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A Strategic Approach for Global Supply Chain Management Simulation System Development over WWW

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Web 상에서 공급사슬경영 시뮬레이션 시스템의 개발을 위한 전략적 접근방법

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The use of the Web-based Simulation Environment (WBSE) provides a strong influence on supply chain simulations. A virtual supply chain simulation is available to evaluate strategies for reducing response time to customers and for shrinking the finished goods inventory along its supply chain. This paper presents the basic concepts and definitions of Web-Based Global Supply Chain Management (WBGSCM) simulation system. It also discusses the advantages of supply chain simulation modules integration. A Time Synchronization Mechanism (TSM) called Phased Bucket Scheme (PBS) is introduced as an approach of the distributed simulation modules integration.

1. Introduction

Many manufacturing businesses are reforming the process by which they build products because of the market trends toward highly customized products. Manufacturers need more efficient organizations since customers expect greater responsiveness in fulfilling their orders. Due to this increased expectation, supply chain management has become one of the most important sources of competitive advantage in business today. Although a manufacturer does not possess all of the supply chain, it should give customers satisfaction through the entire chain. As a result, evaluating the performance of a supply chain that includes both demand satisfied from inventories and demand for specially configured products becomes more critical.

A simulation model is the perfect tool for performance analysis of the supply chain. A supply chain simulation can be used to evaluate strategies for reducing response time to customers and for shrinking the finished goods inventory along its supply chain (Hssain *et al.*, 1998; Kalasky 1996; Wyland *et al.*, 2000). Among other capabilities, the model captures the random variations in sales, transportation lead times, supplier issues for especially configured orders, and inventory levels. By modeling the plant operations in sufficient detail in terms of major operations, product mix, and line scheduling, it provides a tool to balance supply and demand at an aggregate level.

To develop such a supply chain simulation model, two approaches are available: (1) to develop a completely new simulation system from scratch, or (2) to construct a system utilizing existing simulation systems. The second approach should be a more effective allocation of scarce resources and would be even more effective if modules were integrated from physically different sites through the Internet .

Integrating simulation modules in several locations will be attempted by connecting the computers in the modules via the Internet or Intranet for integrating the information flow. Information in each module will be transferred through Active Data Translator(ADT). It considers the integration of simulation modules as the Web-Based Global Supply Chain Management(WBGSCM) simulation system to utilize the potential effectiveness of simulation

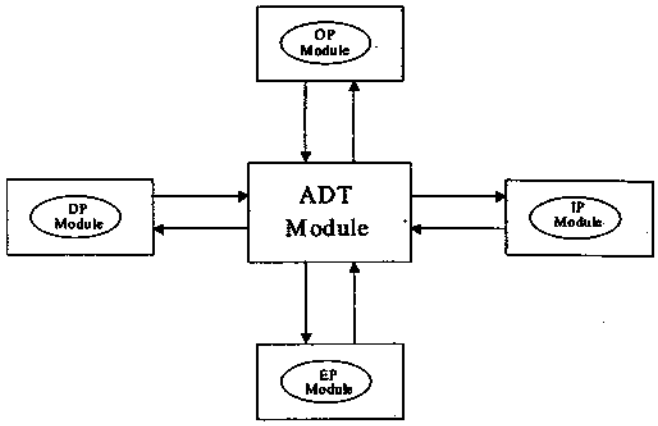

Figure 1. GSCM modules connected by the ADT.

modules for overall improvement of the design and management of a GSCM(Kang, 2000). <Figure 1> shows the GSCM modules connected by the ADT.

In figure 1, supply chain includes four sub-modules - DP (Demand Planning), EP (Enterprise Planning), IP (Inventory Planning), OP (Order Promising) that are common business processes for most manufacturing. The following briefly describes each module:

Demand Planning — The objective of the demand planning process is to understand the buying patterns of the customer and develop aggregate, collaborative forecasts. Demand planning is by definition a planning process that feeds into the supply planning processes and subsequently the demand fulfillment process. Demand planning involves long-term, intermediate-term, and short-term time horizons.

