AN INTEGRATION TEST-BED SYSTEM FOR SUPPLY CHAIN MANAGEMENT

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ABSTRACT

This paper proposes an integration test-bed system for supply chain management, which forms the foundation for the construction of a valued manufacturing chain. The core system of the test-bed is a hierarchical simulation system to support production management in supply chain. The test-bed possesses sub-components linked with the simulation system. These are: 1) an enterprise integration model which represents business and information process in supply chain, 2) the communication data interface between the simulation and the suppliers companies, 3) the decision support system based on statistical methods. This paper describes the details of the system architecture and system configuration. After the detail description, the authors discuss simulation integration methodologies through an application example.

1 INTRODUCTION

Modern manufacturing enterprises are required to collaborate to design and produce their products with their business partners, such as vendors, retailers, and distributors. They must review continually their strategies and restructure to simplify their business, fabrication processes, and procedures. This restructuring frequently involves fundamental decisions regarding those activities, which really do need to take place internally in full collaboration with business partners. In making these decisions, each enterprise must develop a flexible management system to survive in today's competitive market.

The supply chain often requires to change the original business ways being practiced in individual companies, including changes in the new production introduction process, the organization structure, the management of the business, performance measures, and further the information systems. A systematic approach is required to implement such concepts as these.

Supply Chain Management (SCM) is the management of material and information flows both in and between facilities in the chain, such as vendors, manufacturing plants, and distribution centers. The key issue for successful SCM is full-scale coordination between such partners. Such relationship between partners requires new data networks to share information.

The SCM planning problems are classified into 3 hierarchical levels according as the planning time horizon: strategic, tactical, and operational – strategic planning has the longest and operational planning has the shortest (Ballou, 1992). The scopes at the "strategic level" are the enterprise management issues based on information processing. While, on the contrary, the "Operational level" are mainly the physical control issues of the daily manufacturing operations such as machining, dispatch, transfer, maintenance, material handling and etc.

The "Tactical level" handles the short-term demand planning. It includes master production planning, ordering to internal or external suppliers, and inventory management. These operations must handle both information processing and material controls, and often face to the difficulty to make decisions in various management phases. The optimal implementation often faces to re-engineering issues of business processes and decision processes. According as the above reasons, we decided the first stage of implementation of the proposed system to focus on production and operations management at the tactical level of the supply chain.

The strength of simulation is to enable users to observe and analyze the dynamic behaviors in the target system in comparison with mathematical programming methods (Geoffrion, A.M.,1974) or stochastic model (Cohen, M.A., 1988). To apply simulation to supply chain management, we have two technical problems: business process representation problems and data communication problems. Supply chain management accompanies with the complex business process such as purchasing, procurement, and ordering. These business processes are tightly coupled with the individual material handling processes such as manufacturing in the factories and transportation in the distribution center. Simulation models of supply chain must represent such business process behaviors.

Supply chain management also requires frequent data exchanges among suppliers according as the above business

process behaviors. The operation flows become more complex than the case of single company, and furthermore the process status at the individual company is dynamically changing. These operations must share their data in real time mode considering the company's confidentiality. Simulation must use dynamic parameters of the suppliers in the chain to evaluate system performance in tactical operational phases. It must supports simulation data interface that is applicable to the co-operative works in the integrated system environment.

This paper proposes a simulation-based integration test-bed system supporting such multiple supply chain management operations. The descriptions cover a system concept, architecture, generic implementation methodologies, and an application example. It also discusses database systems design, interfaces and methodologies of data communication among independent firms.

2 TEST-BED SYSTEM ARCHITECTURE

We propose a test-bed system which is composed of the following sub-systems (Figure. 1):

