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A PRACTICAL MODULE-BASED SIMULATION MODEL FOR TRANSSHIPMENT-INVENTORY SYSTEMS

Soemon Takakuwa

School of Economics and Business Administration
Nagoya University
Furo-cho, Chikusa-ku, Nagoya-shi, Aichi, 464 JAPAN

Tsukasa Fujii

Aichi Prefectural Police Academy
Aichi Prefecturral Police Headquarters
Hazama-cho 703, Kasugai-shi, Aichi, 486 JAPAN

ABSTRACT

A method of modeling transshipment-inventory systems is proposed in an attempt to describe the systems flexibly in which a lot of kinds of items are ordered to transport and transship, transported, stored, and delivered to the customers. The system consists of a number of supply, transshipment and demand nodes. However, the problem considered in this study is totally different from the traditional transshipment problem in terms of linear programming. Firstly, any number of different kinds of items can be treated for analysis. Secondly, any size of transportation trucks can be specified to transport items for any number of the two-node combinations. In other words, the capacity of the transportation truck is to be specified in building a simulation model. In addition, any number of supply, transshipment and demand nodes can be specified in a simulation model. Thirdly, the order by a demand node is made toward the associated transshipment node, based on the inventory policy at the demand node, and the so-called the "pull system" is adopted in the demand-supply environment.

An efficient module-based modeling method is proposed to generate simulation models for the above-mentioned transshipment-inventory systems. The proposed method is applied to the actual system. It is found that the time to build simulation models could be drastically reduced. Furthermore, the proposed method is found to be both practical and powerful.

1 INTRODUCTION

The traditional transportation, transshipment, or distribution model is focused on solving problems composed of one-product, multiple "sources" (i.e., the points of departure), multiple points of transshipment (i.e., the transient) and multiple "sinks" (i.e., the destinations) in terms of linear programming (Ignizio 1982). Source or supply nodes are nodes used to describe a terminal at which a supply of discrete items exists. On the other hand, sink or demand nodes are those nodes that "consume" or demand the goods stored within the source nodes. Thus, a convenient analogy is that the supply nodes represent warehouses in the factories while the demand nodes represent warehouses in the business offices.

The transshipment model recognizes that it may be cheaper to ship through intermediate or transient nodes before reaching the final destination; this concept is more general than the one advanced by the regular transportation model, where direct shipments only are allowed between a supply node and a destination node. In the real world, however, there are a lot of products or items to be handled; hence, the problem should be simplified in applying the traditional (linear programming) transportation problem to it. In addition, because the problem is formulated by linear programming, the dynamic analysis cannot be performed.

In my previous study, the procedures for creating practical module-based simulation models for the transportation and inventory system were defined (Takakuwa 1998). In this study, the procedure of creating practical module-based simulation models for the transshipment and inventory system is proposed, by sophisticating the transshipment-inventory modeling system using the idea of buffer in the transshipment node. A modeling method is developed to generate simulation models for the transportation-inventory systems, adopting simulation. An efficient module-based modeling method is proposed to generate simulation models for the transshipment-inventory systems. The proposed method is applied to an actual system, and it is found to be both practical and powerful.

2 TRANSSHIPMENT-INVENTORY MODEL

2.1 Graphical Presentation

Figure 1 provides a convenient illustration of the practical transshipment problems to be treated in this study (Taha 1997). This network model can be divided into three particular types of nodes. Those nodes on the left represent supply nodes, those in the middle are transshipment nodes,

