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SUPPLY CHAIN SIMULATION MODELING MADE EASY: AN INNOVATIVE APPROACH

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ABSTRACT

Simulation modeling and analysis requires skills and scientific background to be implemented. This is vital for this powerful methodology to deliver value to the company adopting it. There are several practices to implement and rely on simulation modeling for strategic and operational decision making, including hiring simulation engineers, building internal simulation team, or contract consultants. These practices are different in terms of budget, time to implement, and returns. In this paper, an innovative approach is described that provide a simulation solution that is affordable at the same time can be quickly implemented. it consists of generic interface that captures the information and structure of the supply chain then automatically generates simulation models. The user, which not necessarily a simulation expert, can quickly jump to the analysis and evaluation of scenarios. The paper presents a case study where the approach was implemented to model, simulate, and analyze NASA's Space Exploration Supply-Chain.

1 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 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.

Supply chains environment have the following characteristics:

- Uncertain and High Variability
- Dynamic
- Distributed

1.1 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 trough 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).

1.2 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"(Fayez, 2005). 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

1.3 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).

2 SIMULATING THE SUPPLY CHAIN

Simulation modeling provides the flexibility to model processes and events to the desired level of complexity, in a risk free, dynamic and stochastic environment. It provides the essential level of realism and utility required to model supply chain environments accurately. The Simulation methodology provides a means by which decision makers can obtain accurate results, given the model is valid, that take into account the uncertainty, dynamism and distributed nature of supply chain environments. With decision support tools based on mathematical models, spreadsheets or process map methodologies, decision makers are making decisions based on too many assumptions that very rarely hold true. Further, very rarely decisions making is solely based on the information provided by an average. For example, by not taking the Bullwhip effect into consideration in an analysis, analyst are planning for significant inefficiencies such as production backlogs and unbalanced capacities. This also leads to loss in revenues due to lost sales, poor customer service, high backlog costs, high inventory costs, etc. The bottom line is that not taking into account variability costs money. Averages cost money. They decrease companies' economic value added by reducing sales, increasing the cost of good sold, total expenses and increasing inventory

In addition, simulation models provide flexibility to allow for the dynamism and distributed nature of supply chain environments. Simulations allow for easy variation of parameters within the model. The modified models can then be immediately run obtaining results sometimes in a matter of seconds. This is not always possible with mathematical modeling and process maps which sometimes require new models to be developed if the parameters change significantly. This increases the investment in time, money and resources that companies have to make when having to re-do models when parameters change.

2.1 Simulation and Supply Chain : A Literature Review

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.)

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.

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. Biswas and Narahari (2004) developed DESSCOM, an object oriented supply chain simulation modeling methodology. 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. Narayanan and Srinivasan (2003), developed a decision support system consisting of a user interface and an object oriented simulation model. Ingalls and Kasales (1999) describe CSCAT, an internal supply chain simulation analysis tool. CSCAT is based on Rockwell Software's ARENA. Jain and Workman (2001), describes their efforts developing a generic simulation tool to model supply chains. Liu, Wang, Chai and Liu (2004) discuss the development of Easy-SC, a Java-based simulation tool. 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. 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 uses the ProModel discrete event simulation language as its simulation engine (ProModel Corporation, 2002).

2.2 Generic and Automatic Simulation: A Literature Review

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 & 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 & 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. Trough 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, & 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).

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.

3 THE METHODOLOGY

This paper presents an innovative approach that addresses these shortcomings by developing an integrated methodology that allows supply chain decision makers to analyze the performance of their supply chain in a fast, sharable and easy to use format. The tool allows 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. **Figure 1** presents the methodology.

