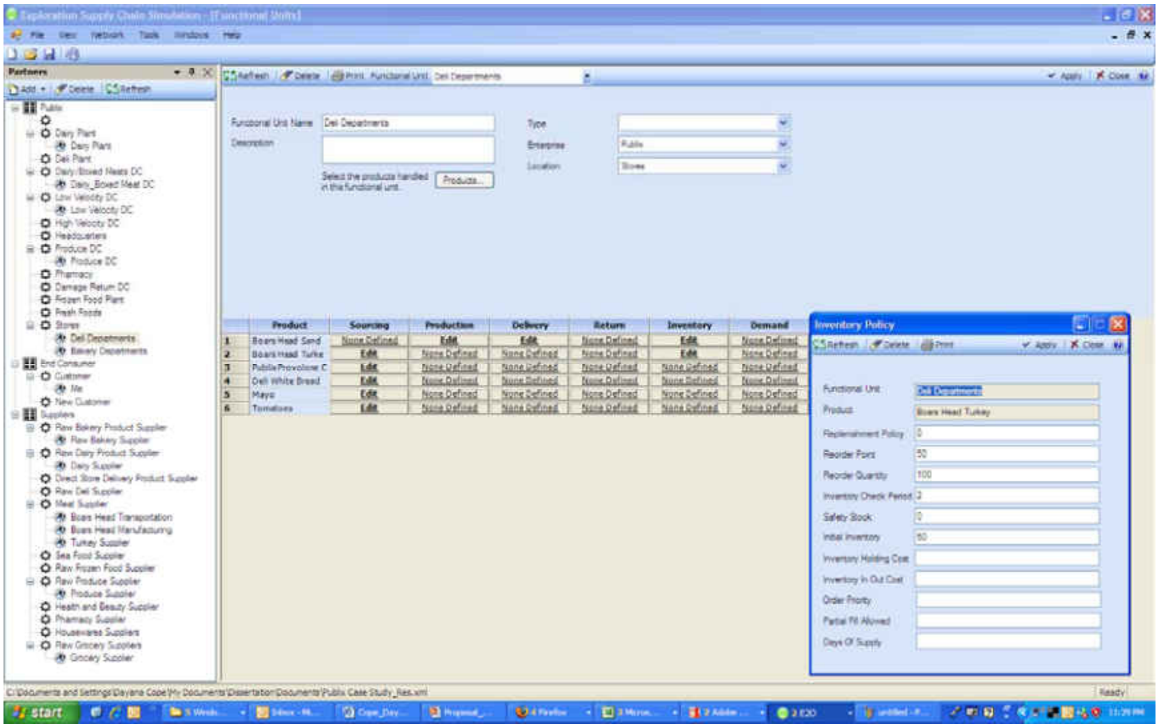


Figure 40: Modifying Inventory Policy for Boars Head Turkey at Deli Department Functional Unit