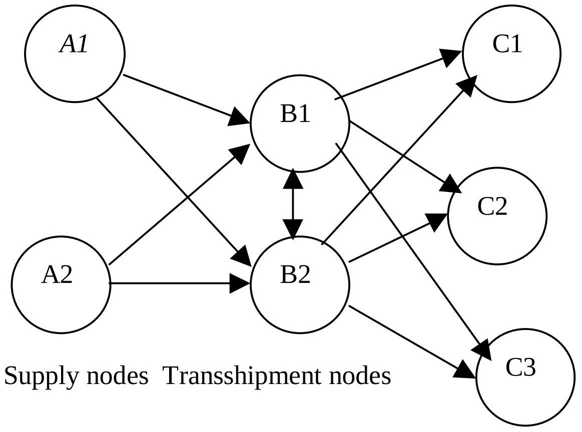


Figure 1: Scheme of Practical Transshipment and Inventory Model

and those on the right are demand nodes. The branches connecting a pair of nodes represent paths of "transmission," or transportation routes between a pair of nodes consisting of supply, transshipment and demand nodes.

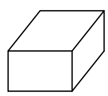
The single objective of the traditional transshipment problem is to find the minimum cost pattern of shipment. The rigid constraints are associated with the amounts available at each source and demanded at each sink. Contrary to the traditional transshipment problem, multiple kinds of products should be actually considered in the model. Furthermore, whether the same kinds of products would be delivered from the different supply or transshipment nodes to the transshipment or demand nodes depends on the actual situation. In the proposed method, the various types of systems comprise any number of kinds of products, supply, transshipment and demand nodes. All can be modeled and simulated.

2.2 The Units of Transportation

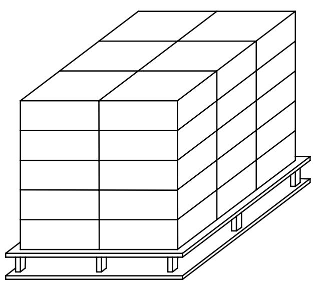
In the traditional transportation problem, the main issue is the cost pattern of shipment, and the form or the unit of transportation is not taken into consideration. In the actual transportation, however, the form or the unit of transportation is one of the most important issues to be considered, because the number of products to be transported at a time depends on the unit of transportation.

The units of transportation at four stages are illustrated in Figure 2, as treated in my previous study. Four stages are on a piece of product, on a corrugated cardboard box, on a pallet, and on a truck. The certain number of pieces of the product are packed in one corrugated cardboard box. The number of pieces for each product is specified, considering the size of both the product and the corresponding corrugated cardboard box. Then, the certain number of corrugated cardboard boxes are put on one pallet, which might be handled by a forklift truck. Finally, a specified number of pallets, on which the corrugated cardboard boxes are being put, are loaded on one truck, necessary that the number of products for one corrugated

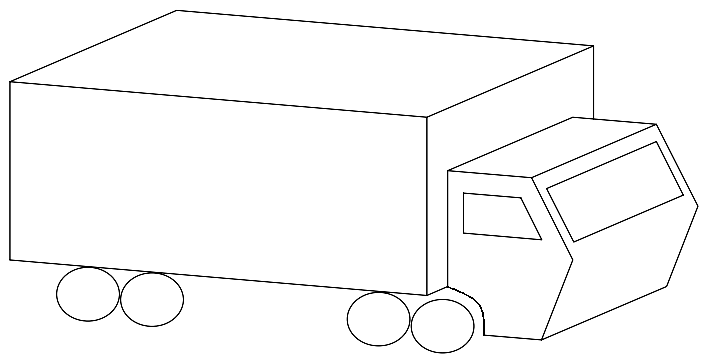
(a) A piece of product



(b) A corrugated cardboard box



(c) A pallet



(d) A truck

Figure 2: Units of Transportation

and transported to the destination. Therefore, it is cardboard box, the number of cardboard boxes for one pallet, and the number of pallets for one truck respectively should be determined for each product to be transported in constructing the associated simulation model. In addition, the capacity in terms of the number of pallets to be loaded on the truck should be decided for each combination of the supply, the transshipment and the demand codes.

2.3 The Inventory-Bank-Replenishment System at the Demand Node

As described in the previous section, the truck is used as a means for transporting products. Now let us assume that a truck can transport products only when the prescribed number of pallets are loaded, that is the truck must be full. Hence, in the case where space is available on the truck, the truck cannot begin to move towards the designation node. While different kinds of products may be loaded on a given truck, only the same product may be placed on a given pallet.