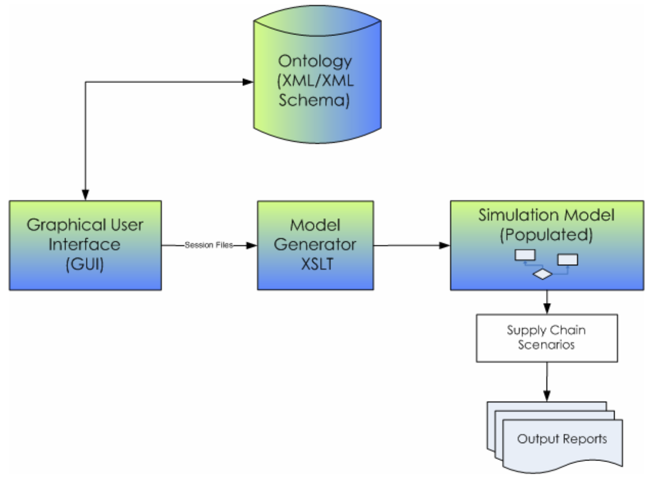

Figure 1: High Level Overview of Methodology

The methodology has the following components:

3.1 The 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, entity with entity. The core of the ontology was built around the SCOR model as the supply chain industry standard operations reference model with over 200 mature best practices and performance metrics. The supply chain structure in SCOR was used to develop different supply chain models and views using the suite of IDEF models. The different views and models were integrated in an ontology. In order to incorporate simulation specific construct (SCOR model does not incorporate simulation specific knowledge), the ontology was modified to include a Resource class, Processing Duration class, Simulation Setup Class and Entity Class. These classes were used to incorporate the knowledge that will be used to define resource capacities, processing durations, run lengths, entity definitions (orders, signals and/or objects), etc. The ontology was implemented using XML and XML schemas, where the schema holds the logic and the relationships usually exists in the supply chain, the schema was designed to be flexible and extensible in such a way that can be customized and altered to define a particular supply chain specifics.

3.2 The Simulation Modeling Methodology

The simulation modeling methodology should 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 should be flexible, scalable and expandable to allow for modeling systems in diverse fields at varying levels of fidelity.

The simulation modeling methodology 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. 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. 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.

3.3 The Automatic Generator

The main goal of this automatic simulation model generator is to provide sound tools for the end users to input their logistics structures and interactions accurately without requiring too much knowledge of simulation techniques.

The automatic generator serves as a link between the supply chain simulation ontology and the modeling engine. The automatic generator parses the ontology knowledge to automatically generate a simulation model of the system of interest and to populates the simulation model with the required instances of data that will drive the simulation scenarios. Furthermore, the automatic generator serves as a user interface tool that will also allow for the storing of ontology and scenario files in a sharable, platform independent format.

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 trough 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 XML file follows a schema that allows for the definition of Supply Chain systems in an easy and user friendly manner. **Figure 2** presents a sample XML GUI output file.

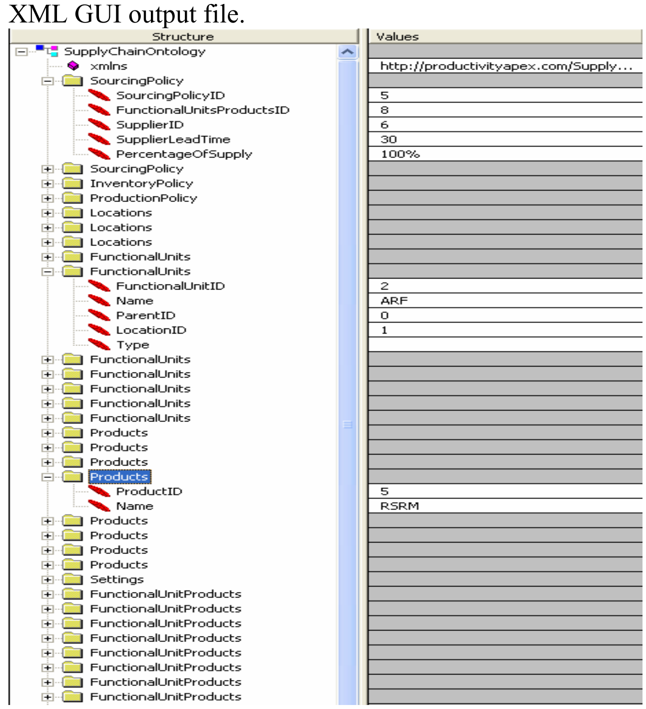

Figure 2: XML File Structure

In order to generate models, the file above 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 obtains the initial XML file and transform them into a new XML file that follows the schema of the XML file above. 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). **Figure** 3 presents the Automatic Generation methodology.