Enterprise Planning — The objective of the enterprise planning process is to optimally position enterprise resources to meet demand. This is a planning-level sub-process that spans the strategic and tactical supply-planning processes. Long-term planning, distribution planning, collaborative procurement, transportation planning and supply allocation are all parts of this sub-process.

Inventory Planning — The objective of the inventory planning is to determine optimal order-up-to levels of each inventory in a supply chain under an uncertain environment during a finite time horizon. Raw material inventory, in-process inventory, and end-product inventory are linked in a serial.

Order Promising — The objective of the order promising process is to provide fast, accurate and reliable delivery-date responses to customer orders. Demand Fulfillment is mainly an execution- level sub-process that includes order capturing, customer verification, backlog management and order fulfillment.

Throughout the remainder of the paper, the configuration of the Web-Based GSCM simulation system is presented in Section 2. The Phased-Bucket Scheme to model development is discussed in Section 3. Before the conclusion of this study, Section 4 describes the steps for simulation system development.

2. Configuration of the WBGSCM Simulation System

This section reviews the necessary requirements to construct an integrated GSCM, and then considers constructing a GSCM in a distributed computer network environment. A synchronization mechanism is proposed for a distributed simulation system, called the phased bucket scheme.

2.1 Web and Internet Technology

Current Web technology can provide Web-based Simulation (Fishwick 1996) that is an advanced form of distributed simulation. Although the Web was not developed specifically for distributed simulation, it allows collaborators in remote sites to share their ideas and all aspects of a common project (Lorenz *et al.*, 1997; Mann *et al.*, 1998). Because Web-based Simulation is similar to other projects of the WWW such as interfacing from remote sites, sharing knowledge, and common projects, it can serve as a method for the sharing of modules in a Web-Based Global Supply Chain Management (WBGSCM) simulation system.

WBGSCM is based on an n-tier distributed environment where any number of tiers of application logic and business services are separated into components that communicate with each other across a network. In its most basic form, WBGSCM can be depicted as a "logical" three-tier computing model, meaning that there is a logical, but not necessarily physical, separation of processes. This model is designed to support clients with high function Web Application and Simulation Engine servers (<Figure 2>).

A prototypical WBGSCM three-tier architecture consists of

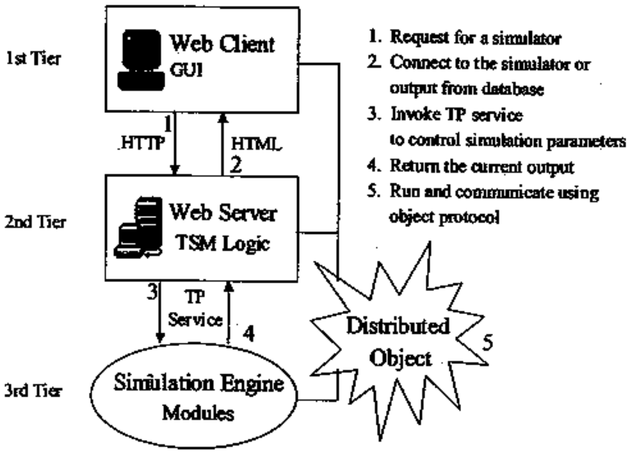

Figure 2. Logical three-tier Simulation Computing Model.

1. A client tier containing logic related to the presentation of information and requests to simulation through a browser.
2. Web application servers containing the TSM logic and process that control the ADT.
3. Simulation engine servers that provide the execution of simulation models and generate outputs.

With the logical three-tier architecture, network optimization is a necessary process. An overall network structure is critical to reduce communication time between distributed simulation modules.

2.2 Simulation Systems and Basic Assumptions

To construct a Web-based GSCM simulation system, it is necessary to observe a global order flow in a GSCM as shown in <Figure 1>. Although a global material flow or inventory level can be another observation (Hafeez 1996; Petrovic *et al.*, 1998), this study only considers the order flow. <Figure 3> shows a hypothetical flow of order, O_s, from Module i to Module j through the Active Data Translator (ADT), with the following chronological features.

