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A simulation technology for supply-chain integration

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1. Introduction

Modern companies in industrially advanced countries face to low-growth of world scale economy. Every enterprise makes various efforts to survive in such severe management environment. Mass production style has gone away, and manufacturer must provide goods which customer favours, when the customers hope to get them.

Organizations today cannot do it alone. Most of modern enterprises depend on the collective efforts of a group of trading partners to stretch a supply-chain from the raw material supplier to the end customer. A trading partner in this context means any external organization that plays an integral role in the enterprise and whose business fortune depends all or in part on the success of the enterprise. This includes factories, contract manufacturers, sub-assembly plants, distribution centres, wholesalers, retailers, carriers, freight forwarder services, customer broker services, international procurement organization (IPO), and value-added-network (VAN) services.

A supply chain system is a chain of processes from the initial raw materials to the ultimate consumption of the finished product spanning across multiple supplier-customer links. It provides functions within and outside a company that enable the value chain to make products and provide services to the customers. The objectives competitive supply-chain design is to weave each of the trading partners into a seamless fabric of information flow, physical distribution flow, cash flow for the benefit of the end customer. The trading partners achieve their profit, or loss, through their ability to work within the context of a supply-chain where each organization is dependent on the other. Each trading partner benefits by gaining the profits of access to a larger market share than might be possible going it alone.

The supply chain system terminology originated in the “Quick Response” initiative in the '80s. In 1985, Kurt Salmon Associates were commissioned to conduct a supply chain analysis for the apparel industry. The result of this study showed the delivery time for apparel supply chain, from raw material to consumer, was 66 weeks long, 40 weeks of which were spent in warehouses or in transit (Kurt Salmon Associates, Inc. (1993)). This study led to the development of the “Quick Response” (QR) strategy. QR is a partnership in which retailers and suppliers work together to respond more quickly to consumer needs by sharing information.

A group of grocery industry leaders succeeded to this work. They created a joint industry task force called the “Efficient Consumer Response” (ECR) working group in 1992 (Kurt Salmon Associates, Inc. (1993)). The most remarkable result of this study has been an identification of a set of best practices, which, if implemented, could improve overall performance of the supply chain substantially. The successful adoption of ECR for a manufacturer depends on the manufacturing flexibility, which enables matching supply with demand.

ECR was further succeeded by the concept of “Continuous Replenishment” (CR) (ECR Performance Measures Operating Committee (1994)). The CR concept is, in a sense, similar to the Japanese Just-In-Time system concept, which is based on a pull system based on consumer demand. Point-of-Sales (POS) system was introduced to forward sales transactions directly to manufacturers by computers to keep retailers replenished and balanced just-in-time.

More recently, a Supply Chain Operations Reference (SCOR) model has been defined as a generic process model (Supply Chain council). The SCOR model can be used to describe supply chain systems using a common framework and terminology. It defines five process types: PLAN, SOURCE, MAKE, DELIVER, and RETURN, that can be used to describe a supply chain. Levels of detail can be successively added to understand the processes involved. Best practices are being defined at the detailed levels to help industry implement them and measure their own performance.

Modern information and communication technologies have enabled high-speed and low-cost communications. These have accelerated commercial use of the Internet, as is seen in e-marketplaces by increasing use of broadband communications. Such e-marketplaces are currently used not only in consumers’ purchase but also for business-to-business (B2B) purchases among worldwide suppliers. Enterprises must integrate all their business processes to compete and participate in the global business community.

A supply-chain system is hard to be modified, once the system has been built. This is because processes in various organizations are tightly coupled with each other, and its business systems are relative to their business communication rules. System design of a supply-chain needs to estimate its performances and behaviours at assessment stages.

Simulation is a powerful tool to optimize designs and operations of such manufacturing and logistics systems. Especially terminated simulation provides predictions of system’s behaviours potential status by “what-if scenario” (Banks, 1998). Thus, simulations have been used as a powerful solution tool for operational management problems, such as capacity planning, resource planning, lead-time planning, supplier selection, and outsourcing planning.

This chapter describes a new approach to support life-cycle management of supply-chain system. First, section.2 categorizes planning problems, which are often discussed in supply-chain management. Second, section.3 proposes an original supply-chain simulation models and a framework to evaluate system performance. And, section.4 describes results of simulation experiments by using an actual supply-chain system. Section.5, finally proposes a novel framework for supply-chain life-cycle management.

2. Supply-chain problems and simulation technologies

2.1 Supply-chain management problems

This section presents common supply chain planning problems. The problems described here are faced by many system designers and managers during design, planning and operation of a supply chain system (Umeda & Jain, 2004). The problems are interlinked, as will be clear in the discussion.

(1) Capacity planning problems

Capacity planning is a process that determines the amount of capacity required to produce in the future. This function includes establishing, measuring, and adjusting limits or levels of capacity. In general, this planning includes the process of determining in detail the amount of labour and machine resources required to accomplish the tasks of production.

In traditional MRP systems (a planning support system for a single factory), there are two stages to plan the system capacity: Rough-cut capacity planning (RCCP), and Capacity Requirement Planning (CRP).

The RCCP is the process of converting the master production schedule into requirements for key resources, often including labour, machinery, warehouse space, suppliers' capabilities, and, in some cases, money. The master-schedule items and quantities are multiplied by the total time required to build each item to provide the total number of hours to produce the schedule. Historical work centre percentages are then applied to the total number of hours to provide an estimate of the hours per work centre to support the master schedule.

Similar to RCCP, the CRP module estimates workload on each work centre in factories but at a more detailed level. In this case, open shop orders and planned orders in the MRP system are input to CRP. It uses parts routings and time standards to translate into hours at work centres by time period. Even though the RCCP may indicate that sufficient capacity exists to execute the MPS, CRP may show that capacity is insufficient during specific time periods.

These methodologies are also applicable to supply chain systems. These are, so to speak, Rough-cut Supply chain Capacity Planning (RSCP) and Supply chain Capacity Requirement Planning (SCRCP). The problem examples for the former are:

- How much capacity individual suppliers should provide to meet the long-range demand mean? These are, for example, number and types of supplier plants, the location of the suppliers, manufacturing capacity of suppliers, the location and capacity of warehouses for transportations, type of manufacturing plants and warehouses, and so on.
- What workload each supplier should handle?
- How much of the raw materials and products should be prepared to ship among suppliers, plants, warehouses, and customers?

The examples for the latter are:

- Which suppliers would be the bottlenecks, when a particular shipment plan is given?
- When and how much production capacity does each supplier need, when the market demand reaches its peak point during a certain time period?
- How much of demand should be supplied from inventory and from production in a certain time period, when a particular demand variation is given?

(2) Resource planning

Resource planning is capacity planning conducted at the business plan level. It is the process of establishing, measuring, and adjusting limits or levels of long-range capacity. Resource planning is normally based on long-term production plans but may be driven by higher level plans beyond the time horizon for the production plan, e.g., the business plan. It addresses those resources that take long periods of time to acquire. Resource planning decisions always require top management approval.

(3) Lead-time planning problems

The term “Lead-time” has basically two meanings: a span of time required to perform a process (or series of operations), and the time between recognition of the need for an order and the receipt of goods. The second one is often used in a logistics context. Individual components of lead-time can include order preparation time, queuing time, processing time, move or transportation time, and receiving and inspection time. We use this term in this paper with its second meaning. This problem directly impacts the inventory planning problems through the Lead-time inventory, the inventory that is carried to cover demand during the lead-time.

The examples of this class of problems are:

- When and what suppliers should produce, and associated due dates?
- When and how much volume of products or component parts should be transported?
- Which transportation channels should be used?
- Suppose that all of the factories in the chain use a common database for purchase ordering process, what impacts occur on total lead-time in the chain?

(4) Production planning problems

There are two phases of production planning: the first phase is an aggregate production planning and the second phase is an operational production planning.