1. Hierarchical supply chain simulation system

2. Supply-chain management communication server

3. Decision support system for suppliers management

The core system of the test-bed is a hierarchical structured simulation system. The top level is a business process simulator so-called "Virtual Suppliers Manager (VSM)". VSM simulates mainly business-process flow and information flow within chained companies. The middle level is the simulator of individual suppliers such as factory, warehouse, distributors, and transportation among them. The bottom level's one simulates the activities within each process of the factory.
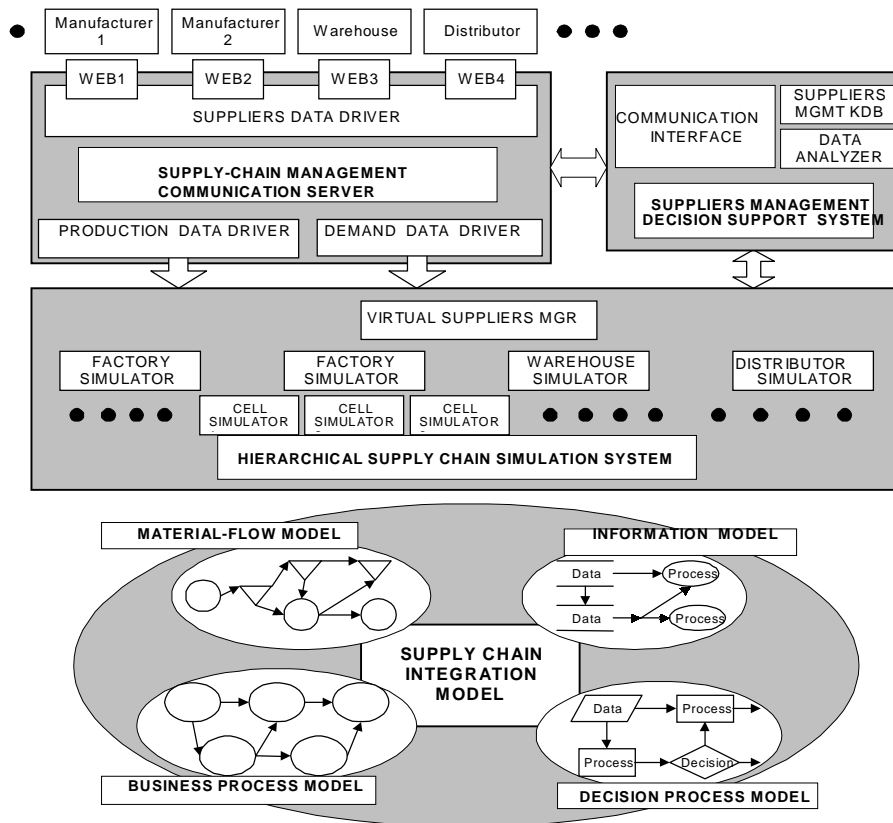

Fig. 1 System Architecture

The communication server contains three modules to communicate the tactical data among the suppliers**.**

1. **The suppliers data driver** collects three kinds of data: production data from supplier's factories, distribution data from retailers, and demand data from resellers and customers. This module also publishes the management data for production and distribution to suppliers, when it is needed.

2. **The production data driver** collects production and distribution data, and processes them to send to the simulation system and the decision support system.

3. **The demand data driver** collects demands data from the distributors and customers, and processes them to send to simulation system and the decision support system.

The communication server also provides the data exchange facilities to transfer the data with the decision support system to generate ordering data as necessary.

The suppliers management decision support system receives the data from the communication server. The system uses the data to produce the value-added data by using "Suppliers Management Knowledge Data Base" and "Data Analyzer". The former is a set of rules to manage suppliers operations, and the later is a set of routines of statistical data analysis or mathematical programming. The "Communication Interface" provides data transformation between these routines and the data gained by communication server.
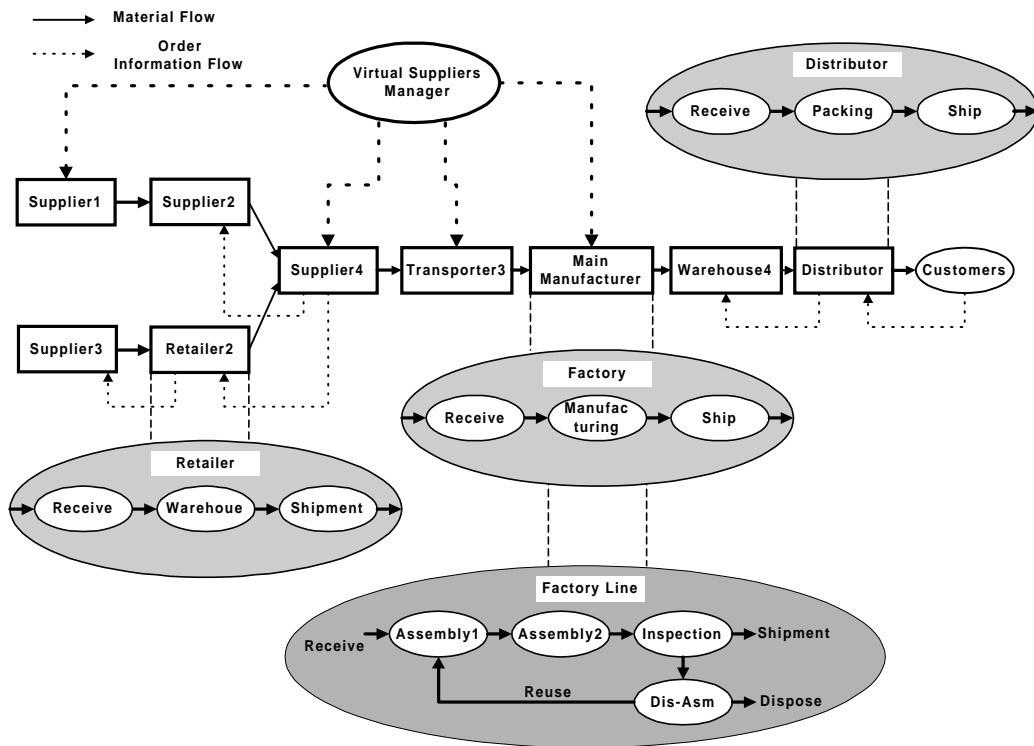

