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MODULE-BASED MODELING OF PRODUCTION-DISTRIBUTION SYSTEMS CONSIDERING SHIPMENT CONSOLIDATION

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ABSTRACT

A module-based modeling method was developed to analyze the production-distribution systems by using a discrete event simulation with ARENA. Excel VBA was also adopted to automatically generate the simulation programs. Using the proposed method, one can quickly create a multistage, multi-item supply chain system such as serials, convergent, divergent or general networks, for analyzing the performance of a supply chain. Both inventory control and shipment consolidation policy were considered in this study. A number of outputs can be used as a performance measure in the decision making; for example, transportation costs, inventory level and costs, and the fill rate. An actual application model was generated using the proposed method. The result shows that the module-based method is a powerful tool for modeling the supply chain systems.

1 INTRODUCTION

In recent years, supply chain management has played an important role in the business environment. One of the most important aspects affecting the performance of a supply chain has been the management of inventories (Musalem and Dekker 2005). Inventory management in the supply chain system is complex because demand at the upstream stage is dependent on an order from the downstream stage. The final downstream stage receives orders from the market in uncertain conditions. Uncertainty is one major obstacle limiting the creation of an effective supply chain inventory model. Another important aspects affecting the performance of a supply chain concerns the transportation management. Shipment consolidation combines two or more shipment orders as a single load in order to benefit from the economies of scale in transportation. The coordination of inventory management and transportation management is crucial for an efficient management of the supply chain (Smits and Kok 2002).

Currently, Tools for understanding uncertainty are limited to traditional mathematical formulas that do not account for variability (Schunk and Plott 2000). Simulation is one of the most widely used operations-research and management science techniques (Law and Kelton 2000). Simulation modeling is a suitable tool for analyzing supply chains because it is capable of capturing uncertainty and complexity (Jain et al. 2001).

Kleijnen and Smits (2003) distinguish four simulation types for supply chain management. That is spreadsheet simulation, system dynamics, discrete-event simulation, and business games. System dynamics is a well-known method for analyzing supply chain system. Forrester (1961) developed the dynamics method and modeled the three-echelon distribution system. The dynamic method can be viewed currently as a supply chain system, even though the term “supply chain” was not used. Van der Vorst, Beulens, and Van Beek (2000) developed a discrete-event simulation and Petri-net modeling approach to food supply chain system. A discrete-event simulation model is more detailed than the system dynamics and spreadsheet. Nomura and Takakuwa (2004) developed a flow-type, multistage manufacturing system adopting the dual-card Kanban system that utilized the discrete event simulation and the module-based modeling method. A module can be thought of as analogous to an object (in object-oriented software) (Kelton, Sadowski, and Sturrock 2004). A Module-based system drastically reduces time and effort for modeling and increases efficiency in constructing models by changing and setting a series of designated parameters. The module-based modeling method was also applied to transportation-inventory model by Takakuwa (1998) and Takakuwa and Fujii (1999). These papers demonstrated that such a method using discrete event simulation is very powerful and pragmatic.

In this paper, a module-based template was developed for modeling and analyzing the production-distribution systems using a discrete event simulation in Arena. Both inventory and transportation policies were incorporated in the proposed method but they are different from Miwa and Takakuwa (2005). In contrast with the previous study in which the inventory-bank-replenishment policy was adopted, the (*s*, *S*) policy was adopted and several transportation policies are examined. In addition, stockout at upstream is considered, while that was not considered in the previous study. The decision-maker who uses proposed method can quickly create a multistage, multi-item supply chain to analyze the performance of the supply chain. The primary motivation in developing the modeling method in this paper was driven by the need to analyze the supply chain performance of a consumer goods company, which produced detergent products and sold them nationwide via the distribution system.

The rest of the paper is organized as follows. Section 2 describes the system being studied. Section 3 illustrates the development of the template. Section 4 presents possible applications and section 5 presents the conclusions.

2 SUPPLY CHAIN SYSTEM

2.1 Supply Chain Structures

According to Beamon and Chen (2001), the supply chain structures are classified as: convergent (assembly), divergent (arborescent), conjoined, or general. In this research, all the structures mentioned above are considered. Furthermore, the supply chain is considered as a pull system. Typically, the retailer receives and then fulfills a customer order. When the retailer's inventory is lower than the reorder point, an order is placed to the upstream supplier. The upstream supplier may be a distribution center (DC), a wholesale, or a factory. The preceding upstream supplier receives the order from the retailer, fulfills it, and then delivers it to the retailer. The supplier checks its inventory whether or not to place an order after. The process will be continuing until the supplier is the final supplier in the supply chain.