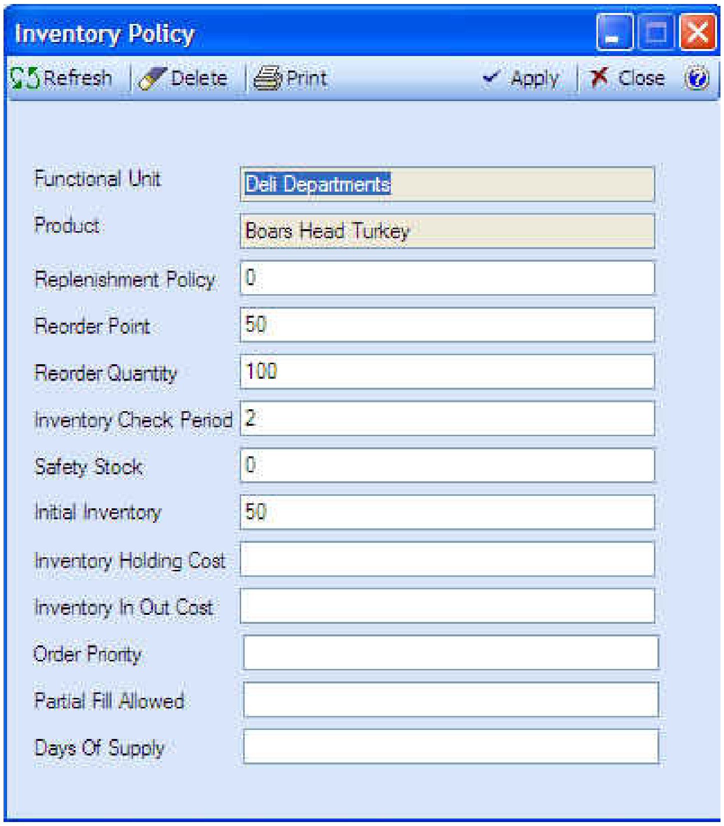


Figure 41: Modify Inventory Policy

The process of automatically developing a simulation model for this scenario can be completed in less than one minute.

Table 6 reflects how well each scenario developed demonstrates adherence to the criteria defined through a series of yes/no questions.

Table 6: Methodology Evaluation Criteria by Scenario

Questions	*Scenario*				
	A	*B*	*C*	*D*	*E*
Does the resulting model take into account uncertainty?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Does the resulting model represents the entire supply chain including the supply chain processes, their interactions, information flow, object and material flow for the different supply chain partners?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Is the resulting model easily and quickly modifiable to examine different conditions or scenarios?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Is the model easily reconfigurable to represent a "to be" state from an "as is" state?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Does the model allow for quickly varying parameters without requiring a lengthy modeling process?	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Can models be easily developed that represent varying levels of detail? At Enterprise Level? At Functional Unit Level? At Facility Level?	**No**	**No**	**Yes**	**No**	**No**
Can the models developed address decision making for Supply Chain design?	**Yes**	**No**	**Yes**	**Yes**	**Yes**
Analyzing/Implementing Inventory Strategies? Effect of varying Safety Stock?	**No**	**No**	**No**	**No**	**Yes**
Can the models be easily shared to enhance communication among stake holders?	**Yes**	**Yes**	**Yes**	**No**	**No**

In addition, when comparing the implementation of these scenarios by using the developed methodology vs. a "traditional" simulation methodology, a significant reduction in definition and execution time can be observed for all the scenarios. These scenarios could require days to design and implement using a traditional approach compared to a less than 10 minute definition and execution time using the developed approach.

CHAPTER SIX: SUMMARY AND FUTURE RESEARCH

The literature is rich with research and development efforts that use modeling to aid decision makers in supply chain systems. These efforts address certain aspects of supply chain environments (stochastic, distributed and dynamic system) independently or a combination of these. However, no past effort exists that addresses all of these aspects comprehensively. This research addresses these shortcomings by developing an integrated methodology that will allow supply chain decision makers to analyze the performance of their supply chain in a fast, sharable and easy to use format. The methodology was implemented by developing a stand alone tool that allows users to define a supply chain simulation model using SCOR based ontologies. The ontology includes the supply chain knowledge (supply chain elements, functional units, processes, information, etc) and the knowledge required to build a simulation model of the supply chain system. This information is then passed to an automatic model generator. The automatic model generator parses the conceptual (or structure) model (obtained from the Ontology) and the model logic, parameters and data (obtained from user input through a GUI) to obtain a fully executable simulation model of the scenario described by the user. The parser performs a series of XSLT transformations that provide as an output an xml file. The xml file generated is then used to automatically generate the models. Simulation models can be generated automatically from the ontology system definition to provide the flexibility to model at various levels of details changing the model structure on the fly.

In summary the contributions of this research are:

- An automatic generator of simulation models from a common, cross-industry, comprehensive supply chain definition.
- A supply chain simulation ontology that extends the Supply Chain ontology developed by Fayez (2005).
- A user-friendly tool that allows supply chain decision makers to design, develop and experiment with simulation models using their own domain language in a fast and comprehensive manner.