- $TR_{is} = TR_{ts}$
  The order, O_s, becomes ready to be sent to Module j at time TR_{is} and a decoding translation is requested in an ADT. It assumes the request is received by the ADT at time TR_{ts} with no delay; hence, $TR_{is} = TR_{ts}$.
- $TS_{is} = TS_{ts}$
  A translation assigned to service the decoding data from Module i at time TS_{ts}. The order, Os, is encoded to move to Module j at time TR_{is}. It assumes the uploading is instantaneous; hence, $TS_{ts} = TR_{is}$.

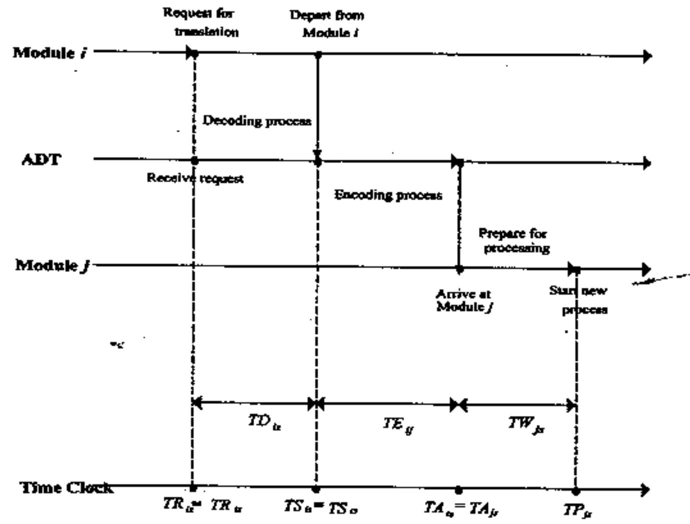

Figure 3. Global Order Flow from Module i to Module j.

- $TA_{ts} = TA_{js}$
  The order, O_s, arrives at Module j and instantaneously is downloaded, hence $TA_{ts} = TA_{js}$.
- TP_{js}
  The order, O_s, undergoes processing in the waiting area of Module j and becomes ready to put into the operation at time TP_{js}.
- $TD_{is} = TR_{is} - TR_{is} = TSts - TR_{ts}$
  The decoding time of the order, O_s, at Module i
- $TE_{is} = TA_{js} - TR_{is} = TA_{ts} - TS_{ts}$
  Time require for the order, O_s, to encode from Module i to Module j.
- $TW_{js} = TPjs - TA_{js}$
  Time Wait of the order, O_s, in the waiting area of Module j.

In the conventional simulation on a single processor, all events are processed in chronological order resulting in an accurate representation of the above order flow. In a distributed simulation on multiple processors, however, a special device, named a synchronization mechanism, is necessary to synchronize the timing of sending and receiving operations of a request and decoding and encoding operations of order since the processes simulating Module i, Module j and ADT are different in their computations.

Based on the above discussion, basic assumptions are described for simulation systems:

1. A site, i.e., Module i, is mostly operated independently for a certain period. In the period, orders in the module at the beginning of the period are processed. The processing stops

until new orders arrive at the module at TA_{is} and are ready for processing at TP_{is}. That is, the new orders are ready for processing if the orders are completely consumed in the period, if the number of orders at the beginning of the period is sufficiently large and if the length of the period is sufficient.
2. The time required for encoding translation from one module to another, TE_{ij}, could be relatively long when the supply chain is large and the size of a module is set to be large, as assumed in item 1. This suggests that the following assumption is acceptable: the orders completed at Module i in a period will not be used in another module, e.g., Module j, in the same period even if the orders become ready for processing.
3. The capacity of the network for sending/receiving is large enough and no blocking of order flow will occur due to the breakdown of the network.