The supply chain system may have more than three echelons, each echelon in turn may consist of more than one facility, and one facility may include more than one upstream supplier or downstream customer. For example, a DC replenishes different products from different suppliers and deliveries these products to different retailers. Which type of supply chain structure is adopted for analyzing is based on the actual conditions of the system.

2.2 Inventory Policy

Factory facilities perform make-to-order policies within many capacity constraints. Other facilities adopt an (*s*, *S*) system. Whenever the inventory position (outstanding orders + on-hand inventory - backorders) becomes lower than the re-order point *s*, a new order is placed to raise the position to the order-up-to level of *S*. Actually, (*s*, *S*) systems are frequently encountered in practice (Silver, Pyke, and Peterson 1998). The optimal value of the re-order point *s* and the order-up-to level *S* may be given by a decision-maker who calculates the value in advance or is obtained by simulation experiments.

2.3 Shipment Consolidation Policy

A shipment consolidation policy, that accumulates the small different orders into a single load, is a systematic program to decrease total transportation costs. Higginson and Bookbinder (1994) distinguished between three types of shipment consolidation policies: the time policy, the quantity policy, and the time-and-quantity policy. The time policy dispatches each order at a predetermined shipping date. This type approach sometimes is referred to as scheduled shipping. Figure 1 is a schematic illustration of the time policy. The focus of a time policy is often customer service, with the shipping date set to meet consignee requirements. The quantity policy dispatches orders when a fixed quantity is consolidated. The fixed quantity is equal to the truck capacity. In this study, the capacity of trucks is defined in pallets. In contrast to the time policy, the quantity policy is often the cost perspective; Figure 2 illustrates the quantity policy. The time-and-quantity policy dispatches orders when the shipping date is expired or the accumulated quantity reaches the predetermined quantity.

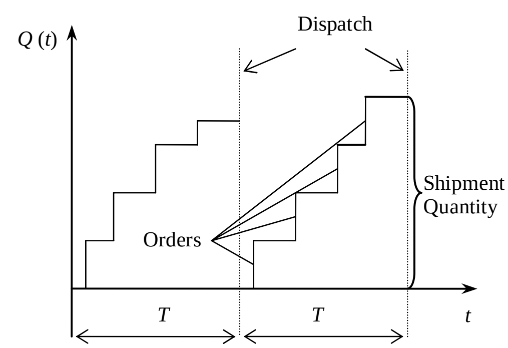


Figure 1: Schematic Illustration of the Time Policy

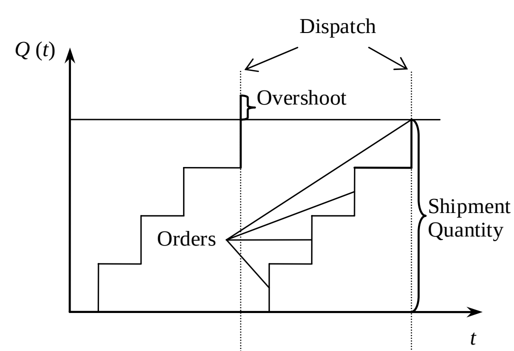


Figure 2: Schematic Illustration of the Quantity Policy

Because the distances from factory or factory warehouse to DC was usually long and a full truckload was desired, the quantity policy was adopted for shipment consolidation at the factory and warehouse facilities. Because the split order was undesirable and impractical, the overshoot of the last order before shipment dispatch was also delivered with the order in the same truck. The load dispatch was often larger than the truck capacity because of overshooting. An assumption was made that a truck holds a flexible capacity so that an overshoot can be delivered as well. On the other hand, a DC performs the function of delivering products to regional retailers with small quantity orders and a high level of service required. Therefore, the time policy for shipment consolidation was adopted. In addition, the DC consolidated the orders from all its downstream retailers, and delivered them in a milk run fashion. A famous convenience store in Japan, Seven-Eleven, delivered the products from the DC to the stores at a predetermined time. For example, frozen foods were delivered from 3 to 7 times a week and processed foods were delivered 3 times weekly.

2.4 Performance Measures

In order to understand the characteristics of the supply chain, relevant performance measures should be identified. The following performance indicators are selected for this modeling approach.