An “Aggregate production plan” implies budgeted levels of finished products, inventory, production backlogs, and plans and changes in the work force to support the production strategy. Aggregate planning usually includes total sales, total production, targeted inventory, and targeted customer backlog on families of products. One of the primary purposes of this plan is to estimate the production rates, when the system works according to the given plan. The production rate is an important decision parameter since it determines whether the system is meeting its’ management’s objective of satisfying customer demand while keeping the work force relatively stable. As the production plan affects many company functions, so it is normally prepared with information from marketing, and coordinated with the functions of manufacturing, engineering, finance, materials, etc.

It is the function of setting the overall level of manufacturing output (production plan) and other activities to best satisfy the current planned levels of sales (sales plan or forecasts), while meeting general business objectives as expressed in the overall business plan such as profitability, productivity, competitive customer lead times, and so on.

Operational production plan is a more detailed set of planned production targets that meet the goal of the higher level manufacturing output plan. It is based on an agreed-upon plan that comes from the aggregate (production) planning function. It is usually stated as a monthly rate for each product family. Measurement units depend on the plan and the

products, such as units, tonnage, standard hours, and number of workers. The production plan is management's authorization for the master scheduler to convert it into a more detailed plan, that is, the master production schedule.

2.2 Simulation technologies for supply-chain management

Simulation software tools have been on the market for at least 40 years. Simulation software comes in two flavours: languages and packages. Simulation languages, which first appeared in 1960's, deal with the flow of entities through the system. Examples of material entities in manufacturing line simulation include parts, operators, tools, and machines. There are three different views of that flow: activity, event and process. Simulation packages support many features including graphical model building tools, tabular data entity, automated debugging, and wide range of animation utilities. Graphical model building tools simplify, but not eliminate, the need to use underlying language.

Several industrial companies have developed supply-chain simulation systems. These companies own by themselves huge supply-chain systems that include their own and vendors factories. These are originally used as internal tools rather than software products. IBM developed a Client/Server/Web-based system tool to support supply-chain management (Chen, et al.). CSCAT (Compaq Supply Chain Analysis Tool) by Compaq Corporation owns simulation elements of supply-chain systems, and it supports performance evaluation. They further make additional functions such as animation facilities and business-score boards. (Ingalls & Kasales, 1999)

Umeda and Zhang developed generic simulation models for supply-chain system analysis, and applied them to several types of supply-chain systems. (Umeda & Zhang, 2006) The scopes of their works are a Push-system, a Pull-system, and a Hybrid-push-pull system. Their analysis covers inventory management problems, lead-time planning problems, and system performance analysis in supply-chain systems.

2.3 Simulation technologies appeared in Winter Simulation Conference

Society of Computer Simulation (SCS) organizes Winter Simulation Conference (WSC) every year. This conference is the biggest one related to discrete event simulation in the world. This conference covers the topics of every areas of discrete event simulation: theory, architecture, application, tools, and so on.

This section summarizes a states-of-the-art in supply-chain simulation and its relative fields from a point of applications views by academic and industrial papers mainly using recent winter simulation conference proceedings.

(1) Supply-chain system simulation

There are several characteristics in supply-chain system simulations. These are (1) Consideration of information-flow, (2) Consideration of business process flows, (3) Pull system concept, (4) Simulation modelling, (5) Huge system simulation, and et al.

First, the scopes of supply-chain simulation often include information-flow in addition to materials-flow in comparison with manufacturing system simulation, which had been very popular. This is because one of the principle of designs for supply-chain systems to introduce information sharing mechanisms. Sarac et al. reported the impacts of introducing of RFID in supply-chain systems (Sarac et al, 2008). Liu et al. showed simulation results for

supply-chain configuration based on information sharing (Liu et al., 2006). Gavirneni evaluated supply-chain performance in the case that the system performed fully centralization of information (Gavirneni, 2005). Its information-flows often include scheduling information.

Second, business process-flows are often scope in design supply-chain systems. Business process simulation includes such transformation of organizations (Ding et al., 2006). Cui et al. presented a case study of using the BPS tool to demonstrate the effects of BPR on restraining stocking-up and overdue payments in the distribution management of a supply chain (Cui et al., 2008). Consideration of Small-and-Medium-sized Enterprise (SMEs) is one essential items of supply-chain management. Byrne and Heavey summarized useful methods to analyzing SME industrial supply-chains (Byrne & Heavey, 2004).

Third, Supply-chain system needs implementation of "Pull" system. Bagdia and Pasek proposed an analytical method enables projection of the end-customer demand information to upstream of the supply chain and estimate demand forecast at the individual tier levels (Bagdia & Pasek, 2005). Bhaskaran proposed a simulation methodology for supply-chain systems, and applied it to a supply-chain of General Motors Co. (Bhaskaran, 1998). His scope is systems' stability through inventory management. His analysis covers an opportunity of practice of continuous improvement of systems. His reports also include comparisons between MRP and Kanban system.

Fourth, modelling methodologies are often discussed in supply-chain simulation. As supply-chain systems are generally huge, so modelling workload, needless to say, becomes heavy. Vieira and Junior developed conceptual models, which are useful to creation of certain types of supply-chain simulation projects (Vieira & César, 2005). Song et al. applied a methodology of simulation meta-model to a multi-echelon supply chain problem and make statistically analysis of the parameters (Song et al., 2008). Cope et al. proposed an approach that provides a simulation solution that is affordable at the same time can be quickly implemented (Cope et al., 2007). Umeda et al. developed generic simulation models for supply-chain system analysis, and applied them to several types of supply-chain systems (Umeda & Lee, 2004b). The scopes of their works are a Push-system, a Pull-system, and a Hybrid-push-pull system. Their analysis covers inventory management problems, lead-time planning problems, and system performance analysis in supply-chain systems. Jain focuses on issues in building a generic simulation capability for supply chains. His work discussed approaches for building generic supply chain simulation capability. Such approaches include data-driven simulators, interactive simulators, and sub-models for supply chain components (Jain, 2008).

Fifth, the scale of supply-chain system is often very huge. Examples are semiconductor and chemical industries. Arons et al. presented an application of a supply-chain simulation for bulk chemicals by using system dynamics methods (Arons et al., 2004). As other scopes, there are many discussions on performance evaluation and simulation optimizations problems (Jain & Leong, 2005)(Yoshizumi & Okano, 2007). Chong et al. proposed a semiconductor supply-chain distributed simulation by using HLA (High Level Architecture)(Chong, 2004).

(2) Manufacturing (including semi-conductor)

Manufacturing applications had been on the top position in discrete-event simulation areas. It still keeps many discussions, today. Benedettini proposed a method to integrate resource

allocation methods and simulation for Engineering-To-Order (ETO) type supply-chain system (Benedettini et al., 2001). This method has been applied to an aerospace manufacturing supply-chain system. Krishnamurthy and Claudio discussed a pull system simulation (Krishnamurthy & Claudio, 2005). A group of Lendermann reported a case study of an integrated manufacturing and service network in Singapore (Lendermann, 2005). MacDonald and Gunn applied simulations to analysis and design of a production control system (MacDonald & Gunn, 2008). Enns analyzed a model for total inventory and delivery performance by mathematical formation, and compared with simulation results by using experimental design methods (Enns, 2007).

One of current major application is semiconductor manufacturing system. Jarugumilli et al. discussed assembly-test facilities using integrated optimization-simulation models for semiconductor manufacturing system (Jarugumilli, 2008). Recently, these discussions are expanded from single manufacturing system to areas of supply-chain simulation. Similar examples are semiconductor supply-chain simulation based WIP management (Miyashita et al., 2004), and semiconductor supply-chain systems (Morrice et al., 2005) (Chang, 2005)).