In this research, the period in item 1 is named as a Time Bucket and the following terms are defined:

- BT
  Bucket Time (time length of a Time Bucket)
- TB_k
  k-th Time Bucket in the simulation run
- STB_k, ETB_k
  Times in a clock of the total simulation at the beginning of and at the end of k-th Time Bucket, TB_k, respectively. $STB_{k+1} = ETB_k = STB_k + BT$

2.3 Synchronization Simulation Mechanism

When a sub-system such as Modules or ADT is modeled in one simulation system, the arrival at and departure from the sub-system are represented by generating and absorbing nodes of transactions. In constructing a virtual supply chain simulation as a distributed simulation system, these nodes in a model of a sub-system are connected as in <Figure 4>. Arrival of order will occur at any time. Therefore, an accurate realization of order flow depends on the method used to represent the arrival of orders.

In a distributed simulation, order flow may be realized by transmitting a message to generate an arrival event in the sub-system of the destination. A synchronization mechanism, which can respond to

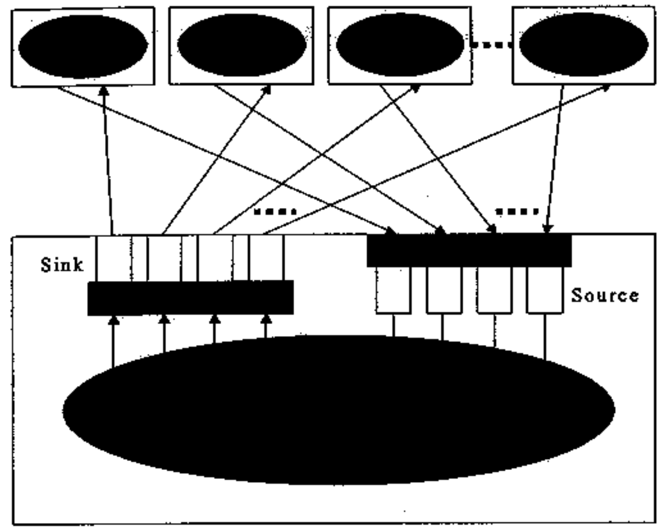

Figure 4. Connection of Sub-Modules with ADT.

the order flow and is essential to process the arrival event in a chronological order without conflict is also required. The Time Warp mechanism (Jefferson, 1985) is proposed for synchronization, even though it requires state saving and exchanging functions for rollback operations (Misra, 1986; Das *et al.*, 1994) that are not easily applicable in commercial simulation languages.

3. Development of the Phased-Bucket Scheme

A kind of block-resume scheme is used to keep processes synchronized in WDSE. It is necessary to synchronize the time of operations between modules because processors simulating sites are different in WDSE. A communication algorithm, called a phased-bucked scheme, between the distributed operations will be developed in this study. A random interval and a series of periodic intervals can be applied for the performance evaluation of the scheme.

3.1 Basic Concept of Time Bucket Scheme

The Time Bucket Mechanism in this research is schematically shown in <Figure 5>. Simulation runs of sub-systems, i.e., Modules and ADT, in kth Time Bucket, TB_k, start at STB_k and stop at ETB_k. Since the simulation contents of sub-systems are different from one another, the run lengths in Real World Time (RWT) are different. When the latest run is completed, e.g., Module j with Local Virtual Time (LVT), which is a clock in the simulation of the Module, $k+1^{st}$ Time Bucket, TB_{k+1}, starts. This

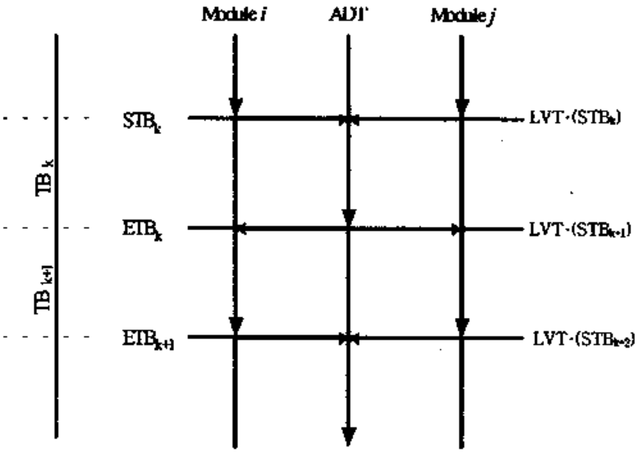

Figure 5. Basic Concept of the Phased Bucket Scheme.