To ensure that the methodology developed is validated/verified, a series of scenarios (or models) were generated. The scenarios generated were tested based on a series of validation and verifications tests. The results of these tests provide confidence that verified and valid simulation models may be developed using the methodology. However, like any simulation model developed using a "traditional" simulation approach, the process of validation should be repeated throughout the life cycle of the methodology.

Once the validity/verification of the methodology was ensured, an implementation of the methodology was demonstrated by using a case study. The case study defines the supply chain of a grocery retailer, ABC Supermarkets. The baseline scenario developed included sufficient detail to demonstrate the ability to model a complex supply chain with multiple Functional Units (Suppliers (multiple tiers), Distribution Centers and Manufacturing Centers). Each of these Functional Units was defined with unique characteristics (products, information, objects, and sourcing, delivery, manufacturing and inventory policies).

In order to evaluate the methodology, a series of scenarios (based on the baseline scenario) were developed using the methodology. The scenarios developed were designed to address the shortcomings in Supply Chain Modeling (Banks, 2002) and to demonstrate the ability of the methodology to provide models that follow the defined evaluation criteria. The following scenarios were used to evaluate the methodology:

- Scenario A: Add a Warehouse or Distribution Center
- Scenario B: Vary Demand, Add/Remove Customer
- Scenario C: Modify Supplier to include more detail
- Scenario D: Adding a new supplier.
- Scenario E: Vary Inventory strategy

At a high level, the methodology should allow supply chain decision makers to support informed decision making in a **fast**, **shareable** and **easy to use format**. Specifically, it was of interest to evaluate the methodology based on its adherence to the following detailed criteria: realism, usefulness, flexibility, scalability, extensibility and adoptability. In summary the criteria was defined as follows:

- ***Realism*** has to do with the ability of the methodology to produce models that account for uncertainty. In addition, a methodology with a high degree of realism allows for modeling entire supply chain systems including their entire processes, interactions, information flow, object and material flow for the different supply chain partners.
- The methodology should be ***useful*** to decision makers by providing a means to analyze the entire supply chain under different conditions.
- Due to the high degree of dynamism present at all levels of supply chain environments, the methodology should be ***flexible*** to allow for change. The methodology should allow for changing model parameters fast and easily to facilitate the decision making process

and allow decision makers the opportunity to make informed decision when the need arises not being delayed by a lengthy modeling process.

- Supply chains are distributed systems with multiple partners; the methodology should be ***scalable*** to allow for dynamically changing the scope and the level of detail within the model.
- Similarly, due to the variety of problems that can be addressed in supply chain environments (i.e. strategic and tactical decision making like supply chain design and analyzing/implementing inventory strategies; operational decision making like safety stock and inventory quantities, etc..) the methodology will be ***extensible*** to address different problems with minimal change in the methodology. Furthermore, the modeling methodology should allow for the addition of new processes as supply chain environments evolve (i.e. transportation and training process).
- The methodology should be easily ***adopted*** by practitioners to encourage it use. This is achieved by a methodology that is easily understood, simple to implement and maintain.

A series of yes/no questions were defined to determine how well each evaluation scenario met the criteria defined above. The models developed using the methodology described in this research showed adherence to the criteria defined (see Table 6). Furthermore, the models developed were also compared against comparable models modified using a "traditional modeling approach" to determine the effect of scenario implementation on model definition and execution. When comparing the implementation of these scenarios by using the developed methodology vs. a "traditional" simulation methodology (with identical resulting models), a significant reduction in definition and execution time was observed for all the scenarios defined.

Future Research

To achieve a fully automated process, future research efforts should be directed towards automating the content (data) definition, validation/verification process and experimental design and output analysis phases (see Figure 8).