1. Inventory holding cost.
2. Shortage cost. The shortage cost is imposed when the stockout occurs at retailer.
3. Transportation cost. The transportation cost occurs when the shipment release.
4. Inventory level.
5. Fill rate for the retailer echelon if it adopts lost sales. It is a customer service measure. The fill rate is the fraction of customer demand that is met routinely; that is, without backorders or lost sales.
6. Backorder fraction. Backorder fraction is also a customer service measure that calculates the proportion of backorders at the warehouse and distributor echelons.
7. The real lead time. Except for the transportation time between two facilities, the replenishment order lead time also includes the waiting time for shipment consolidation and order fulfillment.

From a practical standpoint, the selection of performance measure should be done, considering the purpose of the actual problem.

3 MODULE-BASED MODELING SYSTEM

In order to realize the system mentioned above, a template that consists of five modules using a discrete event simulation was developed in Arena software. Corresponding to the real system mentioned earlier, the modules were named as Factory, Warehouse, Distributor, Retailer, and Products. Microsoft Visual Basic for Applications was used for generating the simulation model automatically. Input data were collected from Microsoft Excel and output data were also saved in Excel files. The rest of this section will describe the details of the procedures in developing the modeling system.

3.1 Modules

3.1.1 Retailer Module

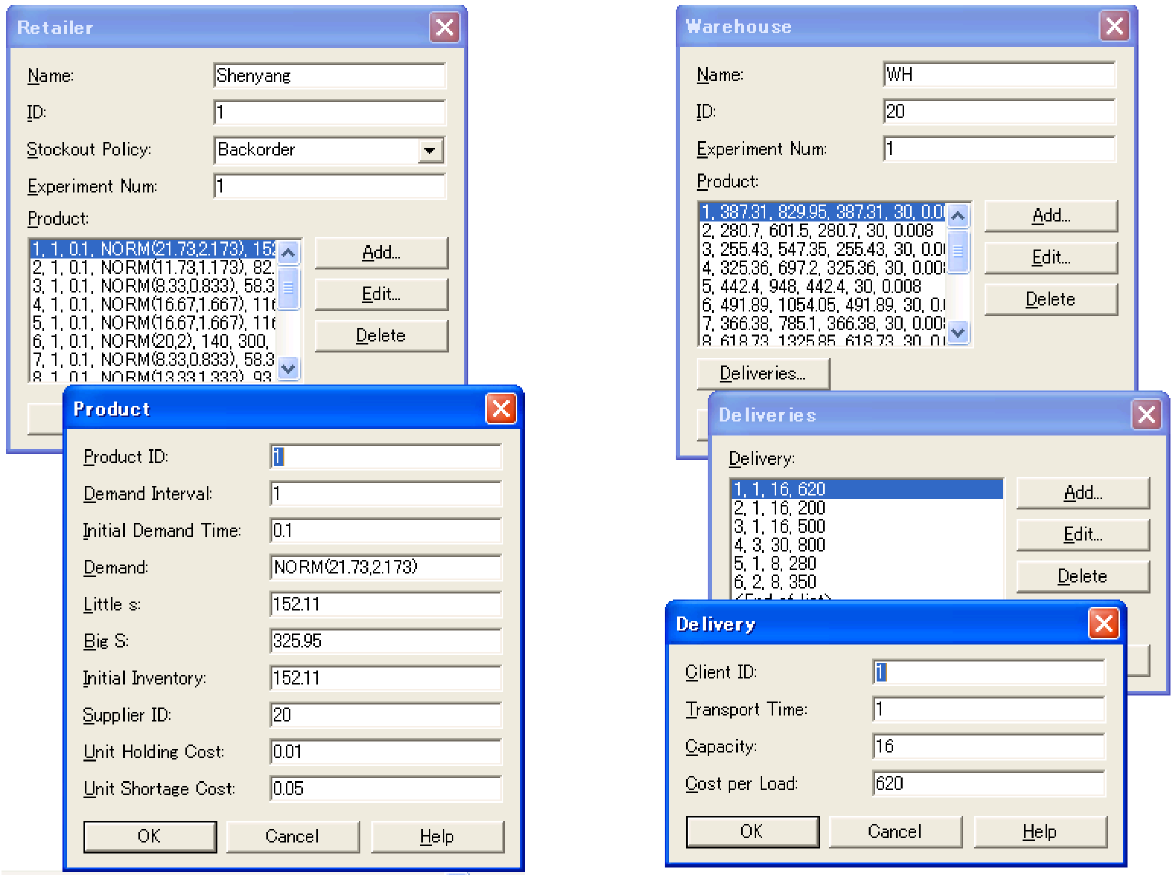
This module is designed to perform functions of a retailer. It also can be used to model a DC if the DC performs an end customer role at a supply chain. Only the retailer module receives orders from outside customers. An alternative stockout policy is considered for modeling that is lost sale and backorder. The lost sale policy means that any demand when out of stock is lost, and the backorder policy means that any demand when out of stock is backordered and filled as soon as an adequate sized replenishment arrives. The interface of the module is shown in Figure 3.