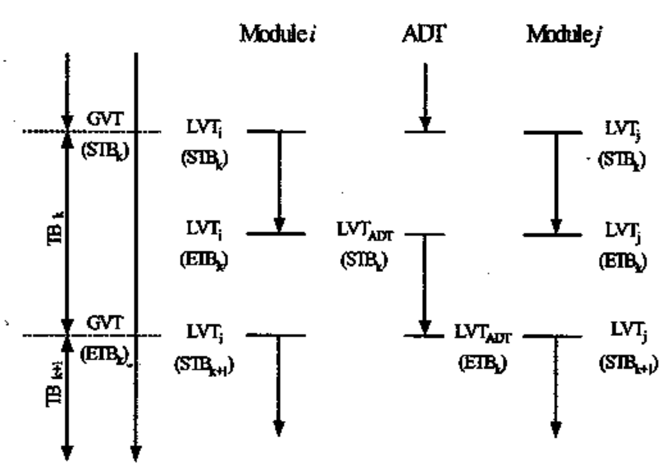

Figure 6. Phased Time Bucket Scheme.

means a processor stopped at LVT(ETB_k) will wait until RWT(ETB_k) before starting the new bucket.

3.2 Phased-Bucket Scheme

The Time Bucket Mechanism has shortcomings caused by the concurrent processing of all simulation sub-modules, including ADT. In <Figure 3>, Module i sends a translation request message to an ADT. In reality, TR_{is} should equal TR_{ts}, but the Time Bucket Mechanism does not permit the ADT to receive the appropriate message, because an ADT can receive messages only at the end of a Time Bucket. As a result, the erroneous interval between TR_{is} and TR_{ts}, ΔT, can influence the simulation results.

To deal with this problem, a modified Time Bucket Mechanism, called Phased Bucket Scheme (PBS), is proposed. In the PBS algorithm, simulation processing during a bucket is divided into two phases: namely, a Module simulation phase, and an ADT processing phase. These are executed alternately. Since an ADT starts its processing of one Time Bucket after all Module simulators come to the end of the Time Bucket, it can receive translation request messages appropriately, as shown in <Figure 6>. Global Virtual Time (GVT) is indicated as a clock of the total simulation in the figure.

Step 1. Module simulators execute their simulation process for TB_k independently and stop their processing at the end of TBk. They then send translation messages to an ADT.

Step 2. After the ADT receives messages from all Module simulators and registers all times for translator requests in its event list, it starts the execution of its processing for TB_k.

Step 3. When the ADT stops its processing at the end of TB_k, it sends order arrival messages to Module simulators.

Step 4. When the Module simulators receive messages, they modify their status and statistical data in TB_k.

Step 5. Loop to Step 1.

Via the PBS, the order which arrives at Modules during TB_k is reported at the end of TB_k, and assumption (3) is required.

4. Simulation System Development

The proposed modeling methodology incorporates four steps of the modeling life cycle, as shown in Figure 7;

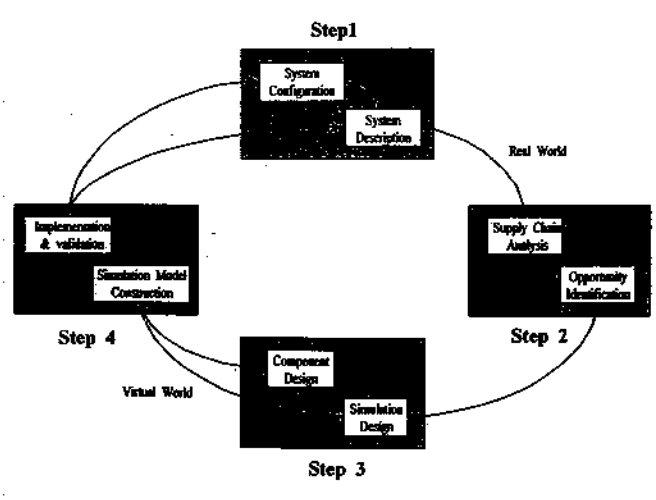

Figure 7. Modeling Life Cycle for the Proposed Methodology.