(3) Logistics and transportation

There are also a lot of reports of applications to logistics system and transportation system. The targets system in this area generally owns large scales. Examples are a proposal of a flexible modelling method for a large-scale transportation-inventory system (Miwa & Takakuwa, 2005), a shipment delivery supply-chain (Oh, 2005), warehouse operations (Gagliardi et al., 2007), a simulation-based optimization retailer network (Subramaniam & Gosavi, 2004).

Object-oriented modelling is a just fit approach for logistics simulation. This is because transporters (a truck, a train, a ship, et al.) and stock facilities (warehouses, shipping facilities) have common specifications, individually. Object-oriented methods provide reduction of workload for simulation modelling and for reuse of models. Rossetti and Nangia presented an object-oriented framework for simulating full truckload transportation (Rossetti & Nangia, 2007).

(4) Risk management

Discussions introduced here belong to different types of discrete-event simulation. Deleris and Elkins presented a supply chain risk analysis that is based on a Monte Carlo simulation of a Generalized Semi-Markov Process (G.S.M.P.) model. Specifically, they estimated the probability distribution of supply chain losses caused by disruptions (Deleris & Elkins, 2004). Deleris and Erhun used similar approaches for supply-chain risk management (Deleris & Erhun, 2005).

(5) SD and its applications

Rebelo et al. introduced a methodology for detecting and predicting supply-chain behaviour changes based on dynamics of the supply-chain business environment (Rebelo et al., 2004). Dulac et al. used system dynamics to analyze risks of management in complex systems (Dulac et al., 2005). An and Jeng developed system dynamics models based on a given business process models along with associated reference contexts, and further, and analyzed a case of supply-chain (An & Jeng, 2005). Venkateswaran analyzed effectiveness of effect on stability of supply-chain (Venkateswaran & Son, 2005). Alvarez analyzed impacts of traffic status in Panama canal to make political decision support. The common item among

these examples is to utilize a merit of System-Dynamics' merit that is good at analyzing feedback mechanisms in a system.

(6) Theory and methodologies

Mazzuchi and Wallace discussed to use discrete-event simulation and experimental design method together (Mazzuchi & Wallace, 2004). The discussion a relation between simulation and experimental design is very important, however, discussions of this kind are not so many.

Benjamin et al. discussed solution concepts for the use of ontology for simulation model integration (Benjamin et al., 2007). A group of Fayez proposed an ontology-based approach to integrate several supply chain views and models which capture the required distributed knowledge to build simulation models. The core of the ontology core is based on the SCOR model (Fayez, 2005). A group of people of IBM discusses similar topics on ontology for supply-chain simulations (Fordyce et al, 2008).

Many of discussions of simulation methodology cover simulation modelling areas. This would be because modelling process is the most important and it also needs workload. Muler gave an overview of a framework for automatically generating large-scale simulation models in a domain of semiconductor manufacturing (Mueller et al, 2007). Adams et al. propose a teaching method of supply-chain management by usages of spreadsheet and discrete event simulation (Adams, 2005). Yang discussed possibilities of data-driven simulations through inventory simulation model. He also compared with the case using discrete event simulations (Yang, 2008).

(7) Tools and package development

Simulation packages include graphical user interfaces, window-based utilities, and multi-purpose simulation languages. These packages support many features including graphical model building tools, tabular data entity, automated debugging, and wide range of animation utilities. Graphical mode building tools simplify, but not eliminate, the need to use underlying language.

Several industrial companies have developed supply-chain simulation systems. These companies own by themselves huge supply-chain systems that include their own and vendors factories. These are originally used as internal tools rather than software products. IBM developed a Client/Server/Web-based system tool to support supply-chain management (Chen et al., 1999). Gensym Corporation developed a supply-chain simulator that is based on SCOR model (Barnett & Miller, 2000). This system provides performance evaluation functions with graphical visualization facilities. This system is available not only to estimations of business model at introduction stage but to estimations for performance improvement.

CSCAT (Compaq Supply Chain Analysis Tool) by Compaq Corporation owns simulation elements of supply-chain systems (Ingalls & Kasales, 1999), and it supports performance evaluation. They further make additional functions such as animation facilities and business-score boards.

(8) Gaming and simulation

Gaming is one of the effective methods to train business practitioners, and supply-chain planner is the same. However, implementation of such training game needs very high programming skills. Verbraeck and Houten developed an object-based module library to

implement supply-chain training games (Verbraek & Houseten, 2005). They also implemented a distributor game, and analyzed it by using in a MBA courses (Houten et al, 2005). A group of Zhou et al. implemented an internet-based supply-chain business game (Zhou et al., 2008). The major objectives of the proposed game are to increase players’ SC awareness, facilitate understanding on various SC strategies, and to foster collaboration between partners, and to improve problem solving skills. Further, A group of Ingalls reported on-going work of integrating supply-chain research into the graduate curriculum in the form of a Supply Chain Modelling course (Ingalls et al., 2008).

(9) Others
The works in other application categories are quality controlled logistics (van der Vorst, J. G.A.J. et al.), a call center communication (Takakuwa & Okada, 2005), economic policy analysis (Barnes et al., 2005).

3. Simulation modelling framework

3.1 A hierarchical modeling framework

Simulation modelling is to describe visible target systems by using abstracted simulation modelling notations. A hierarchical framework often clarifies such simulation modelling structure (Fig. 1).

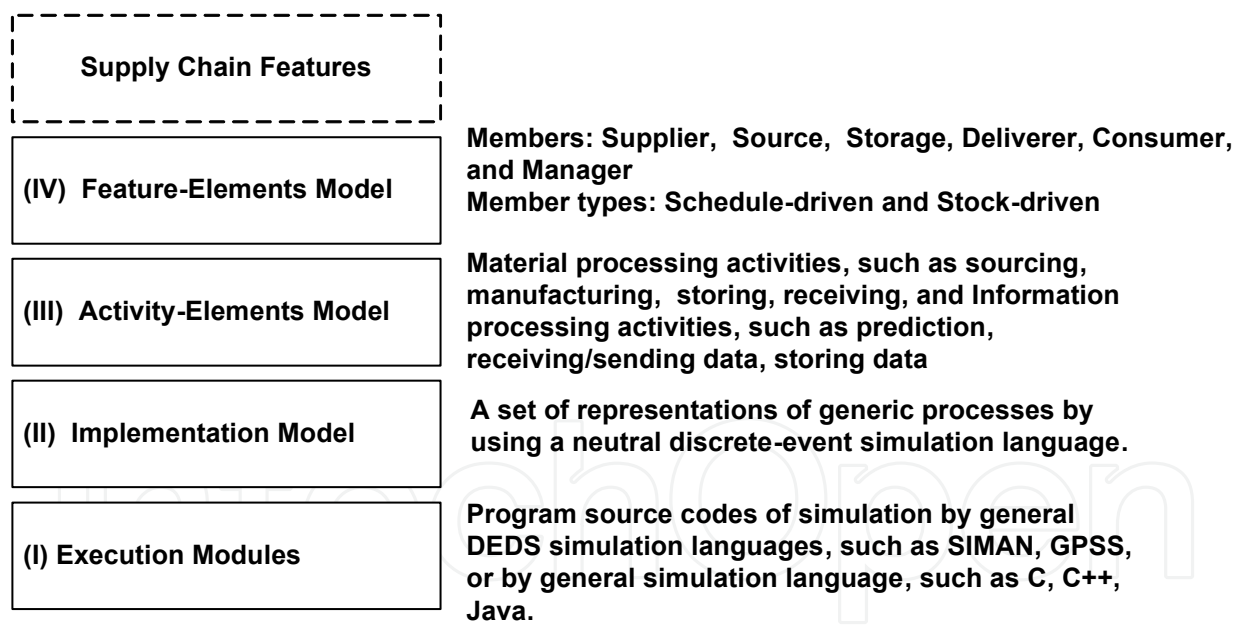


Fig. 1. A hierarchical simulation modelling framework

3.2 Feature-Elements model

There are many supply-chain systems; meanwhile, the types of chain member are countable. Feature-Elements model (LEVEL IV) is such a set of models representing chain members. The members in supply chain systems are categorized into six types by way of organization view: These are “Supplier”, “Source”, “Storage”, “Deliverer”, “Consumer”, and “Manager”. Some of these are further classified into two types by way of control view: stock-driven and

schedule-driven. Stock-driven member autonomously work to replenish its relevant inventory stock. Its inventory stock level is often defined as its replenishment point. While, a schedule-driven member basically work to operational orders given by the manager. The details of these control views are described later.