3.1.2 Distributor Module

This module performs the functions of a DC. The main processes include order processing, shipment consolidation, and inventory replenishment. First, it receives the orders from the retailers, then fills the orders if its inventory is enough, otherwise the orders will be backordered to await completion until the inventory become available. Second, after fulfillment, the orders (physical products) will be consolidated for delivering. Finally, the physical products are delivered to the retailers. This describes the process for order processing and shipment. Whenever, the inventory position is lower than the re-order point, the order would be triggered to the supplier. The supplier may be a warehouse, a factory, or a DC. The process flow is shown in Figure 4.

3.1.3 Warehouse Module

This module performs the same functions as a DC except for the difference in the shipment consolidation process. In the warehouse module, the shipment is consolidated for a single downstream customer by contrast with the distributor module wherein shipment consolidation occurs for all downstream customers. In addition, the warehouse uses the quantity policy, while the distributor exploits the time policy for shipment consolidation. The interface is shown in Figure 3.



(a) Retailer Module (b) Warehouse Module

Figure 3: Retailer and Warehouse Module

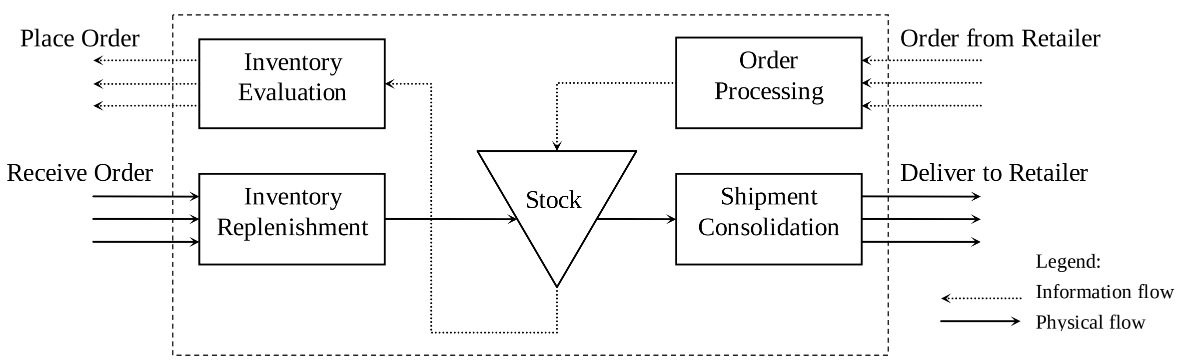


Figure 4: Process Flow of Distributor Module

3.1.4 Factory Module

This module is designed to accomplish the functions of the factory. Because the focus of this study is on a production-distribution system, the module was designed at a high-level. The material procurement was not considered. A Factory module is designed in a make-to-order fashion, with limited capacity, and two downstream customer types are considered: inside and outside. The inside type can be viewed as an in-house warehouse where the transportation is not considered. In contrast to the inside type, the outside type is generally considered a downstream customer, who may be a distributor, a retailer, or a wholesaler.

3.1.5 Products Module

This module is designed to define the characteristics of the product. The information of the products is used in other modules.

3.2 Simulation Model

3.2.1 Procedures for Building a Simulation Model

A simulation model was generated by selecting and allocating the required modules of the template in Arena. In order to build the supply chain model using the above modules, the simplest method is to directly drag the modules from the project bar to the working area of a model window, inputting the parameter, and then connecting the modules. It is time consuming and troublesome to build a supply chain system if done by direct ways, which is usually a complex system consisting of multistage and multi-products. For this reason, the VBA program was designed for creating the simulation model automatically. The procedures for creating a simulation model included two steps: preparing the input data and executing the VBA program. The output data was generated automatically. Figure 5 is an illustration of the procedure for executing a simulation program.