(1) System description step
(2) Supply chain analysis step
(3) Simulation model design step
(4) Model implementation step

The system configuration in Step 1 is the task that describes the simulation system and is seen as one of the most crucial tasks in modeling. Separating the system description from other models provides better management of models and modeling processes. Therefore, the system description that constructs the Meta model is separated from the analysis phase in Step 2. Step 1 and Step 2 are not clearly distinguished in the very first modeling effort because the configuration of the simulation system can be seen as one of the analysis activities. However, once the Meta model is built, the analysis phase can use an already existing Meta model; thus Step 1 may not be required.

Step 2 generally has two objectives: (1) Supply Chain Analysis and (2) Opportunity Identification. Based on the system description, the business processes and activities in the chain are analyzed. In Step 3, the idea of object-oriented modeling and analysis will be applied for the Simulation Design phase. Also, design and development of Web-based simulation components are necessary in Step 3. Once a specific model has been defined, the construction and implementation phase is the next step. A good implementation plan should ensure that improvement potential is realized through detailed planning, low risk testing and early wins to build momentum.

4.1 System Description

To construct a GSCM simulation, the following steps of description are considered:

Step 1. Modules and ADT are modeled independently on processors (computers) as simulation models of sub-modules, such as DP, IP, OP, EP, and ADT. In this step, the order information flow within each sub-module is the primary focus of the model. The arrival of order from other sub-modules and the departure of order from the sub-module to other sub-modules are generally represented by the functions of source and sink nodes in a simulation model, respectively.

Step 2. Simulation modules in Step 1 are connected by a computer network (Internet/Intranet) to be integrated into a total simulation model. In order to express the global order flow among sub-modules, source and sink nodes in a simulation model of a sub-module are connected by specially designed messages transmitted through the computer network system to appropriate source and sink nodes of other modules.

Step 3. In addition to exchanging messages for order flow, special capabilities are to be added that synchronize the processing of simulation modules.

Step 1 is a stage to develop conventional simulation models that can be used for the simulation study of stand alone systems. Step 2 and 3 require modification to the models in Step 1 to implement distributed simulation. However, the development of sub-modules, excluding ADT, is not considered in this research. It can be assumed that the sub-modules are ready to use. Therefore, the degree and the difficulty required for the integration and modification of sub-modules with ADT are the key to obtaining the GSCM simulation system.

4.2 Supply Chain Analysis

The simulation plays a role in the following activities:

(1) The business processes and activities in the chain,
(2) The individual suppliers' (factories) physical activities according to the orders, which are generated in the chain, and
(3) The data transactions through the communication among suppliers which occurred at manufacturing process in the chain.

The above activities can be described as a supply chain Meta model. The Meta model is then converted to function and information models. Each Meta model can be used to derive the individual supplier's function and information models. However, the development of individual models are not considered in this research, since modeling methodology for an individual organization is not the object of this study.

Instead of the methodology development, a modified IDEF0 model (Nam, 1995) can be used as a function model. The supply chain function model (modified IDEF0) primarily shows which function is