(1) Element: Supplier; An organization that provides materials in the chain. There are two types of Stock-driven and Schedule-driven. Stock-driven supplier observes material stocks of an item in a particular supplier. The observation target is usually a stock of input materials at an immediate downstream supplier. When the stock volume is below the replenishment point, supplier autonomously starts to work to replenish the target part / product inventories. Schedule-driven Supplier receives production orders from Planner, which generates a Master Production Schedule (MPS). It executes the order, when it receives production orders from the Planner. Examples are Parts manufacturers, material manufacturers; parts assemble manufacturers, and final products plants.

(2) Element: Source; An organization that starts the material-flows in the chain. There are two types of Stock-driven and Schedule-driven. Stock-driven Source observes material stocks of an item in a particular supplier. The observation target is usually a stock of input materials at an immediate downstream supplier. When the stock volume is below the replenishment point, source autonomously starts to work to replenish the target part / product inventories. Schedule-driven Source receives material orders from the Planner, which generates a Master Production Schedule (MPS). It executes the procurement orders per the schedule received from the Planner. Examples are Material manufacturers, and Parts manufacturers.

(3) Element: Storage; An organization that holds materials, parts, or products. There are two types of Stock-driven and Schedule-driven. Stock-driven Storage receives materials from other chain members to hold them, and it autonomously ships materials to replenish stock inventories at particular suppliers. Schedule-driven Storage receives materials from other chain members to hold them, and it ships materials when it receives delivery orders from a planner. Examples are Warehouses, transportation bases, store- houses, wholesalers, and plant warehouses.

(4) Element: Manager; An organization that controls material-flows and information-flows in the chain. Manager receives orders from Consumers, and sends delivery orders to deliverer. The Manager stores the order as a demand-log. It predicts products demand in next phase and generates Master Production Schedule (MPS). This MPS is updated by orders that are given by the Consumer. The functions of this organization include: master scheduling, receiving orders from Consumer, forecasting demands, making commitments on replenishment with stock-driven members and sending orders to chain members. For stock-driven stages in the supply-chain, the role of the manager is to set the replenishment points and change them as required over time due to changes in market and demand. Examples are a headquarters of a final products manufacturer, and a supply chain control centre.

(5) Element Deliverer; An organization that transports products, parts, and/or materials between members. It receives delivery order from other chain members, and it works according to the delivery order. The sender of this order is the upstream supplier of this deliverer. Examples are 3rd party logistics companies, UPS, and post office.

(6) Element Consumer; An organization or individual who acquires products. It gives products purchase orders to manager. Also inspects the incoming products for quality and tracking. Examples are Buyers, consumers, and trading companies

3.3 Function-Elements model, Implementation model, and Execution modules

Function-Elements Model (LEVEL III) is a set of representations of fundamental business activities in supply chain operations. These activities are classified into material processing operations or information processing operations. The former includes "Material sourcing", "Manufacturing", "Storing", "Receiving", "Delivering", and the latter includes miscellaneous information/data processing, such as "Demand prediction", "Sending/Receiving data", "Storing/Updating data", and others. Individual is transferable to micro-scale modeling provided in Level II.

Implementation Model (LEVEL II) is a set of representations of activities by using a neutral DEDS simulation language, which provides generic activities, such as Enter_queue, Exit_queue, Size_resource, Release_resource, Set_attribute, Get_attribute, Reset_Attribute, Delay, and others. Individual is transferable to language descriptions provided in level I.

An Execution modules (LEVEL I) is a set of simulation object codes Programming source codes of simulation by using DEDS simulation language (SIMAN, GPSS, etc.) or general programming languages, such as C, C++, Java, and etc.

3.4 Supply-chain Control model

The previous section described that particular feature element models are controlled by two types of methods: Schedule-driven and Stock-driven. These features are useful to model supply-chain simulation. (Umeda & Jain, 2004) (Umeda & Lee, 2004a). The details of these are described here.

(1) Schedule-driven control

Schedule-driven control uses a production schedule, the so-called "Master Production Schedule" (MPS), which the supply-chain manager generates. The manager receives purchase orders from marketing channels in a periodic cycle time, and it saves the orders as demand data. It also periodically updates the MPS by using the accumulated demand prediction data. MPS is a schedule about which finished-goods items are delivered to consumers. To generate MPS, the manager is generally based on demands forecast, production plan, availability of materials, and availability of capacity.

The main function of the chain manager is to give periodical operational orders to supply-chain members by using MPS and Bills Of Materials (BOMs). The schedule-driven suppliers regularly work according as orders from manager. As shown in Fig. 2, the manager uses schedule-driven control to repeat the above activities cycle. The activities of "Manager" are summarized as follows:

1. It receives purchase orders from consumers.
2. It accumulates this purchase data.
3. It generates future demand predictions by using the accumulated demand data.
4. It updates MPS by using the predicted demand and feedback data from supply chain members.
5. It gives orders (sourcing, manufacturing, and shipping) to corresponding chain members.