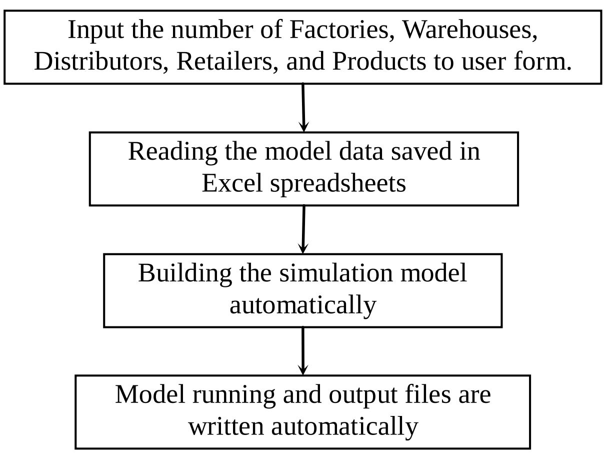


Figure 5: Procedure of Building Model

3.2.2 Input Data

All input data are stored in an Excel file that consists of a number of worksheets. One worksheet contains one module data.

3.2.3 Output File

The output files were also used for collecting various performance statistics and monitoring the status of the system. A set of files were used for keeping information at the factory, warehouse, distributor, and retailer facilities in order to record the inventories, transportation, and conditions of order fulfillment in the system. All Output files were stored in CVS format and distinguished by a module name, product ID, and experiment number, for example, Beijing_1_2_Inventory.cvs represents the inventory information of product 1 at Beijing in the second experiment.

4 AN APPLICATION EXAMPLE

The proposed modeling method was applied to an actual production-distribution system. In this system, daily commodities were delivered from the warehouse of the factory located in Qingdao to the warehouses of local DCs in Shenyang, Shandong, Shanghai, Guangzhou, Beijing, and Chendu. The system is characterized as follows:

1. Number of Factories: 1. No capacity constraints.
2. Number of Warehouses: 1.
3. Number of Retailers: 6 (because the DC was the first stage at the supply chain system, the Retailer module was used instead of Distributor module).
4. Number of kinds of products transported from warehouse to DC: 13
5. Transportation time in days: 1 through 3 (specified for each warehouse-DC and factory-warehouse combination).
6. Capacity of the truck in pallets: 8, 16, or 30 (specified for each warehouse-DC combination).
7. Number of corrugated cartons put on one pallet: 40 through 100 (specified for each product).
8. Simulation period: 300 (days).

The parameters for transportation between the warehouse and the DCs are shown in Table 1. Products characteristics and the demands at the DCs are shown in Table 2. The daily demand for each product at each DC is also assumed to follow the normal distribution with coefficient of variation 0.1. In addition, the transportation time from factory to warehouse was 1 day, and processing time was ignored. The re-order point and order-up-to level at the DCs and warehouse were 7 and 15 times the daily demand. The model is shown in Figure 6. Figure 7, meanwhile, shows the inventory plot of product 1 at Shenyang DC. Figure 8 displays a copy of the animation of the model.

Table 1: Parameters for Transportation

DC Name	ID	Transport Time (Days)	Truck Capacity (Pallets)	Cost per Load (Yuan*)
Shenyang	1	1	16	620
Shandong	2	1	16	200
Shanghai	3	1	16	500
Guangzhou	4	3	30	800
Beijing	5	1	8	280
Chengdu	6	2	8	350

* US $1.00 = Yuan 8.00

Table 2: Average Daily Demand and Product Characteristics

Product ID	Cases per Pallet	Average Daily Demand (Cases)					
		Shenyang	Shandong	Shanghai	Guangzhou	Beijing	Chengdu
1	96	21.73	14.87	13.33	3.33	1.67	0.40
2	96	11.73	11.97	11.67	3.33	0.00	1.40
3	96	8.33	3.33	7.67	5.00	3.33	8.83
4	40	16.67	10.67	6.67	11.67	0.00	0.80
5	40	16.67	13.70	6.67	23.33	0.00	2.83
6	40	20.00	26.93	6.67	13.33	2.67	0.67
7	40	8.33	13.30	1.67	21.67	1.67	5.70
8	40	13.33	29.23	8.33	18.33	0.00	19.17
9	45	11.73	3.40	11.67	8.33	0.00	0.47
10	60	11.73	2.33	10.00	6.67	3.33	1.10
11	100	13.33	8.77	18.33	21.33	5.00	3.80
12	100	11.00	3.27	8.33	14.33	1.00	0.40
13	100	9.00	5.43	11.67	14.33	2.67	0.37