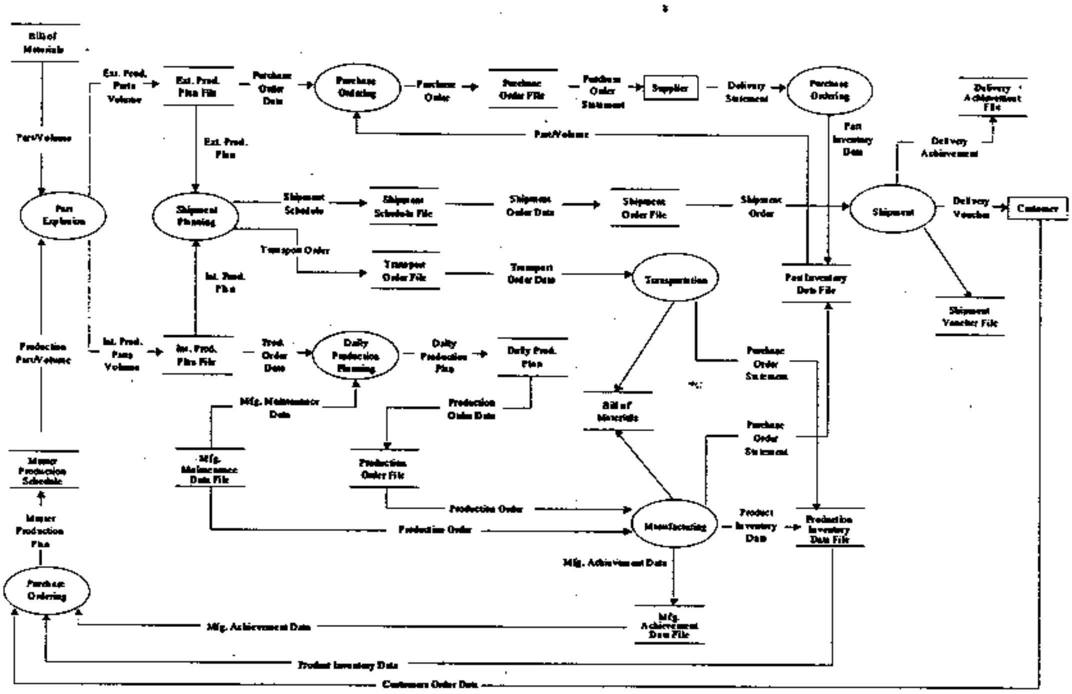

Figure 8. Example of Business Function Process Model.

related to customer and supplier interaction, how long it takes and who is responsible for the communication. It also provides data entity transmitting between factories. <Figure 8> shows an example of the business function process model for supply chain management (Umeda, 1998).

The supply chain information model includes data entities that are used for both internal processes for the individual organization and the cascading supply chain. The supply chain information model primarily shows what data entities are sent and received between companies, how long it takes to send, receive, or feedback, what the relationship of the entities to other entities is, and what the ratios of a data entity to other transmitting entities are. The model does not include all the detail of data entities and their relationships. It only shows what the supply chain information model looks like.

Again, this research is not to design a supply chain model for the individual organization. The above example for supply chain analysis, developing the Meta model and converting function/information models from the Meta model, is a single way of many possible methodologies. Therefore for implementation, it can be assumed that the supply chain analysis step is done and ready to use.

4.3 Simulation Model Design

The necessary procedures in conduct of a Web-Based GSCM are different from conventional procedures in most of the simulation literature. Specifically, the idea of object-oriented modeling and analysis will be applied for the model. The object-oriented Web-based simulation (OOWBS) approach (Cubert and Fishwick, 1997) interacts or communicates among the object models through the Web. Those objects may be located in several different locations and they are virtually linked through the network to create a Web-based simulation model. Each object in OOWBS works as a module in a Web-based GSCM simulation system.

In addition to those module objects, a Process Control object, which is the most important new concept in this research, controls all other objects using the Phased-Bucket Scheme. In the GSCM simulation model, possible objects are Demand Planning object, Enterprise Planning object, Inventory Planning object, Order Promising object, ADT object, and Process Control object.

To construct a GSCM simulation, a generic modeling concept is considered. The generic model contains the above objects. The generic model provides the capability to build specific models by integrating from commonly used existing simulation models rather than constructing one from scratch. Users may modify the generic model with the updated data, if there are any. With an understanding of the system and the type of model, virtual simulation experts can get a more efficient and accurate generic model. An embedded expert system will be proposed to adapt simulation model configurations to user-defined target performance requirements to identify initial feasible values for simulation system design variables. Finally, users can find a feasible model producing a stable system design from the generic model.