Fig.2 Hierarchical Supply Chain Simulation

The individual system uses the data model to communicate each other. The specification of data is defined in "Supply chain integration model", which composes four sub models: "Material-flow model", "Information model", " Business process model", and "Decision process model". These models describe the entities (objects), which provide the detail definitions for each of flows. They also identify all of the relationships that exist among these entities. The modeling method used here is based on our previous research (Umeda, 1996,1997).

3   SUPPLY CHAIN SIMULATION SYSTEM

3.1 Hierarchical structure of simulation

The simulation plays a role to simulate the following activities.

1) The business processes and activities in the chain,

2) The individual suppliers (factories) physical activities according as the orders, which are generated in the chain, and

3) The data transactions through the communication among suppliers occurred at manufacturing processes in the chain.

The simulation kernel provides 3 layers hierarchical models according as the operational level. The top layer's ("Chain") simulation is composed of the objects representing individual suppliers such as vendor's factories, warehouses, distributors, and so on. The middle layer's ("Factory") simulation is a factory simulation, which posses processes, transporters, and buffers. The bottom layer's ("Process") one is, what we call, a cell simulation, representing equipment like NC machines, robots, controllers, and trucks. (Fig.2)

The "Chain" simulation constructs a network of suppliers linked each other with the global transportation facilities. The suppliers include factories, warehouses, distribution centers, retailers, and transporters. This layer also posses a process simulator other than simulators of the suppliers members in chain. The process simulator is called as "VSM" (Virtual Suppliers Manager). VSM is a simulator that simulates business process activities in supply chain management. VSM also owns data entry points from demand information server and data entry points to the middle layer (factory) simulator. It uses these entry points to get/put information or data, and generates production or transportation orders to send suppliers. In some cases, a particular supplier communicates with another factories or transporters in direct.