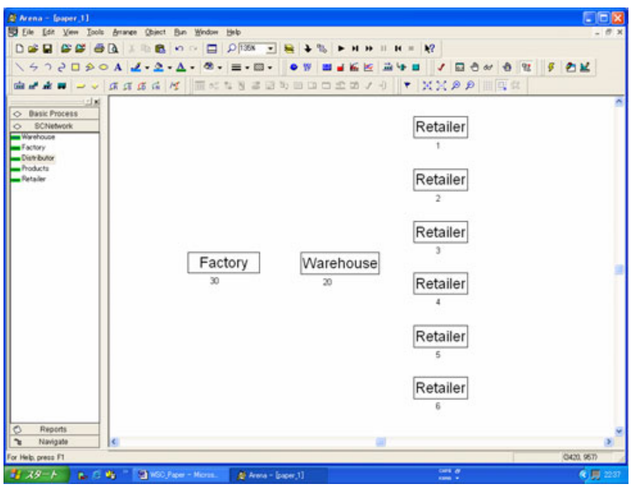


Figure 6: Model of the Application

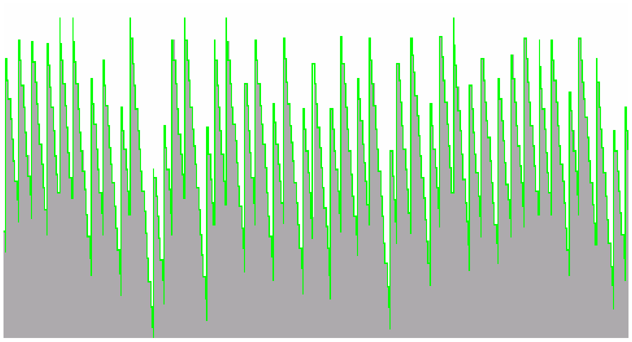


Figure 7: Inventory Plot of Product 1 at Shenyang DC

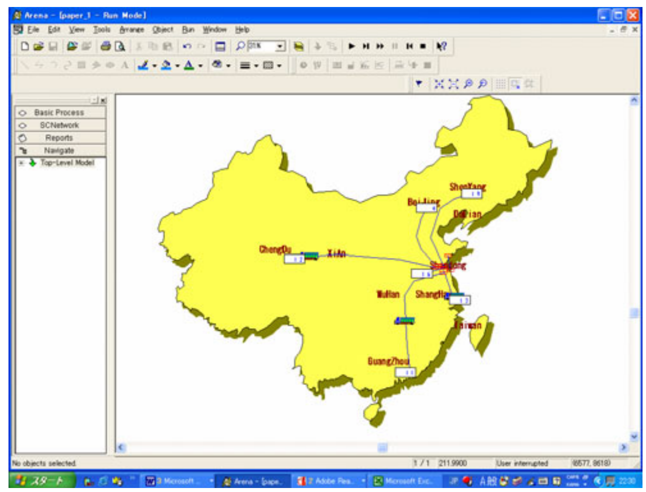


Figure 8: Animation of the Model

After simulation running, a total of 95 files were generated. Table 3 shows the transportation cost and the number of trucks between the warehouse and DCs.

Building a simulation model by using the proposed module-based modeling method only takes short time. In addition, it is very easy for a modeler to build such a simulation model. Consequently, this demonstrates that the proposed method is a very efficient and effective tool.

Table 3: Result of Transportation Cost and Trucks

Client ID	Avg. Transportation Cost (Yuan*/Day)	Number of Trucks
1	103.85	51
2	27.50	41
3	56.25	34
4	76.00	29
5	9.80	11
6	34.13	30

* US $1.00 = Yuan 8.00

5 CONCLUSIONS

An efficient module-based modeling method, using discrete-event simulation with ARENA combined with Excel VBA, was presented as a way to generate simulation programs for any type of production-distribution supply chain system. In this study, both multistage multi-product inventory management and shipment consolidation were considered. The simulation model was built by using the proposed method and can be applied to analyzing the performance of a supply chain, such as the trade-off between the transportation costs and inventory costs, the trade-off between cost and service levels, or the inventory control.

The proposed modeling method was presented by employing an actual case to demonstrate the applicability to the actual production-distribution system. By utilizing the proposed module-based modeling method, it was possible to quickly build a complex system and rapidly change the configuration of the system.

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