Every t units of time a decision with respect to a replenishment is made (Naddor 1966). The amount to be replenished at time i raises the available inventories $A(i)$ to a bank $B(i)$. No returns are allowed. Thus the basic quantity $C(i)$ ordered for replenishment of inventory may be formally given by

$$C(i)=\max[B(i)-A(i),0] \tag{1}$$

Then, the cumulative number of pallets is compared with the capacity of the truck. The actual replenishment is not performed toward the associated source until the cumulative number of pallets become equal to the capacity (in pallets) of a truck.

It is assumed that the variable t is prescribed and is not subject to control. Furthermore, for ease of description, t will be assumed to be one day.

Analysis will thus be concerned only with the bank $B(i)$ which is subject to control by a decision maker. The bank may be viewed as composed of several days of average demand,

$$BANK(i)=N \times DAVE(i) \tag{2}$$

where N is the number of days in the bank and $DAVE(i)$ is the average demand as of day i.

Several methods may be used to determine the average demand $DAVE(i)$. In this study only one such method is studied: the average demand at time i is determined by finding the mean demand over a period of M days immediately preceding time i:

$$DAVE(i) = (1/M)\sum_{j=i-M+1}^{i} D(j) \tag{3}$$

The parameters N and M thus completely specify how decisions may be reached in the inventory system. The notation is used as follows:

- i : day number,
- $QB(i)$: the inventory on hand at the beginning of day i,
- $D(i)$: the demand during day i,
- $QE(i)$: the inventory on hand at end of day i,
- $DAVE(i)$: the average demand as of end of day i, based on equation (3),
- $BANK(i)$: the bank as of end of day i, based on equation (2),
- $AVAIL(i)$: the available inventory as of end of day i, before ordering a replenishment (i.e., the amounts on hand and on order),
- $C(i)$: the quantity given by equation (1),
- $REP(i)$: the replenishment quantity ordered at the end of day i, based on equation (1),
- $REPADD(i)$: the replenishment added to inventory at end of day i, available at beginning of day i+1.

Let L designate leadtime in days. Then, the equations can be obtained:

$$QE(i)=QB(i)-D(i) \tag{4}$$

$$AVAIL(i) = QE(i) + \sum_{j=i-L}^{i-1} REP(j) \quad (L > 0) \tag{5}$$

$$REPADD(i)=REP(i-L) \tag{6}$$

$$QB(i+1)=QE(i)+REPADD(i) \tag{7}$$

The use of decision rules based on equations (1), (2), and (3) in inventory systems involving many items stems from practical considerations.

The decision rule of equation (3) is also claimed to have another desirable feature. Presumably it can detect trends in demand, particularly if the parameter M is relatively small. On the other hand, large random change in demand may unduly influence the average demand $DAVE(i)$ leading to excessive inventories or shortages.

2.4 The Inventory-Replenishment System at the Transshipment Node

At each transshipment nodes, whenever the amount in stock at the end of the day is at or below s quantity units for each product, the inventory is immediately replenished so that the amount after the leadtime to deliver is S quantity units. Therefore, this is an inventory system with an (s, S) policy. Again, as described in the previous sections, the truck is used as a means of transporting products. Let us assume that a truck can transport products only when the prescribed number of pallets are loaded on the truck, that is, the bed of the truck is full.

3 SIMULATION MODEL FOR TRANSSHIPMENT-INVENTORY SYSTEMS

3.1 Efficient Modeling System for Transshipment-Inventory System

In the proposed procedure, there are two steps to perform simulation experiments. The first step is to generate simulation programs, by selecting and allocating the required modules of the Arena template for describing a particular transshipment-inventory system. There are five modules for the particular type of the transshipment-inventory system, as shown in Table 1.