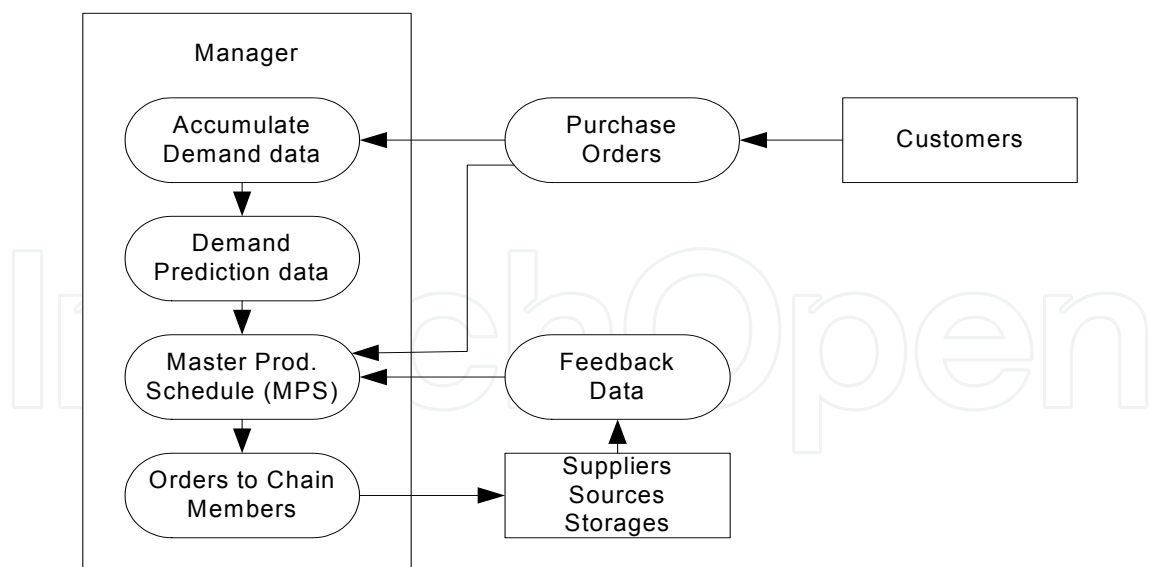


Fig. 2. Schedule-driven Supply Chain Control

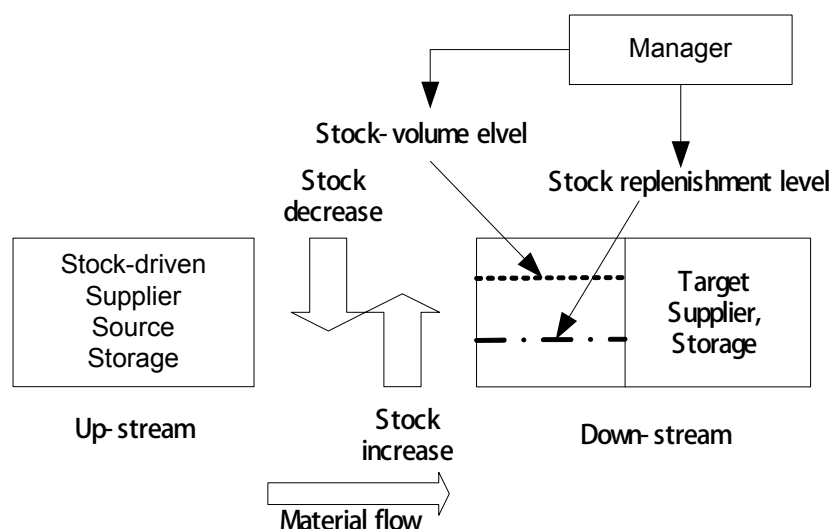


Fig. 3. Stock-driven Supply Chain Control

3.5 Supply-chain configurations by using schedule- and stock-driven control

Combinations of the Feature-Elements models enable to define the configuration of supply-chain systems. This section demonstrates some of typical supply-chain system configuration using Feature-Elements models (Umeda & Jain, 2004).

Fig. 4 represents a configuration example of schedule-driven supply-chain system. In this system, the chain manager receives purchase orders from consumers and it gives production orders to each chain member. Every supplier produces products according to orders given by the supply chain planner. A particular member might receive orders directly from other chain members as is shown in the deliverer in this case.

Connection of schedule-driven members results in a supply chain operating as a push system. The manager plays a very important role in this system. The manager receives purchase orders from consumers and accumulates past order data to predict demands in

future. It further generates production orders and sends them to each chain member. The manager needs to collect various kinds of data from the chain members so as to give proper orders to each member. This configuration results in concentration of data and information with the planner, and the success of the supply chain is dependent on decision making capability of the manager.

A particular supplier might operate using stock-driven control. When the system includes such members, commitment would be needed between the supplier and the manager. An example illustrated in Fig. 5 includes a stock-driven source that autonomously provides materials to the parts supplier.

Fig. 6 illustrates a configuration example of purely stock-driven supply-chain system. In this system, manager receives commitment from the suppliers to provide materials and parts. Every supplier works autonomously to provide materials to individual downstream suppliers. The data and information are distributed to individual supplier, and manager’s direct control on suppliers is minimized in this system.

Connection of stock-driven members makes a pull system. The role of the manager is less important here than in the case of push system. Individual stock-driven supplier autonomously works according to the predefined operational commitments with the planner. The manager plays a role of communicator between consumers and final product plant. Another role of the manager is to define the replenishment points and receive operational commitments from suppliers for maintaining the stock.

The role of manager is more of a data communication enabler rather than a controller of suppliers.

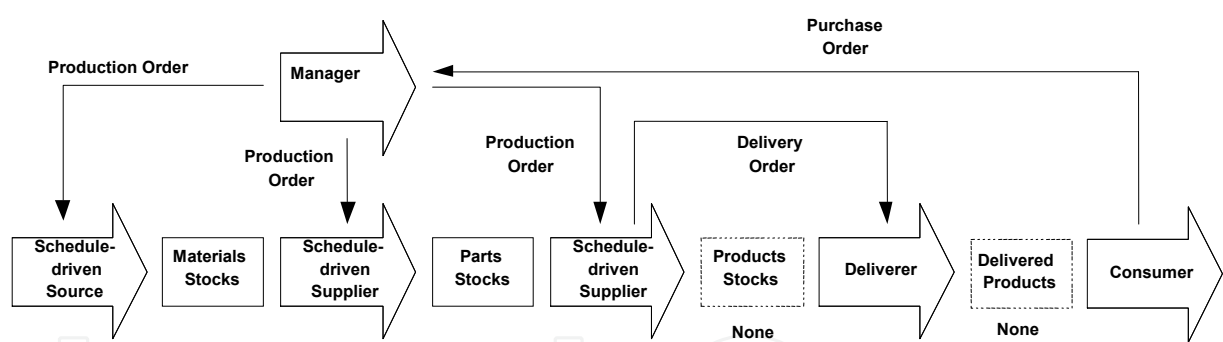


Fig. 4. A configuration example of schedule-driven supply chain

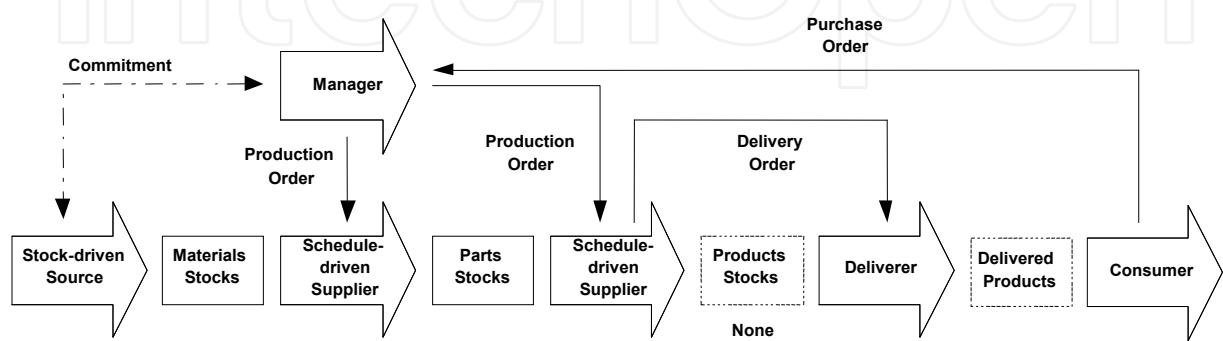


Fig. 5. A configuration example of hybrid schedule and stock-driven supply chain

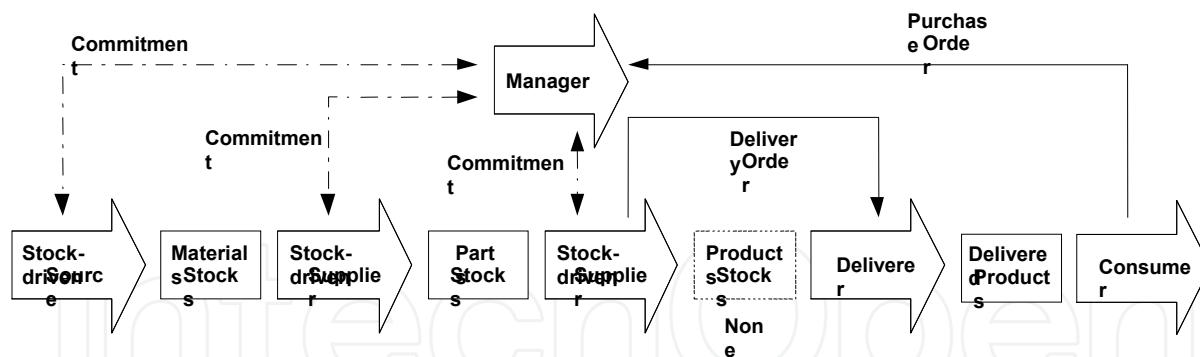


Fig. 6. A configuration example of stock-driven supply chain

3.6 Management environment model

Supply-chain activities have relevance to its business environment. Suppose that a supply-chain system realizes a high performance and it shorten the consumers' purchase lead-time. In this case, the demand volume in market would increase because of the shortened purchase lead-time; the system would be busier by the increased demands. These activities give favourable or harmful influences to its external world, and their feedbacks can also give similar influences to the supply-chain.