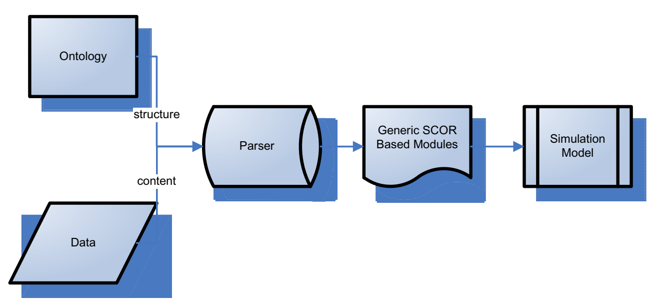

Figure 3: Automatic Generation Methodology

3.4 Evaluating the Methodology

In order to evaluate the methodology, a series of scenarios were developed using the methodology. The scenarios developed were designed to address one or more of the shortcomings in Supply Chain Modeling (Banks, 2002). The following scenarios were defined:

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

Table 1 presents these scenarios and how they address the shortcomings.

Table 1: Shortcomings in SCM (Banks, 2002) addressed.

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

The methodology was evaluated against a set of criteria. Table 2 presents the criteria defined. The models developed using the methodology met the criteria defined with a significant reduction in model design and development time from the traditional approach.

4 THE EARTH TO ORBIT SUPPLY CHAIN: A CASE STUDY

The case study summarizes the application of the approach in NASA Supply Chain projects. The objective of the project is to develop an end-to-end Space Exploration Supply Chain modeling, simulation, and strategic analysis capability focusing on Earth-to-Orbit (ETO) operations. The Space Exploration Supply Chain is defined as "The integration of NASA centers, facilities, third party enterprises, orbital entities, space locations, and space carriers that network/partner together to plan, execute, and enable an Exploration mission that will deliver and Exploration product (crew, supplies, data, information, knowledge, physical samples) and to provide the after delivery support, services, and returns that may be requested by the customer. The project will deliver a unique strategic analysis capability that will enable system operations analysts and decision makers to understand, estimate, and make informed decisions about the Supply Chain for Exploration and Space Transportation Systems early in the decision making. The Space Exploration Supply Chain is one of the largest chains known to man-kind. This complex Supply Chain brings together a space transportation system for which a usable payload is a small percent of extreme value. It starts on Earth, passes through different locations in space, reaches deep space, ends on a planet or lunar surface, collects samples and runs experiments, delivers back to Earth data and information through the deep space network, and later delivers physical samples back to Earth.

Table 2: Evaluation Criteria

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

After understanding the supply chain understudy, the project team used the GUI to define the supply chain and its structure. The team defined the supply chain in a top down approach starting with the products, enterprises, geographic locations, and functional units. At the functional unit level the products flows through a functional unit were linked to that functional units. For each product at each functional unit several policies were defined. There are policies for sourcing, production, delivery, return, and inventory. The combination of functional units, materials, and policies define the material flow. Figure 4 presents a screenshot of GUI showing material at a functional unit.

As shown in Figure 4, there are ten different materials defined, all except material 2 are considered inbound material as they only have sourcing policies. Material 2 is the is produced and delivered to the next tier. Each policy can be edited and further customized to the process level, as for example, the sourcing policy shown above and its processes can be selected and resources can be assigned for each process. After defining the entire supply chain, the simulation model can be generated, executed, and output parameters selected, and output report generated.