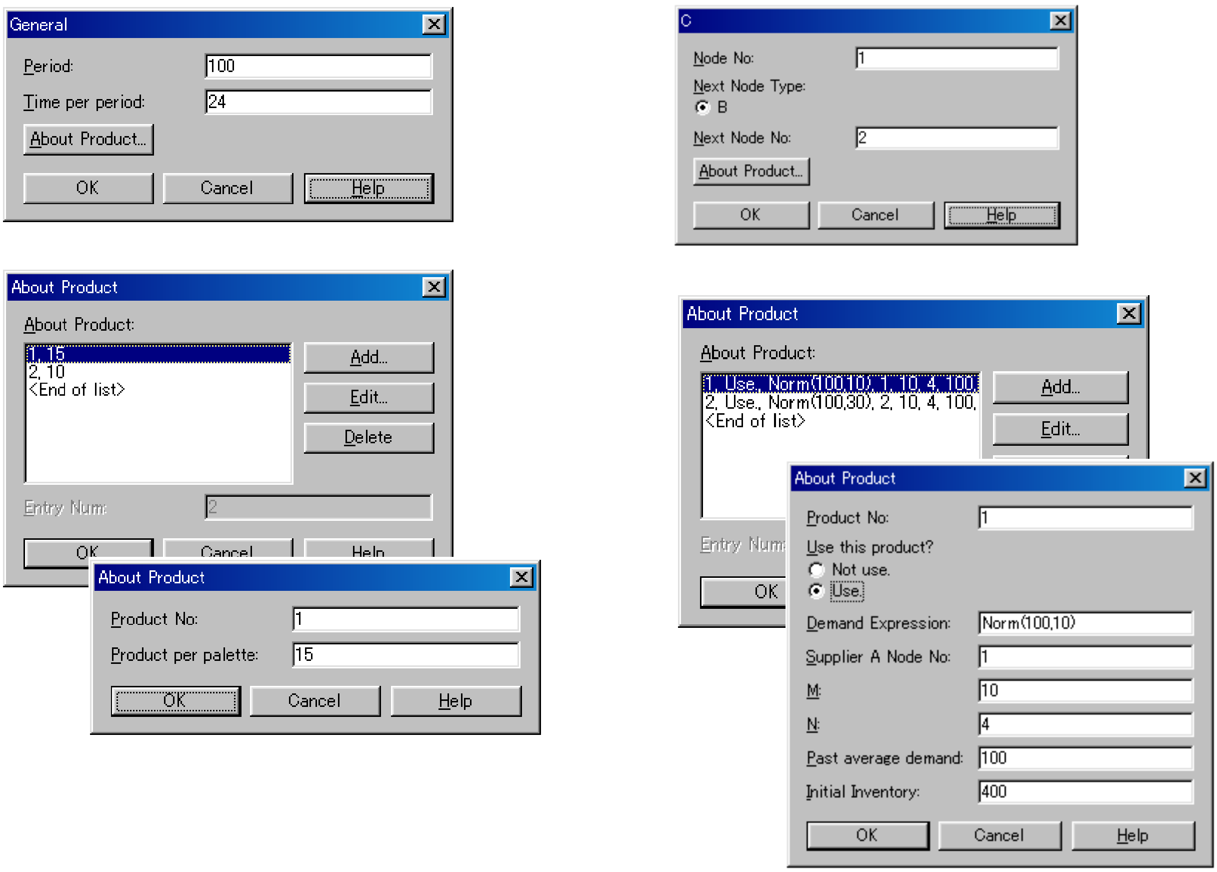
In this study, the simulation is performed by SIMAN/Arena (Pegden et al. 1994, Kelton et al. 1998); however, the basic idea of this procedure can be applied to other simulation languages. Similarly, this approach has been applied for the flexible modeling system on AS/RS-AGV systems, as described in my previous paper (Takakuwa 1996).