Similar scenarios would be applicable to relations between other supply-chain systems' activities and their feedbacks. They are, for examples, quality improvement programs in factories, manufacturing process automation programs, and operational improvement in parts/products transportation between suppliers.

System dynamics has been defined as "A method of analyzing problems in which time is an important factor, and which involve the study of how the system can be defended against, or made benefit from, the shocks which fall upon it from outside world" (Sterman, 2000). There are many SD applications to manufacturing systems, such as relations between demand-supply operations and manufacturing system performance, cause-and-effect relations among equipment maintenance, productivity, manufacturing cost, and others (Riddalls et al., 2000).

This approach is useful to capture complex real-world situations, which include delays and feedback mechanisms. Practical applications include understanding market environments and assessing possible future scenarios. Dynamics complexity is not related to number of nodes or actors concerned, but the behaviour they create when acting together.

One of the advantages of SD is to describe complex systems including uncertainty and cause-and-effect relations in a system. The SD models represent interdependency in a system by using elements, such as "Stock", "Flow", and the relative variables. SD evaluates both systems' effect on a particular element and its feedback effects on the system in itself.

We tried to implement a model that describes product supply capability, market demands, and their mutual feedback mechanisms. Fig. 7 illustrates a conceptual mechanism that the consumers in market react to supply-chain performance and it gives feedbacks to the chain as order volumes. This figure represents a cause-and-effect mechanism between supply-chain performance and market order volumes by system dynamics notations.

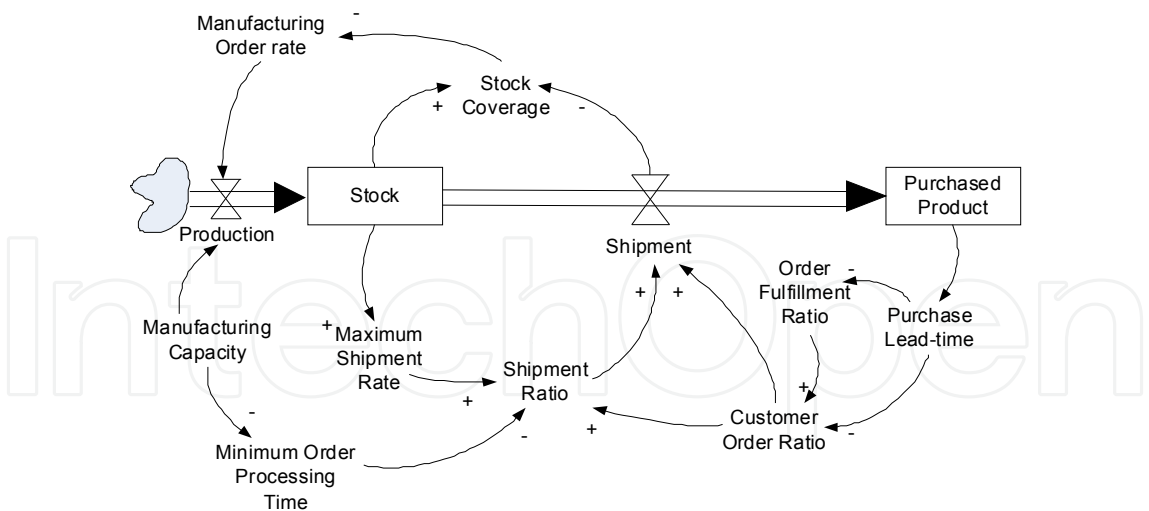


Fig. 7. Causes and effects relation by using System dynamics modelling

3.7 Hybrid modeling framework for supply-chain system

Based on the above discussions, this paper proposes a generic hybrid-modelling framework for supply-chain simulation. Fig. 8 represents a conceptual chart of this modelling framework. Framed rectangles represent supply-chain members’ model, which is discrete-event-based, and rounded rectangles represent dynamics of supply-chain management environment (Umeda & Zhang, 2009) (Umeda & Zhang, 2010).

Supply-chain feature model represents abstracted supply-chain members, which described in 3.2. The manager get purchase orders from consumers, and it gives orders to suppliers and transporters.

Market dynamics model represents reaction mechanisms of consumers to supply-chain system performance. If serviceability of supply chain would be measurable in market, the consumers’ satisfactions to its serviceability would be influential with their future purchase preference. Plant dynamics model represents influences of process performance improvement in supplier’s plants on the system performance. And further, traffic dynamics model represents changes in outside transportation systems

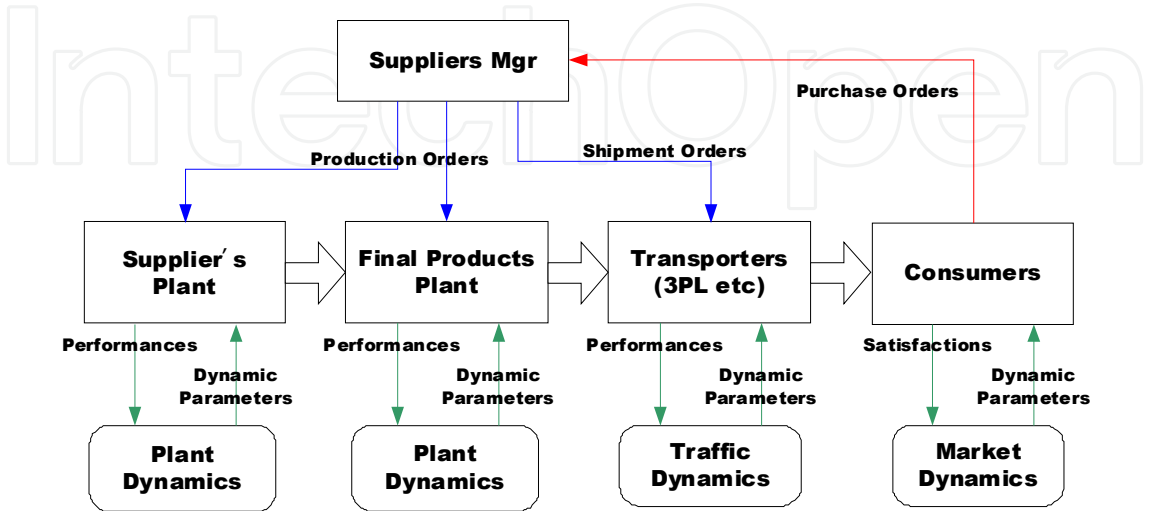


Fig. 8. A hybrid-modelling framework for supply-chain simulation

4. Simulation experiments

4.1 Supply-chain system

The supply-chain system discussed here is originally a very huge system. It possesses more than ten first-tier suppliers. Several of them own subordinate second-tier suppliers. It includes eight parts suppliers and a final product plant. The distinctive features of them are described as the following items.

- This supply-chain system belongs to a schedule-driven type. The manager builds a master schedule based on a demand prediction mechanism.
- The final product is manufactured in a product factory that possesses an assembly line.
- The final product plant works according to daily production orders from the manager.
- The final product plant controls the manufacturing line so that a variance of daily-going-rate keeps a small range.

There is a variance of every order from consumers; however, the demand trend does not change in the long term. Majority of first-tier and second-tier suppliers work according to a periodic ordering method. The period is almost a week and the order volume is variable. The particular first-tier suppliers work according to the daily-based manufacturing orders as well as the final product plant. A particular second-tier supplier owns a long order lead-time. A particular first-tier supplier works according to stock-driven operations. Third party logistics companies deliver between suppliers; accordingly, every delivery time is a constant regardless of volumes. A configuration of the target system is shown in Fig. 9.