"Factory" simulation handles the factory levels interactions in the chain including warehouses, retailers, and distributors. These simulation construct networks of processes linked each other with the inner plant transportation facilities. Factories include, at least, more than one material processing systems (manufacturing line). These lines include multiple manufacturing cells, parts buffers, material entry processes, shipment processes, and the in-line transporter like AGV. The inspection process is often included in them for the purpose of the product quality management. The general feature is similar to the traditional manufacturing line simulation. The difference with them is that the activities at several particular processes (manufacturing, shipment, transport, and material entry) are controlled by the orders from the VSM. The "Cell" simulations make up the lowest level. These are usually control logic simulations.
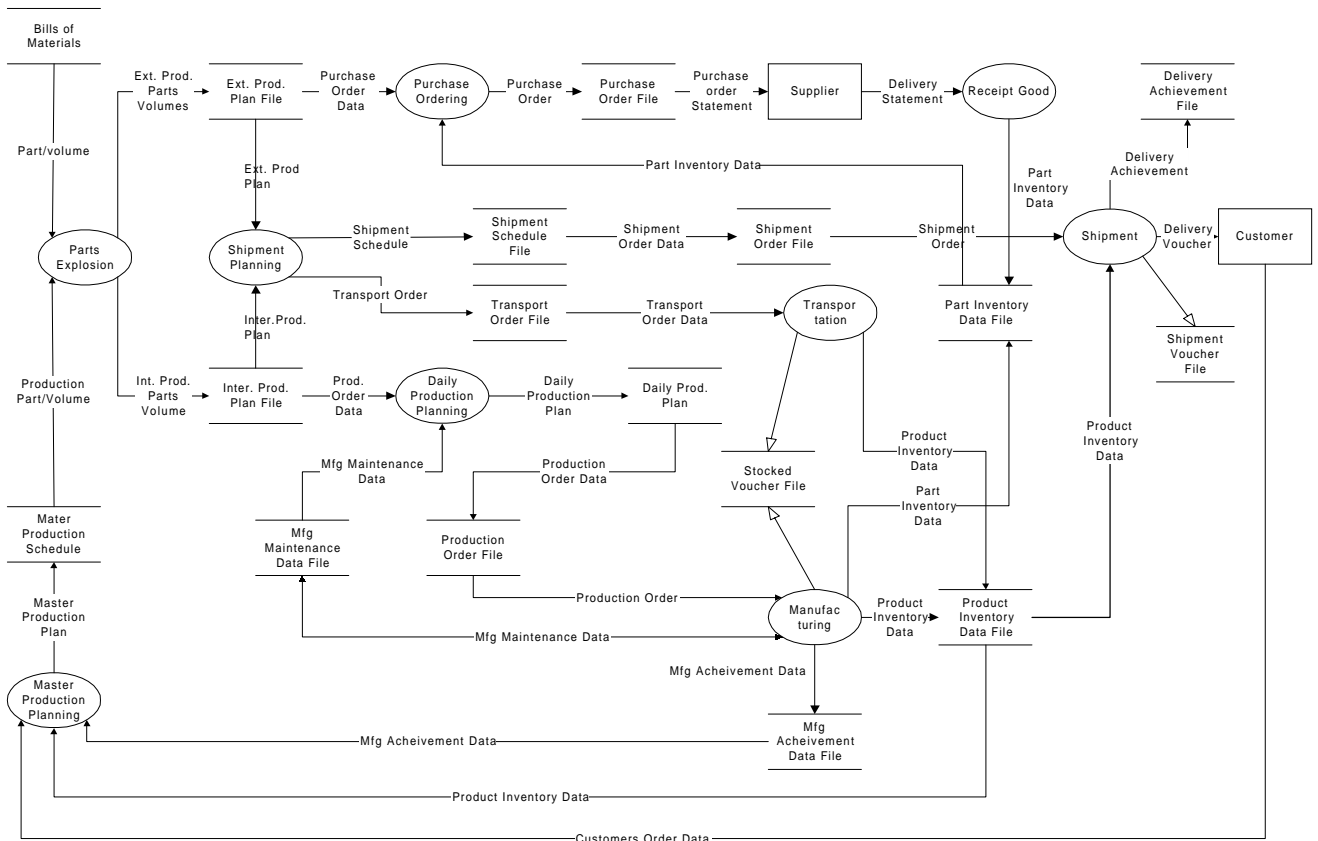

Fig. 3 Business Process Model for Supply Chain Management

The input is the physical transaction control rules of a particular machine or resource, such as NC machines or robot control program. The output is, for example, machine performance or part quality.

3.2 Virtual Suppliers Manager

Virtual Suppliers Manager (VSM) is a virtual organization, which manages all of production management activities and information flows in the supply chain. The entrance process and the exit process at the factory are also linked with VSM.

While simulations at the factory and cell levels are predominantly concerned material flow through physical activities, VSM deals mainly with the information flows through business activities. These simulated activities include demand receiving, production ordering, transportation ordering, purchase ordering, shipment ordering, and activity cost estimation.

Each of these models is composed of a set of functional activities (the business processes) and relationships among them. While there are many activities in each supplier company, we believe that there is a collection of activities common to all suppliers (see Figure 3). This common set of activities forms the basis for a coherent production and operations management plan for the supply chain. Individual activity can have its own internal decomposition. Eventually this decomposition will end with a sequence of primitive processes or actions. A primitive action consumes both time and some combination of information and material resources. This is so because all business activities get materials and/or information, process them to add value, and make them available for use by the next process. Some examples are generate, dispose, assemble, branch, batch, unbatch, merge, split, join, transform, copy, assign, seize resources, and, release resources.