Table 1: Summary of Parameters in Five Modules

Module	No.	Items	No.	Items	No.	Items	No.	Items
General	1	Period						
	2	Time period						
	3	About product	1	Product No.	1	Product No.		
					2	# product per pallet		
			2	# Entry				
A(Supply)	1	Node No.						
	2	Next node type						
	3	Next node No.						
	4	(automatically entered.)	1	Product No.	1	Product No.		
			2	# Product type				
			3	File length				
			4	Station name				
B(Transshipment)	1	Node No.						
	2	About product	1	About product	1	Product No.		
					2	Maximum inventory		
					3	Initial inventory		
					4	Minimum inventory		
					5	Supplier A node No.		
			2	# entry				
	3	About node	1	About node	1	Next node type		
					2	Next node No.		
			2	# entry				
	4	(automatically entered)	1	File length				
			2	Station name				
C(Demand)	1	Node No.						
	2	Next node type						
	3	Next node No.						
	4	About product	1	About product	1	Product No.		
					2	Use this product?	0	No
							1	Yes
					3	Demand expression		
					4	Supplier A node No.		
					5	M		
					6	N		
					7	Average past demand		
					8	Initial inventory		
			2	Entry No.				
	5	(None; station name)						
D(Route)	1	Type						
	2	No.						
	3	Type						
	4	No.						
	5	Delay						
	6	Capacity						
	7	Pic						

The template system in this system consists of the following five modules:

(1) General Module. This module is designed to specify the overall characteristics of the system (Figure 3 (a)).
(2) A Module. This module is designed to specify the parameters on each supply node.
(3) B Module. This module is designed to specify the parameters on each transshipment node.
(4) C Module. This module is designed to specify the parameters on each demand node (Figure 3(b)).
(5) D Module. This module is designed to specify the parameters on routes between a pair of nodes.



(a) General Module (b) C Module (Demand Node)

Figure 3: Special-Purpose Modules for Transshipment-Inventory Models

In addition, M/S Visual Basic for Applications (VBA) code is utilized to describe a rather complicated logic construct. In this study, the major VBA modules are as follows:

(1) Logic Module: This module is designed to display VBA codes.
(2) ThisDocument Module: This module is usually attached in the model file.
(3) InfoForm Module: This is a form module, and designed to display information on the model.
(4) TSMModule Module: This module is designed to specify the parameters referenced from all VBA modules, and hold the required procedures.

Figure 4 shows a portion of the VBA code which creates the D Module.

```
Public Sub fromAnimeRoute()
'By using routes of animation, D modules are to be created; Connecting modules
are to be set for A, B, and C modules.
    Dim myRouteNum As Integer
    Dim myRoute As Arena.Route
    Dim myNode1 As Arena.Module
    Dim myNode2 As Arena.Module
    Dim myD As Arena.Module
    Dim myX As Long
    Dim myY As Long
    Dim i As Integer
    Dim j As Integer
    Dim D1 As Integer, D2 As Integer, D3 As Integer, D4 As Integer, D5 As Integer

 '   To examine whether it will be executed or not.
    i = MsgBox("You can use this procedure only 1 time. All ready?", vbOKCancel)
    If i = vbCancel Then
        MsgBox "At this time, Canceled."
        Exit Sub
    Else
```

Figure 4: One Portion of a VBA Code

3.2 Building A Simulation Model

Figure 5 shows an illustrative example of Arena template and a series of associated modules for the transshipment-inventory systems which is described in Figure 1. In Arena, simulation models are built by placing modules in a working area of a model window, providing data for these modules, and specifying the flow of entities through modules. A module defines the underlying logic that is applied when an entity is directed to the module, as well as the associated graphical animation, to depict the module's activities during a simulation run.