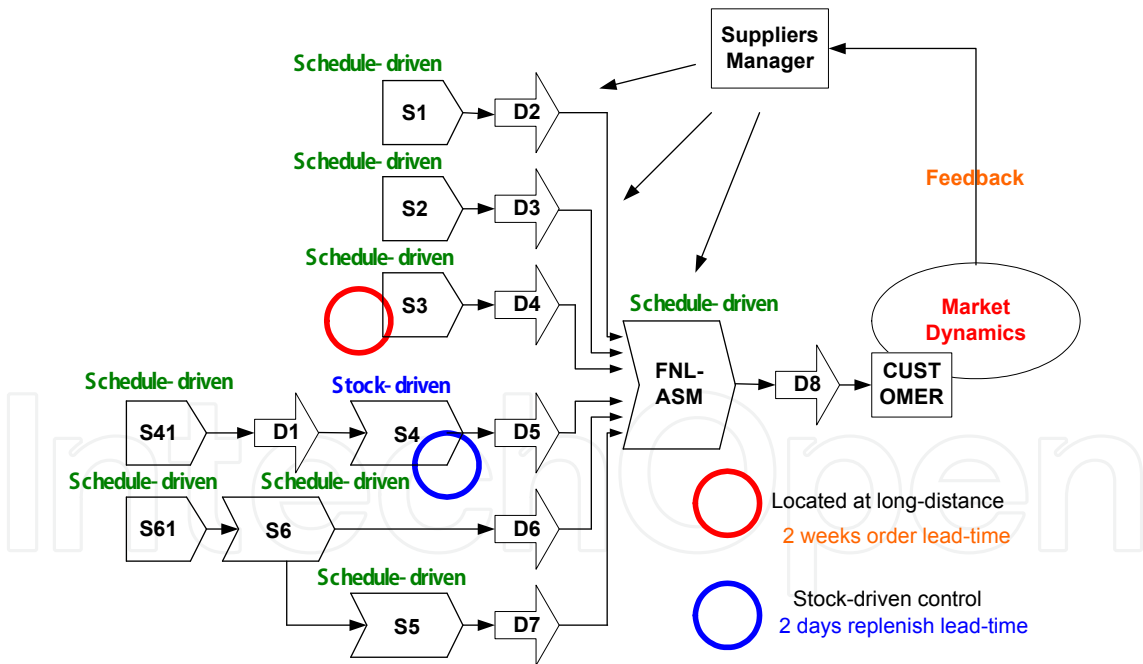


Fig. 9. A configuration of the target supply-chain system

Supplier S4 is an only supplier that is controlled by “Stock-driven” method. The manager decides both stock replenishment level and stock volume level. S4 autonomously provides parts to the final assembly parts by using this stock volume information.

The outlines of activities and controls of every chain member (agent) are based on the description in the previous section. Every chain member owns its processing capacity. When it receives an order that is over its capacity, the overflowed one is transferred to the next one. The feedback mechanism works by using a monitoring data of supply-chain performance in an observation phase and decisions mechanism for demand volume in the next phase. A summary of this mechanism is as follows.

Purchase orders from market occur every day. When products are moved to consumers, system observes order lead-time in all of these orders. At that time, the system also calculates its moving average and variance. When the moving average and its variance is large, system restrains purchase order volume in next term. System then uses smaller random variables on orders' generation. Meanwhile, when the moving average and its variance is small, system releases purchase order volume in next term. System then uses larger random variables on orders' generation.

System uses a system-dynamics (SD) model at that time. In this model, the mainstream data flow starts "source" (data generation), and go through "flow" (data modification that make a decision of demand volume), and finally reaches "stock" (data store). In these processes, system uses the past observation data and their variance data.

4.2 System performance evaluation by using test case models

We, at first, compared two patterns of demand distributions in this system. These are Normal distribution and Uniform distribution. The difference of these does not give any influences on performance of the supply-chain system. System performance is measured by parts inventory volumes at supplier S4 and S5, parts inventory volumes at the final assembly plant, and order lead-time of consumers.

When the demand mean is set on low level, the difference of its variances does not give any influences on system performances. However, when the demand mean is set on middle and high level, even so keeping demand variance at low level, the differences of its variance are increased. Performances are, for examples, measurable by observations of the following items.

- (1) Parts inventories at the final assembly plant
- (2) Purchase order lead-time observed by consumers
- (3) Parts inventory at supplier-5 (Schedule-driven supplier)
- (4) Parts inventory at supplier-4 (Stock-driven supplier)

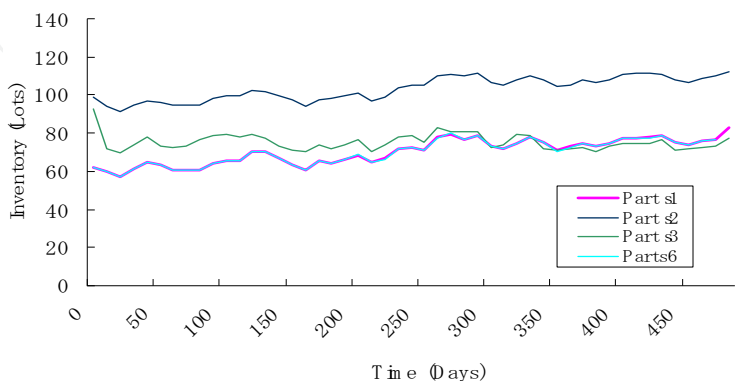


Fig. 10. Transition of the parts volumes at final assembly plant (Demand distribution = $N(40,6)$)

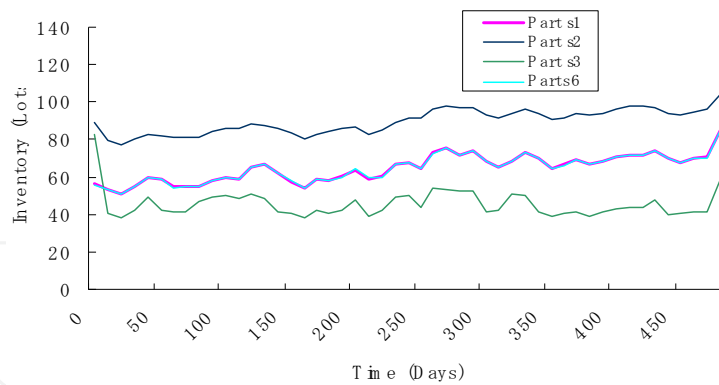


Fig. 11. Transition of the parts volumes at final assembly plant (Demand distribution = $N(60,6)$)

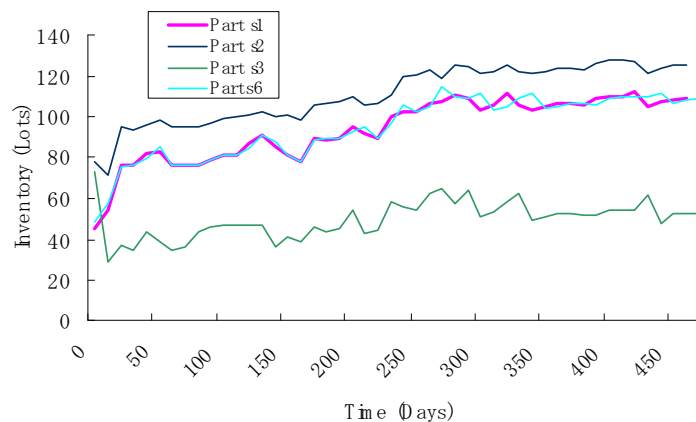


Fig. 12. Transition of the parts volumes at final assembly plant (Demand distribution = $N(80,6)$)

Transition curves of inventories at the final assembly factory are shown in Fig. 10, 11, and 12. The differences of inventories of each part are enlarged, according as increase of the demand mean. The transitions of order lead-time are shown in Fig. 13, 14, and 15. When demand mean is in high level, lead-time transition raises up immediately after the simulation starts, and it keeps in high level through the simulation. This phenomenon explains that the delay of orders has passed into a chronic state. Transitions of parts volume at final assembly plant are shown in Figure 7, 8, and 9. The part volumes stocked there are proportion to the average of demand distribution that is given as the parameters.