The input data to VSM includes delivery orders from customers, and status information on existing orders from suppliers. VSM also uses inventory data of input/output parts, demands data in phased time, and BOM tables representing parts construction. On the while, VSM sends the process orders to the individual suppliers for production, transportation, purchase, shipment, and others.

The main job of VSM is to provide individual suppliers with such orders according as the "PUSH" ordering mechanism. Therefore, some processes of VSM are linked with the plant schedulers that schedule the activities needed to fill those production orders. The entrance process and the exit process in the chain are also liked with VSM. It can get and put all data of ordering activities, when it needs. According as the predefined planning tables or rules, it sends orders of production, transportation, purchase, and shipment to the individual suppliers.

The details of this scenario can be described as follows:

1. Predicts customers' demand volume in the next phased term by using the past log data of demand and production, and builds "Master Production Schedule"(MPS). MPS is an anticipated build schedule for those items assigned to the master scheduler. The master scheduler maintains this schedule, and in turn, it becomes a set of planning numbers that drives material requirements planning.

2. Calculates the each part volume required in individual factory. It represents what the company plans to produce expressed in specific configuration, quantities, and dates. This stage is the simulation of the part explosion using a BOM (Bill Of Material) table. In this mechanism, the synchronization of suppliers is performed in schedule-driven. At this time, it uses the suppliers/part table, which shows parts name and its supplier.

3. Gives the production orders to individual supplier. The order information transaction flows from VSM to suppliers, and the materials flow from up-stream factory to down-stream factory.

We have also stated that some members of the chain may interact according to a "PULL" system. A typical "PULL" system is a Kanban system. The "PULL" system can be defined as a buffer-driven system. This scenario can also be extended to a supply chain environment. Part suppliers or distributors individually define the replenishment point on the inventories. When the input material volume becomes lower than the predefined stock level, the suppliers independently make orders to their up-stream suppliers. The up-stream suppliers who received the orders generate their own production orders. Materials flow from up-stream to down-stream, while the order information transactions flow from down-stream to up-stream.

In practical production management, some particular supplier's factories receive production orders not from the central control system (VSM) but from their down-stream's factory directly. In other words, some suppliers' factories or field warehouses use replenishment points to control input part inventories. When the volume of input parts goes below the predefined replenishment point, the factory independently publishes production orders of a fixed volume. These suppliers re-stock inventory whenever it becomes too low. We define this scenario as "hybrid PUSH-PULL" system.

VSM provide such "hybrid PUSH-PULL" system environment to represent manufacturing logistics in supply chain. This facility can give a good solution to the "PULL

factory selection problem", which is often difficult to implement. The solution impacts not only material flow, as we have seen, but also the information flow (and the communications infrastructure needed to support that flow) between the prime contractor and suppliers.

3.3 Business Process Planning using VSM

VSM is a business process simulation to support supply chain managers in their job of designing and reengineering the makeup and behavior of the chain.

This business process simulation provides estimates for both order completions and supplier behavior. Such estimates help managers make decisions regarding a redesign or re-engineering of the chain. When a problem is detected, managers can simulate various business scenarios to find a cause for the problem. When solutions are proposed to eliminate the problem, managers can simulate their impact to determine if they really work. After each simulation is run, managers can examine the outputs to find out why the proposed solution did or did not work. Finally, managers can use the results to pick the best of the proposed solutions.

This combination of BPR and simulation within the VSM enables managers to gain insight that will help them control the operation of the chain. The insight and the process analysis will help to identify areas that need reengineering and to predict the quantitative impact of reengineering efforts. The managers of the suppliers could use this same approach to evaluate changes to their organizational structure, business processes, and the policies and methods by which those process are implemented. This type of reengineering emphasizes the overall improvement of a process based on its quality, cost, and efficiency. If it is not done on a regular basis, the damage to the company, and to the supply chain, can be huge.

Figure 3 includes all of the modeling primitives of the business process flows that generate process orders (manufacturing orders, shipment orders, etc.) to individual factories. These are critical to understanding the potential impact when the structure is changed. The examples are:

1. Suppose that all of factories in the chain uses common database for purchase ordering process, what impacts occur on total lead time in the chain?

2. Suppose that two processes of internal and external production planning are linked together, what impacts occur on the total productivity in the chain?