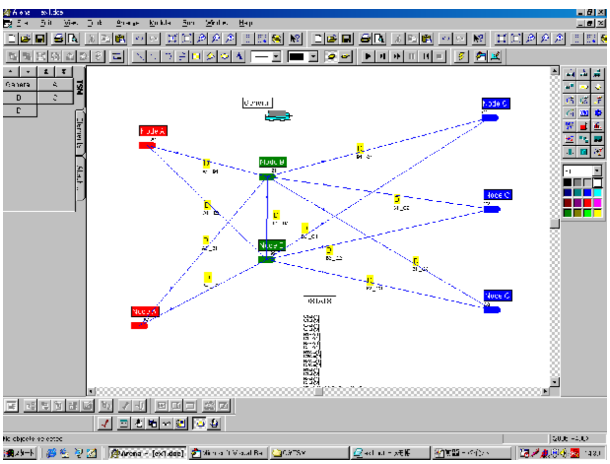


Figure 5: Illustrative Simulation Model Using Special-Purpose Modules

After a module has been placed in the model windows, its associated data may be edited. Each item has more detailed parameters to be set interactively. By responding to the prompt for each parameter, appropriate figures may be inputted; some these operations are shown in Figure 3 in the previous section. After all necessary modules are placed in an appropriate fashion for a particular model and the corresponding values are provided for their operands, a simulation run may be performed.

3.3 External Files

The external files are also used for generating requests for replenishment, collecting various performance statistics, and monitoring the status of the system. In addition to the typical simulation/animation program, three kinds of the additional files are used for keeping information at supply, transshipment, and demand nodes, respectively, to record on transportation and inventories in the system.

(1) File Group 1: "A'No'_Out.txt". This file contains information on products shipped from an A Module. The items will be displayed on the day, time, number of units of trucks, the destination node, number of pallets on each product.
(2) File Group 2: "B'No'_Out.txt". This file contains information on products shipped from a B Module. The items will be displayed on the day, time, number of units of trucks, the destination node, and number of pallets on each product.
(3) File Group 3: "C'No'_Out.txt". This file contains information on inventory and replenishment at a C Module. The items will be displayed on the day, the inventory on hand at the beginning of a day, the demand during the day, the inventory on hand at end of the day, the average demand as of end of the day, the bank as of end of the day, the available inventory as of end of the day

before ordering a replenishment, the replenishment quantity ordered at the end of the day, and the replenishment added to inventory at end of the day.

4 APPLICATION

The proposed modeling method is applied to an actual case. In this system, daily commodities are delivered from the warehouses of the factories to the warehouses of business offices via a warehouse for transshipment. The system is characterized as followed:

(1) Number of supply nodes: 1.
(2) Number of transshipment nodes: 1.
(3) Number of demand nodes: 12.
(4) Number of kinds of products transported from supply node 1: 36.
(5) Leadtime in hours: 1 through 9 (specified for each two-node combination).
(6) Capacity of the truck in pallets: 28 or 32 (specified for each two-node combination).
(7) Number of corrugated cardboard boxes put on one pallet: 16 through 96 (specified for each product).

An associated simulation model is shown in Figure 6. In this case, three external files are generated as File Group 1, and four external files are generated as File Group 2. Figure 7 shows the content of one file of File Group 2, and it is generated to record the detailed contents of products transported from each transshipment node. This table is one part of the list of the files at transshipment node No. 1. In addition, 432 external files of File Group 3 are generated to record the detailed contents of the inventory-bank-replenishment system at each demand node. Figure 8 shows one part of the list of an external file at Demand node No. 1. In the table, the notation is indicated in the section 2.3.

Furthermore, the transition of the inventory on hand on each product at each node at both the beginning and end of each day could be shown, if necessary. These figures might be used as occasion demands.