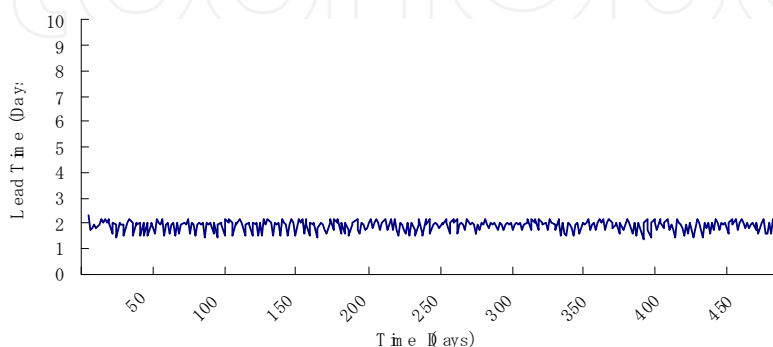


Fig. 13. Transition of the purchase lead-time (Demand distribution = $N(40,6)$)

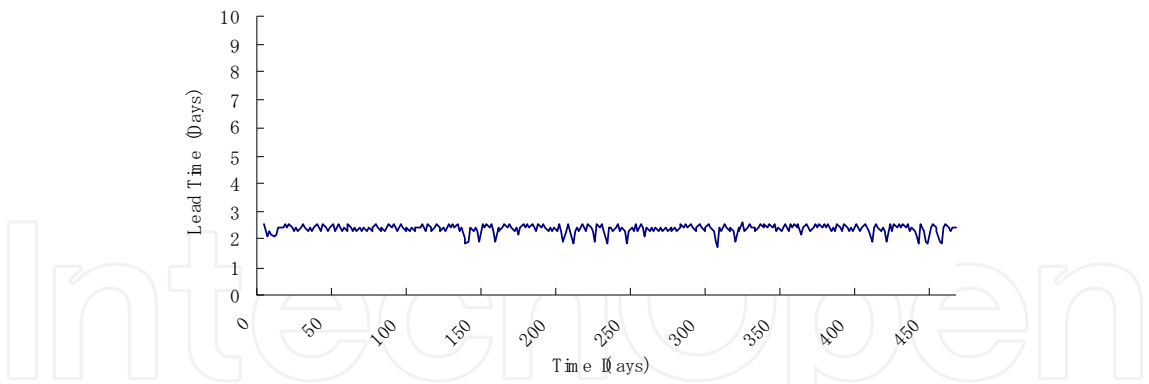


Fig. 14. Transition of the purchase lead-time (Demand distribution = $N(60,6)$)

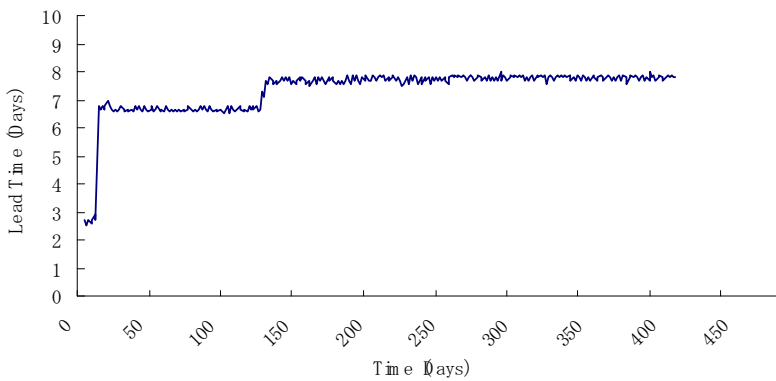


Fig. 15. Transition of the purchase lead-time (Demand distribution = $N(80,6)$)

4.3 Hybrid simulation considering management environment

Supply-chain activities have relevance to its business environment. We consider here this issue according as the scenario discussed in 2.4. The principal cause is the observed purchase lead-time in every purchase activity. The rule defined here is, in a word, summarized as follows.

Short purchase lead-time gives favourable impression to customers, and the order volume increases. Accordingly, the chain system becomes busy; order processing at every task in the chain becomes tight. While, long purchase lead-time gives unfavourable impression to customers, and the order volume decreases. Accordingly, the chain system becomes calm; order processing at every task in the chain becomes loose.

Fig. 16 represents the transition curves of purchase order volume by customers and demand prediction by the manager. The value draws a cyclical curve in initial duration of simulation, and it becomes stable later. This phenomenon is based on the fact that a chronic order delay occurs. The curve of purchase lead-time also shows the same patterns as this transition. And further, there is no case that parts become shortage. This is the reason why the purchase order volume becomes stable.

“Process Design” is a designing stage of supply-chain processes. A supply-chain builder plans and designs supply-chain business processes. Many existing processes should be re-constructed in many cases. A reference business model, like SCOR model, would be very useful in this stage.

“Hybrid Simulation” stage verifies the designed process by using the supply-chain simulator which section 3 described in detail. Simulation can evaluate supply-chain behaviours in tactical phase using the discrete-event simulator alone. The simulation output would help to solve supply-chain problems such as discussed in section 2.

“Hybrid simulation” accompanied with system-dynamics models, would provide solutions of the supply-chain problems. Hybrid simulation can evaluate system behaviours considering the business environment of the chain. It would provide solutions in a comparably long term. Most of strategic problems described in section 2 would find management solutions by considering transitions in a long term. Particular simulation results can be feed-backed to “Constraints Management” to rebuild major constraints of the chain.

The relationship among these stages is similar to the case of Water-fall model accompanying with prototypes. The prototypes help to find faults in external design phase, and to prevent design bugs from sending to next stage. The role of the “Hybrid Simulation” corresponds to such prototypes. “Process & System Building” is an implementation phase. After that, practice phase would start. This is a stage named as Process Execution”.

After continuing practices in several years, the supply-chain system would be faced to the stage of “Review & Audit”. This stage discusses not apparent modifications but drastic changes. Large-level constraints would be discussed for the next cycle in management.

6. Conclusions and future researches

This chapter has described a new approach to support life-cycle management of supply-chain system. The core technology of the proposed framework is a hybrid modelling method, which combines discrete-event modelling and system-dynamic modelling.

The proposed framework and models would be effective in supply-chain system evaluation for a long duration. Similar scenarios would be appropriate to other supply-chain systems’ activities such as quality improvement programs, manufacturing processes automation programs, and efficient transportations operational programs.

The proposed approach will be the first step to a simulation & gaming methodology to support supply-chain operations. More case studies would be needed. The scale of this kind of simulation is complex and very large. Accordingly, it includes lots of simulation parameters. Efficient ways for simulation experiments design would be needed. “Taguchi method” would be the best solution to apply supply-chain simulation experiment design. This method uses orthogonal matrices to assign simulation parameters. The merit of this way is that parameters are assigned by a fixed form. In addition, experiment numbers are extremely reduced in comparison with traditional design methods.

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Considered by many authors as a technique for modelling stochastic, dynamic and discretely evolving systems, this technique has gained widespread acceptance among the practitioners who want to represent and improve complex systems. Since DES is a technique applied in incredibly different areas, this book reflects many different points of view about DES, thus, all authors describe how it is understood and applied within their context of work, providing an extensive understanding of what DES is. It can be said that the name of the book itself reflects the plurality that these points of view represent. The book embraces a number of topics covering theory, methods and applications to a wide range of sectors and problem areas that have been categorised into five groups. As well as the previously explained variety of points of view concerning DES, there is one additional thing to remark about this book: its richness when talking about actual data or actual data based analysis. When most academic areas are lacking application cases, roughly the half part of the chapters included in this book deal with actual problems or at least are based on actual data. Thus, the editor firmly believes that this book will be interesting for both beginners and practitioners in the area of DES.

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