3. Suppose that all factories and distributors works on PULL-mode, all of planning processes will be extremely simplified. While, all factories always keep balanced inventory, and require distributed inventory

management system. Which is better? (PULL suppliers selection problem)

4   AN APPLICATION EXAMPLE

The current version of the system can demonstrate a case study of PC manufacturing supply chain (Fig. 4).

The chain is composed of parts factories (Keyboard, CDROM, SDRAM, Circuit board, and Main box), warehouses, and distribution center. In the models, the operations for production management are concentrated in VSM, which is a virtual organization to manage suppliers. The tasks of VSM are to generate production orders to send to individual suppliers by using BOM (Bills Of Materials) tables and inventory volume at each factory or warehouse.

The PC manufacturing industry is one of the typical examples that are composed of "hybrid PUSH-PULL" logistics chain. Each chain member expect their inventory levels to be kept at minimum level, while particular manufacturer has no choice without keeping inventory to some extent having because the products needs is very unstable. The particular suppliers provide their products with other chain. (CDROM in this example). Because the demand prediction of this product is very hard, the calculation of net-change requirements of this product might include errors.
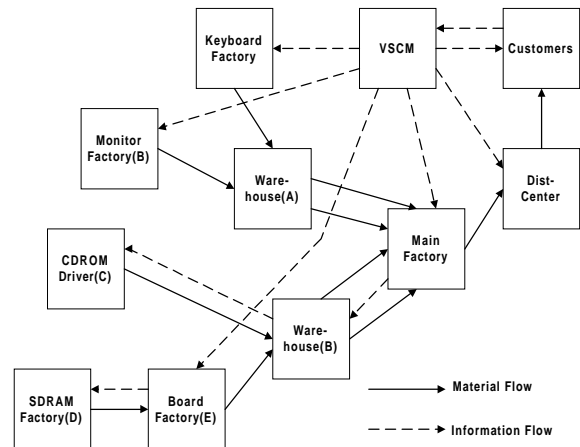

Fig.4 An Example of a Supply Chain System in PC Manufacturing

One of the good choice in such case is to pull directly the products from the suppliers, but, if they so, they must always keep inventories to some extent. Because, the PULL system is based on the policy that both suppliers and users must keep inventories to some extent at any time. There will be many reasons of the choice between PUSH and PULL other than this case.

We show, here, an application example for SCM planning problem. This example (Fig. 4) is the problem how to decide the inventory criteria which each supplier must keep to own. This problem has three propositions.

- The demand volume is decided at every working shift (8 hours). The volume is obedience with a random distribution.

- Individual supplier in the chain owns the same volume of inventory as the average production volume (8 lots) at the simulation start time.

- The planning operation at a particular shift time is done at the previous shift time.

The parameters are stock inventory level and the standard deviation of demand volume. Generally, when the demand variance is large, the required order volume might be over the pre-defined production capacity. Individual suppliers must keep stock inventories not to lose the business opportunity. Fig 5 shows the order fulfillment rates to demand distribution in total supply chain system. In this example, the inventory stock must be kept at "level 4" (Stock inventory volume is equivalent to the production volume during 4 shift operation time).
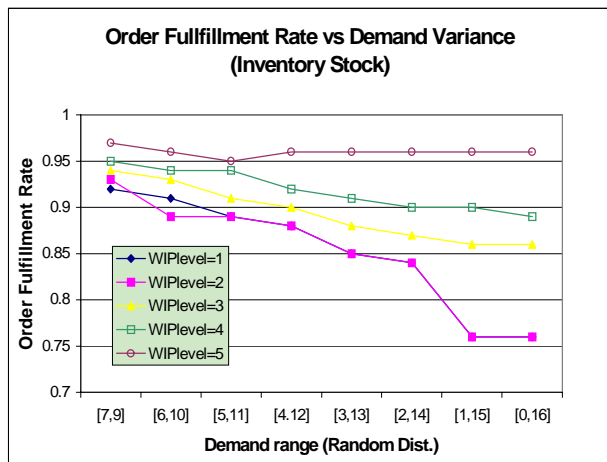

Fig.5 Sensitivity of Order Volumes Variance With Inventory Level

5 TOWARDS SIMULATION INTEGRATION

5.1 Decision support system

The tactical operations in supply chain management covers various practical problems. The significant examples of such problems includes, 1) Material/location selection problems, 2) Capacity planning, 3) Lot-size planning, 4)

Transportation channel planning, 5) Resource location planning, and others.