- Due to the ease of model generation now available as a result of the developed methodology, there is a need to automate and/or facilitate the data collection and analysis phase that precedes every simulation study. This is of particular importance when considering the distributed nature of supply chain models. In a supply chain network data is often located across multiple functional units in different formats and ERP systems, for example. Future research might involve the development of automated agents that can retrieve the available data from different sources and compile it into a useful, common format.
- Similarly, there is a need to automate and/or facilitate the experimental design and output analyses phase that is performed after every simulation study. With the ability to design and develop multiple simulation scenarios in a short amount of time, decision makers need a tool that would allow them to select among different scenarios and evaluate their results quickly and accurately.
- Future research might involve the development of an automated validation and verification methodology that would allow for verification and validation of resulting models through the use of a simulated "Subject Matter Expert" developed using Artificial Intelligence technologies, decision trees or ontological components, for example.

- Enhancement of the current methodology to allow for definition and modeling of “one of a kind” or engineered-to-order products.
- Enhancement of the current methodology to allow for definition and modeling of models for the service industry.
- Other future research might involve the enhancement of the developed methodology. This might involve the use of OWL, as opposed to XML, for data exchange throughout the system.

REFERENCES

Arief, L. B., & Speirs, N. A. (2000). *A UML Tool for Automatic Generation of Simulation Programs.* Paper presented at the Proceedings of the second international workshop on Software and performance.

Bagchi, S., Buckley, S. J., Ettl, M., & Lin, G. Y. (1998). *Experience using the IBM Supply Chain Simulator.* Paper presented at the Proceedings of the 1998 Winter Simulation Conference.

Banks, J., Buckley, S., Jain, S., Lendermann, P., & Manivannan, M. (2002). *Panel Session: Opportunities for Simulation in Supply Chain Management.* Paper presented at the Proceedings of the 2002 Winter Simulation Conference.

Banks, J., Hohn S. Carson, I., & Nelson, B. L. (1996). *Discrete Event System Simulations* (Second Edition ed.). Upper Saddle River, New Jersey: Prentice Hall.

Bansal, S. (2002). *Promise and Problems of Simulation Technology in SCM Domain.* Paper presented at the Proceedings of the 2002 Winter Simulation Conference.

Barnett, M. W., & Miller, C. J. (2000). *Analysis of the Virtual Enterprise Using Distributed Supply Chain Modeling and Simulation: An Application of e-SCOR.* Paper presented at the Proceedings of the 2000 Winter Simulation Conference.

Biswas, S., & Narahari, Y. (2004). Object Oriented Modeling and Decision Support for Supply Chains. ***European Journal of Operational Research**, 153*, 704-726.

Brown, N., & Powers, S. (2000). *Simulation in a box (a generic reusable maintenance model).* Paper presented at the Proceedings of the 2000 Winter Simulation Conference.

Bruschi, S. M., Santana, R. H. C., Santana, M. J., & Aiza, T. S. (2004). *An Automatic Distributed Simulation Environment.* Paper presented at the Proceedings of the 2004 Winter Simulation Conference.

Brutzman, D. (2004). *Extensible Modeling and Simulation Framework (XMSF).* Retrieved September 17, 2005, 2005, from www.MovesInstitute.org/xmsf

Byrne, P., & Heavey, C. (2004). *Simulation, a Framework for Analyzing SME Supply Chains.* Paper presented at the Proceedings of the 2004 Winter Simulation Conference.

Chandrasekaran, B., Stephenson, J. R., & Benjamin, V. R. (1999). What are Ontologies, and Why Do We Need Them? *IEEE Intelligent Systems, 1*(2), 20-26.

Chang, Y., & Makatsoris, H. (2000). Supply Chain Modeling Using Simulation. *International Journal of Simulation, 2*(1), 24-30.

Chatfield, D. C. (2001). *SISCO and SCML- Software Tools for Supply Chain Simulation Modeling and Information Sharing.* Unpublished Ph.D. Dissertation, The Pennsylvania State University.

Chwif, L., Barretto, M. R. P., & Saliby, E. (2002). *Supply Chain Analysis: Spreadsheet of Simulation?* Paper presented at the Proceedings of the 2002 Winter Simulation Conference.

Corporation, P. (2002). Supply Chain Guru.