5 SUMMARY AND CONCLUSIONS

The paper presented an innovative approach that will make adopting and deploying the simulation methodology easier than have ever been before. The approach was implemented in a tool that can be used to model and simulate any supply chain. The tool have been customized for NASA to model, simulate, and analyze the space exploration supply chain. Instead of focusing on the model development, the team in NASA are focusing on defining the exploration supply chain and populating the GUI with required data in their natural language. The tool transforms their definition and data into a simulation model that is generated automatically. The automatic generation significantly reduces the simulation modeling cycle time and allows the team to focus on analysis and evaluating new operational scenarios. It also enabled more stakeholders involvement as there is no need for deep simulation knowledge to develop models and run scenarios. The development team is working on making the tool even easier

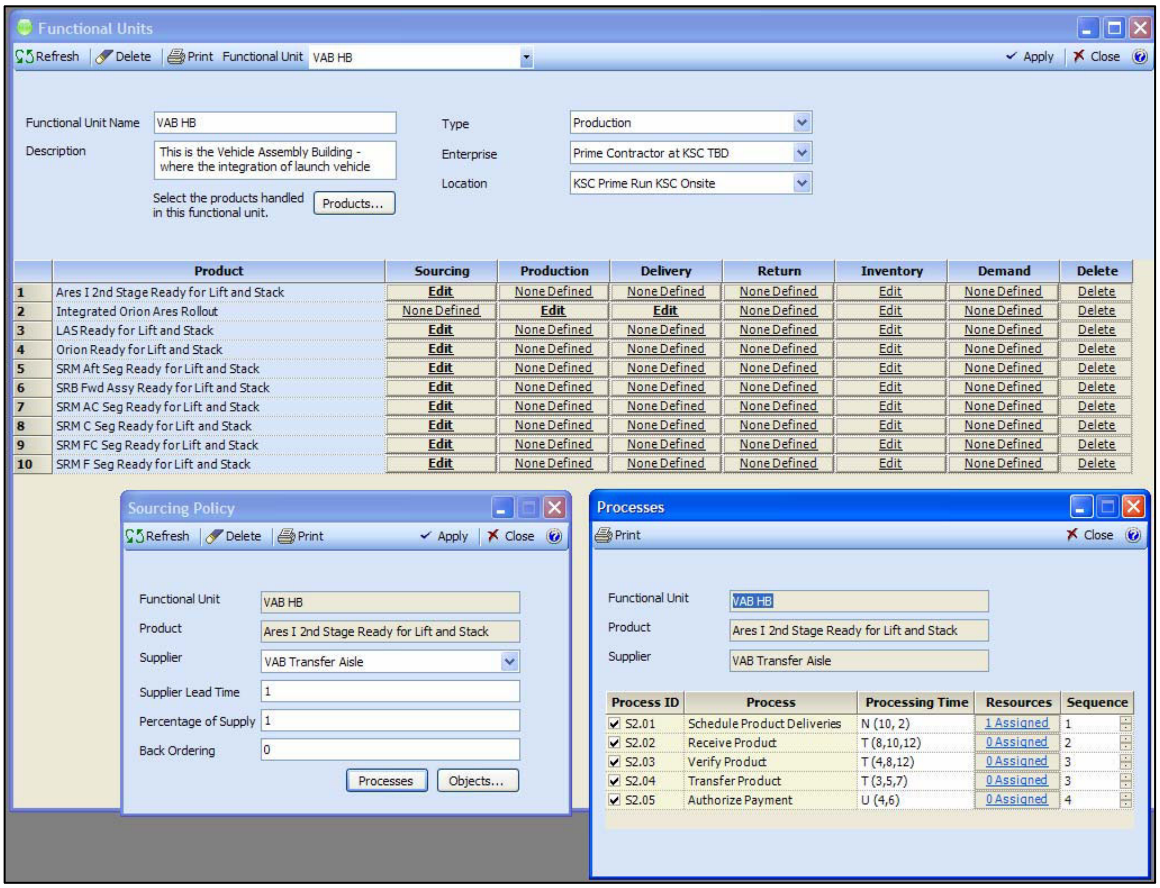

Figure 4: Screenshot of the Simulation Generator

by creating an internal database of best practices based on the SCOR model which will enable the users to select best practices and generate scenarios.

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