Utilization of simulation is effective to get solutions to the most of the above problems. On the while, simulation generally produces a huge volume of data. In addition to that, the solutions often require to take into account several performance measures, such as cost estimation, lead-time, highest utilization of resources, throughput performance, due date, and others. Practical solutions will be multi-objective optimization problems. In the most of such cases, the numerous simulation runs will be required. We face to experiments design problems of multi-objective optimization with multiple variables. It will be hard to find a solution, if we do not make effective combinations of simulation experiments.

We are currently developing a generic methodology to such simulation optimization problems. The methods used there is called "Response Surface Method", which is one of generic methods of sensitivity analysis. We are also applying the "Taguchi methods" to select effective simulation parameters to reduce the run of simulation experiments. In addition to such optimization technologies, we must utilize specific heuristics knowledge of supply chain management to reduce the simulation runs. The combination of the above techniques is effective to get solutions to the most of supply chain management problems.

The proposed model (shown in Fig.2), for an example, includes all of the modeling primitives of the business process flows that generate process orders (manufacturing orders, shipment orders, and etc.) to individual factories. Process planners can use and modify them to pre-estimate the impact when the process structure is changed. The examples are:

1. Suppose that all of factories in the chain uses common database for purchase ordering process, what impacts occur on total lead time in the chain?

2. Suppose that two processes of internal and external production planning are linked together, what impacts occur on the total productivity in the chain?

3. Suppose that all factories and distributors works on PULL-mode, all of planning processes will be extremely simplified. While, all factories always keep balanced inventory, and require distributed inventory management system. Which is better?

5.2 Communication Server

Successful SCM requires the sharing information facilities other than simulation and data analysis support. The current version of the Communication server provides the transportation of the tactical data to manage supply chain.

The objective of this information sharing facility is to perform synchronized manufacturing and logistics operations.

The role of "Communication Server" is to provide both real time data transfer and batch data transfer among the companies in the chain. These include the input /output data of the simulation described the previous sections. At the first stage of implementation, we have currently developed the simulation input data interface by using CGI (Common Gateway Interface), and the simulation output data interface by using Java. These input/output data are transferred in real time mode and published by suppliers data driver when it is required. The communication process is the same as many commercial WEB sites using CGI to manage their data base system. The examples of input data include:

- Inventory volumes at entrance process and exit process of supplier's factories.

- Inventory volumes at warehouses of distributors.

- Production schedules or cyclic schedules at the manufacturing lines of suppliers.

While, the examples of output data are as follows:

- Production throughput at individual process of suppliers

- Inventory volumes of store processes at individual suppliers

The technology used to exchange that information must be cost-effective, reliable, and hardware independent. In the test-bed system implementation, we are examining the following four methods for exchanging large amounts of information.

WWW - The World Wide Web encapsulates communications protocols to organize and access data across the Internet (Berners-Lee, T ,1994).

PART 21 - An international standard that provides a standard physical file structure that is easily produced and consumed by multiple applications (ISO,1994).

CORBA - The Common Request Object Broker allows applications to use each other's resources by supporting message call between objects through a network (OMG,1995). IDL is a language to define application interface.

EDI - Electronic Data Interchange provides a collection of forms for the electronic exchange of a wide variety of business and manufacturing data (Banerjee, S., 1994).

6   CONCLUSIONS AND FUTURE RESEARCH

The prime problem of supply chain management is that customers' demand is always unpredictable. The solutions to such supply chain management are both synchronization of operations among suppliers and optimization of operations in individual company in the chain. Especially, most of the activities must be synchronized either inside the enterprise or beyond its boundaries on production & logistics issues. The principle of this strategy is, what we call, "Quick response than the better prediction."

The test-bed system can simulate the business process behaviors, the material flows, and information process flows. The system can make clear the complex relation among these activities. This facility provides business process planners to assess operations in supply chain management, including logistics methodologies like PUSH, PULL, and Hybrid PUSH/PULL systems.

Through the implementation of this system, the authors recognized that simulation software interface design issues imply several difficulties to implement plague and play computing environment. Simulation software will need to support the input/output interface with application programs. The simulation interface problem will lead a standardization of software interfaces like CORBA, EDI.

ACKNOWLEDGEMENTS

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