Ding, H., Benyoucef, L., Xie, X., Hans, C., & Schumacher, J. (2004). *"One" A New Tool For Supply Chain Network Optimization And Simulation.* Paper presented at the Proceedings of the 2004 Winter Simulation Conference.

Enns, S. T., & Suwanruji, P. (2003). *A Simulation Test Bed for Production and Supply Chain Modeling.* Paper presented at the Proceedings of the 2003 Winter Simulation Conference.

Fayez, M. S. (2005). *An Automated Methodology for a Comprehensive Definition of the Supply "Chain Using Generic Ontological Components.* Unpublished Ph.D. Dissertation, University of Central Florida, Orlando, Florida.

Fishwick, P. A., & Miller, J. A. (2004). *Ontologies for Modeling and Simulation: Issues and Approaches.* Paper presented at the Proceeding of the 2004 Winter Simulation Conference.

Gan, B. P., Liu, L., Jain, S., Turner, S. J., Cai, W., & Hsu, W.-J. (2000). *Distributed Supply Chain Simulation Across Enterprise Boundaries.* Paper presented at the Proceedings of the 2000 Winter Simulation Conference.

Ganapathy, S., Narayanan, S., & Srinivasan, K. (2003). *Simulation Based Decision Support for Supply Chain Logistics.* Paper presented at the Proceedings of the 2003 Winter Simulation Conference.

Gupta, A., Whitman, L., & Agarwal, R. K. (2001). *Supply Chain Decision Agent System.* Paper presented at the Proceedings of the 2001 Winter Simulation Conference.

Hamoen, S. C., & Moens, D.-J. (2002). *Logistic Simulator for Steel Producing Factories.* Paper presented at the Proceedings of the 2002 Winter Simulation Conference.

Harold, E. R. & Means, W. S. (2002). *XML in a Nutshell*: O'Reilly.

Herrmann, J. W., Lin, E., & Pundoor, G. (2003). *Supply Chain Simulation Modeling Using the Supply Chain Operations Reference Model.* Paper presented at the Proceedings of DETC'03, Chicago, Illinois.

Hoover, S. V., & Perry, R. F. (1990). *Simulation: A Problem Solving Approach* (First Edition ed.). Reading, Massachusetts: Addison-Wesley Publishing Company.

Ingalls, R. G., & Kasales, C. (1999). *CSCAT: The Compaq Supply Chain Analysis Tool.* Paper presented at the Proceedings of the 1999 Winter Simulation Conference.

Kelton, W. D., Sadowski, R. P., & Sadowski, A. (2002). *Simulation with Arena*: McGraw Hill.

Khoshnevis, B. (1994). *Discrete System Simulation*: Mc-Graw Hill, Inc.

Lacy, L., & Gerber, W. (2004). *Potential Modeling and Simulation Applications of the Web Ontology Language- OWL.* Paper presented at the Proceedings of the 2004 Winter Simulation Conference.

Lacy, L. (2006). *Interchanging Discrete event simulation Process Interaction Models using the Web Ontology Language- OWL.* Unpublished Ph.D. Dissertation, University of Central Florida, Orlando, Florida.

Law & Kelton. (1991). *Simulation Modeling and Analysis*: McGraw Hill, Inc

Liu, J., Wang, W., Chai, Y., & Liu, Y. (2004). *Easy SC: A Supply Chain Simulation Tool.* Paper presented at the Proceedings of the 2004 Winter Simulation Conference.

Mackulak, G. T., & Lawrence, F. P. (1998). *Effective simulation model reuse: a case study for AMHS modeling.* Paper presented at the Proceedings of the 1998 Winter Simulation Conference.

Miller, J. A., Baramidze, G. T., Sheth, A. P., & Fishwick, P. A. (2004). Investigating Ontologies for Simulation Modeling.

Morgan, S. (1994). *Automatic Generation of Quest Simulation Models.* Paper presented at the Proceedings of the Deneb Users Group Conference.