Web component design is another task for a Web-based GSCM simulation system. The components of the system can be allocated to the same or to different servers. Web clients have access to the components by using Web browsers. The Web-based Simulation Environment (WSE) will especially support model designers. If model designers want to implement new presentations in the Web, they can access appropriate components of the WSE. They call up HTML pages with different content and functionality. The components of the WSE can be classified by user aspects. The model will be implemented to recognize and demonstrate the advantages and problems of such an environment based on currently available Web techniques.

The following can be distinguished and supported by Web components:

1. *Description of the real system* — This can be supported by the Web in a classical way, by presentations of the real objects, processes, or services in static WWW pages.
2. *Acquisition of input data* — The transfer of files with input data can be done easily by the Internet. The use of new and already existing statistical tools in the WBSE is planned.
3. *Creation of a logical or artificial model of the real system* — It can be supported by presenting all relevant information in an HTML page and by allowing the creation of the model to occur on the same page.
4. *Verification and validation of the simulation model* — This step can also be supported by collecting data of the project and presenting it in an overview style page. In addition to this, simulation with deterministic data sets can be executed by the Common Gate Interface (CGI) script or Active Server Page (ASP) technique.
5. *Planning and running of simulation experiments with the model* — This can be done completely by the CGI or ASP technique.
6. *Processing, compression, interpretation, presentation, recording, and comparison of the generated results* — This can be implemented by using the CGI or ASP technique in the Web.
7. *Comparison of the simulation results with the real system and suggestions for changes in the real system* — The presentation of the results and reports can be done in the Web or the data can be transmitted easily by the Internet. It will be an HTML format

4.4 Model Implementation

This final implementation step is the most important and the often the most neglected step. It should be obvious that the benefits of a lengthy and costly analysis will not be realized without proper implementation and acceptance by users. After the construction of the simulation model, the model should be implemented and validated in order to verify that it is a feasible model. Verification focuses on internal consistency of the generic model, while validation is concerned with the correspondence between the model and reality. Since the simulation model is generated by coupling, the verification process is relatively important. In this step, the simulation model will become a more suitable simulation model.

From the suitable model, many valuable simulation results are collected for further evaluation. Simulation results contain the sample mean and variance and the frequency distribution of waiting times in the sample. Since the simulation model outputs are samples, the population parameters and probability distribution should be estimated. Couples of statistical analyses are available for an experimental design. It will know how well a system behaves in an absolute sense, or comparatively.

5. Conclusions

Two sets of conclusions can be drawn from this study. The first set relates to virtual simulation systems in Global Supply Chain Management for evaluating strategies for reducing response time to customers and for shrinking the finished goods inventory along its chain. While the second set relates to overall findings concerning the methodology of the time synchronization mechanism to integrate distributed simulation modules.

Some authors suggest building simulation models by using pre-existing model modules (Zeigler, 1987) as discussed in this paper. They cannot, however, specify a procedure for creating the modules properly, mainly because model building by integration without the removal of the physical locations of the modules is difficult. Also, they have not tried to find a way to connect the distributed modules. The concept of integration for distributed supply chain simulation modules through the WWW is totally new and no one, as yet has attempted to identify the ADT for the integration.

Web-Based GASM simulation systems based on the integration approach will have the following additional advantages over the traditional supply chain simulation model development process:

- The system does not need to develop modules for each supply chain element. This will provide non-supply chain experts access to simulation.
- Since the modules are already verified in their physical location, there is no need for module verification in the integrated model. This will reduce the time for simulation development.
- Simplified and more efficient models can be built because inefficiencies from inexperienced modelers will be eliminated.

Although this study just provides a strategic approach for supply chain management simulation system development, several synchronization mechanisms for WBGSCM can be proposed later. They will be compared from the point of view of their effectiveness in modeling the global order flow or material flow in a supply chain. This will be achieved by examining the behavior of a prototype simulator which is constructed to study the effectiveness of the synchronization mechanisms in further study.

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