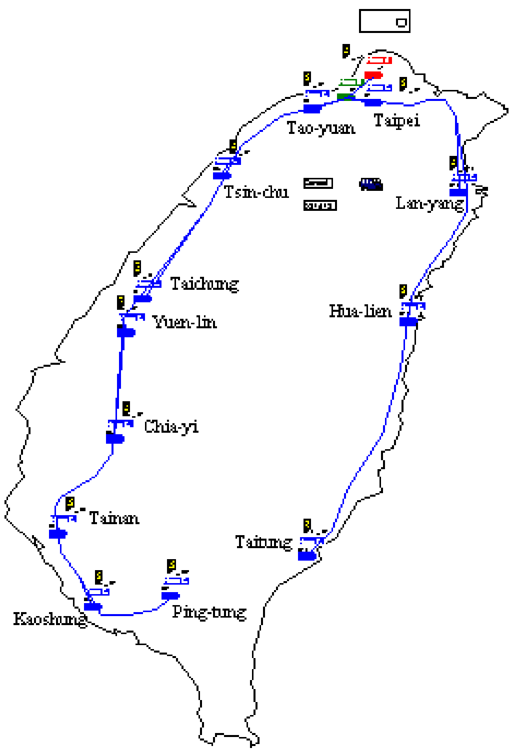


Figure 6: A Simulation Model Based on an Actual System

```
 Ki =     2 , Time =     0 , STNum =     1 , to = C    2 , Palette =     1,    9,
Ki =     3 , Time =     0 , STNum =     2 , to = C    2 , Palette =     5,   15,
Ki =     4 , Time =     0 , STNum =     2 , to = C    2 , Palette =     6,   14,
Ki =     5 , Time =     0 , STNum =     3 , to = C    2 , Palette =    18,   12,
Ki =     6 , Time =     0 , STNum =     1 , to = C    2 , Palette =     3,    7,
Ki =     7 , Time =     0 , STNum =     1 , to = C    2 , Palette =     0,   10,
Ki =     8 , Time =     0 , STNum =     1 , to = C    2 , Palette =     0,   10,
Ki =    10 , Time =     0 , STNum =     1 , to = C    2 , Palette =     0,   10,
Ki =    11 , Time =     0 , STNum =     1 , to = C    2 , Palette =     0,   10,
 :        :           :              :            :                  :          :
```

Figure 7: One Part of an External File for a Transshipment Node

i	QB(i)	D(i)	QE(i)	DAVE(i)	BANK(i)	AVAIL(i)	C(i)	REP(i)	REPADD(i)
1	400	93	307	99	396	307	89	89	0
2	307	102	205	100	400	294	106	106	0
3	205	99	181	99	396	301	95	95	75
4	181	96	205	99	396	300	96	96	120
5	205	101	149	99	396	295	101	101	45
:	:	:	:	:	:	:	:	:	:

Figure 8: One Part of an External File for a Demand Node

Simulation models are excellent for analyzing the interaction effects due to system variability. Such models can identify queuing effects, bottleneck conditions, and delays. In addition, if the system developed in this study is utilized, it would take only a few hours for a programming newcomer to develop a simulation program for a large-scale transshipment-inventory system. Thus, the time required to build simulation programs could be reduced drastically, by utilizing the proposed module-based modeling method. When construction of the simulation model is completed, the corresponding animation can be run immediately; this is a great advantage of the module-based modeling method over traditional modeling systems.

5 SUMMARY

(1) An efficient module-based modeling method is presented for generating simulation programs for practical transshipment-inventory systems.

(2) The proposed modeling method is presented using an actual case to demonstrate the applicability to the actual transshipment-inventory problems.

(3) Flexibility of the proposed system is described. By utilizing the proposed module-based modeling method, the time to build simulation programs could be drastically reduced.

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AUTHOR BIOGRAPHIES

SOEMON TAKAKUWA is a Professor in the School of Economics and Business Administration at Nagoya University in Japan. He received his B.Sc. and M.Sc. degrees in industrial engineering from Nagoya Institute of Technology in 1975 and from Tokyo Institute of Technology in 1977 respectively. His Ph.D. is in industrial engineering from The Pennsylvania State University. He holds a Doctor of Economics degree from Nagoya University. His research interests include optimization of manufacturing and logistics systems, management information system and simulation.

TSUKASA FUJII is a Captain of Aichi Prefectural Police. He received his B.Sc. and M.Sc. degrees in Economics from Nagoya University in 1997 and in 1999 respectively.