Nasereddin, M., Mullens, M., & Cope, D. (2002). *The Development of A Reusable Simulation Model for the Modular Housing Industry Using ProModel and Visual Basic.* Paper presented at the Proceedings of Industrial Engineering Research Conference.

Pathak, S. D., Dilts, D. M., & Biswas, G. (2003). *A Multi-Paradigm Simulator for Simulating Complex Adaptive Supply Chain Networks.* Paper presented at the Proceedings of the 2003 Winter Simulation Conference.

Pidd, M. (2002). *Simulation Software and Model Reuse: A Polemic.* Paper presented at the Proceedings of the 2002 Winter Simulation Conference.

Pundoor, G. (2002). *Supply Chain Simulation Models for Evaluating the Impact of Rescheduling Frequencies.* Unpublished Masters Thesis, University of Maryland, College Park, MD.

Reichenthal, S. W. (2002). *SRML - Simulation Reference Markup Language*. Retrieved September 16, 2005, 2005, from www.w3.org/TR/SRML

Ritchie-Dunham, J., Morrice, D. J., Scott, J., & Anderson, E. G. (2000). *A Strategic Supply Chain Simulation Model.* Paper presented at the Proceedings of the 2000 Winter Simulation Conference.

Rossetti, M. D., & Chan, H.-T. (2003). *A Prototype Object Oriented Supply Chain Simulation Framework.* Paper presented at the Proceedings of the 2003 Winter Simulation Conference.

Sargent, R. G. (1998). *Verification and Validation of Simulation Models.* Paper presented at the Proceedings of 1998 Winter Simulation Conference.

SCC. (2003). *The Supply Chain Council*. Retrieved 10 October, 2003, from http://www.supply-chain.org/Resources/faq.htm

Schunk, D., & Plott, B. (2000). *Using Simulation to Analyze Supply Chains.* Paper presented at the Proceedings of the 2000 Winter Simulation Conference.

Siprelle, A. J., Parsons, D. J., & Clark, R. J. (2003). *Benefits of Using a Supply Chain Simulation Tool to Study Inventory Allocation.* Paper presented at the Proceedings of the 2003 Winter Simulation Conference.

SMMT. (2004). *Society of motor manufacturers and traders - industry forum*

Son, T. J., Jones, A., & Wysk, R. (2000). *Automatic Generation of Simulation Models from Neural Libraries: An Example.* Paper presented at the Proceedings of the 2000 Winter Simulation Conference.

Steele, M. J., Mollaghasemi, M., Rabadi, G., & Cates, G. (2002). *Generic Simulation Models of Reusable Launch Vehicles.* Paper presented at the Proceedings of the 2002 Winter Simulation Conference.

Sudra, R., Taylor, S. J. E., & Janahan, T. (2000). *Distributed Supply Chain Simulation in GRIDS.* Paper presented at the Proceedings of the 2000 Winter Simulation Conference.

Tan, G., Zhao, N., & Taylor, S. J. E. (2003). *Automobile Manufacturing Supply Chain Simulation in the GRIDS Environment.* Paper presented at the Proceedings of the 2003 Winter Simulation Conference.

Umeda, S., & Lee, Y. T. (2004). *Design Specifications of a Generic Supply Chain Simulator.* Paper presented at the Proceedings of the 2004 Winter Simulation Conference.

Vieira, G. E. (2004). *Ideas for Modeling and Simulation of Supply Chains with Arena.* Paper presented at the Proceedings of the 2004 Winter Simulation Conference.

Wartha, C., Peev, M., Borshchev, A., & Filippov, A. (2002). *Decision Support Tool-Supply Chain.* Paper presented at the Proceedings of the 2002 Winter Simulation Conference.

Williams, E. J., & Gunal, A. (2003). *Supply Chain Simulation and Analysis with Simflex.* Paper presented at the Proceedings of the 2003 Winter Simulation Conference.

Xi, H., Cao, H., Berman, L., & Jensen, D. (2003). *Distributed Supply Chain Summation using a Generic Job Running Framework.* Paper presented at the Proceedings of the 2003 Winter Simulation Conference.