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

Soemon Takakuwa

School of Economics
Nagoya University
Furo-cho, Chikusa-ku, Nagoya-shi, Aichi, 464-8601 JAPAN

ABSTRACT

A method of modeling transportation-inventory systems is proposed in an attempt to flexibly describe the systems in which a lot of kinds of items are ordered to transport, transported, stored at the warehouses, and delivered to the customers. The system consists of a number of "sources" and "sinks." However, the problem considered in this study is totally different from the traditional transportation 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 source-sink combinations. In other words, the capacity of the transportation truck is to be specified in building a simulation model. In addition, any number of both sources and sinks can be specified as required to build a simulation model. Thirdly, the order by a sink is made toward the associated source, based on the inventory policy at the sink, and 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 transportation-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 or distribution model is focused on solving problems composed of one-product, multiple "sources" (i.e., the points of departure) and multiple "sinks" (i.e., the destinations) in terms of linear programming (Ignizio 1982). Source nodes are nodes used to describe a terminal at which a supply of discrete items exists. On the other hand, sink nodes are those nodes that "consume" or demand the goods stored within the source nodes. Thus, a convenient analogy is that the source nodes represent warehouses in the factories while the sink nodes represent warehouses in the business offices.

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 transportation problem to it. In addition, because the problem is formulated by linear programming, the dynamic analysis cannot be performed.

In this study, 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 transportation-inventory systems. The proposed method is applied to an• actual system for illustrating the proposed procedure.

2 TRANPORTATION-INVENTORY MODEL

2.1 Graphical Presentation

Figure 1 provides a convenient illustration of the practical transportation problems to be treated in this study. This network model can be divided into two particular types of nodes. Those nodes on the left represent "sources," and those on the right are "sinks." The branches connecting the source nodes to the sink nodes represent paths of "transmission," or transportation routes between each individual source and sink. The single objective of the traditional transportation 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 transportation 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 sources to the specific sink depends on the actual situation. In the proposed method, the various types of systems comprising any number of kinds of products, sources, and sinks can be modeled, and simulation performed.

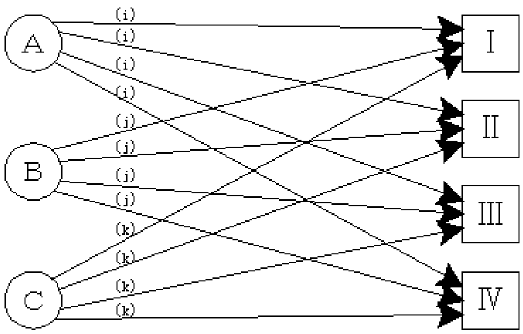


Figure 1: Scheme of Practical Transportation and Inventory Model

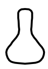
2.2 The Units of Transportation

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 both the capacity and the unit of transportation.

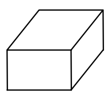
The units of transportation at four stages are illustrated in Figure 2. The four stages are on a piece of product, on a corrugated cardboard box, on a pallet, and on a truck. A certain number of pieces of the product are packed in one corrugated cardboard box. The number of pieces for each product is predetermined, considering the size of both the product and the corresponding corrugated cardboard box. Then, a 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, and transported to the destination. Therefore, it is necessary that the number of products for one corrugated 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 source and the sink.

2.3 The Inventory-Bank-Replenishment System

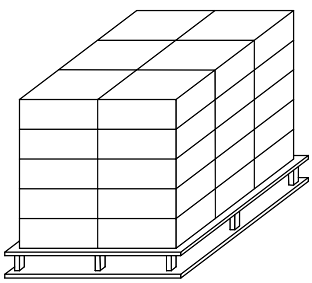
As described in the previous section, the truck is used as a means of transporting products from the source to the sink. Now let assume that a truck can transport products only when the prescribed number of pallets are loaded on the truck, that is, the bed of the truck is full. Hence, in case that there is an available space on the bed of a truck, the truck cannot begin to move toward the designated sink. Some different kinds of products may be loaded on one truck, but the same kind of product should be put on one pallet.



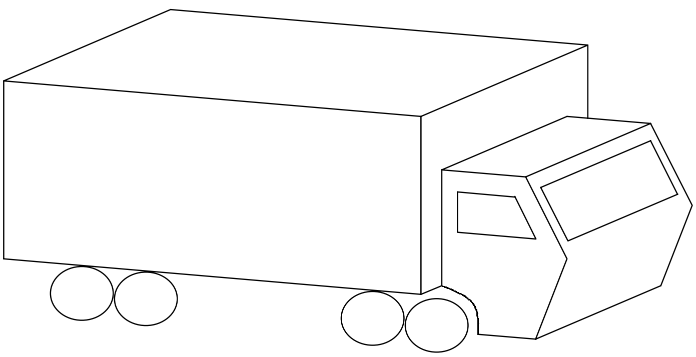
(a) A piece of product



(b) A corrugated cardboard box



(c) A pallet



(d) A truck

Figure 2: Units of Transportation

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,

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

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. Table 1 illustrates the system when the demand is normally distributed with a mean of 98.7 (boxes) and a standard deviation of 9.9 (boxes), leadtime is one (1) day, M is 30, and N is 6. In the Table 1 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, however, a large random change in demand may unduly influence the average demand $DAVE(i)$, and this may lead to excessive inventories or to excessive shortages.

3 SIMULATION MODEL FOR TRANSPORTATION-INVENTORY SYSTEMS

3.1 Efficient Modeling System for Transportation-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 transportation-inventory system. There are three modules for the particular type of the transportation-inventory system, as shown in Table 2. 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 and on a flexible manufacturing system, as described in the previous

Table 1: Inventory Bank-Replenishment System

i	*QB(i)*	*D(i)*	*QE(i)*	*DAVE(i)*	*BANK(i)*	*AVAIL(i)*	*C(i)*	*REP(i)*	*REPADD(i)*
31	588	92	496	97.8	586	496	90	80	0
32	496	82	414	97.267	583	494	89	80	80
33	494	99	395	97.3	583	475	108	96	80
34	475	84	391	96.833	581	487	94	80	96
35	487	108	379	97.167	583	459	124	112	80
36	459	97	362	97.133	582	474	108	96	112
37	474	102	372	97.267	583	468	115	112	96
38	468	96	372	97.2	583	484	99	96	112
39	484	109	375	97.567	585	471	114	112	96
40	471	84	387	97.1	582	499	83	80	112
41	499	89	410	96.8	580	490	90	80	80
42	490	96	394	96.733	580	474	106	96	80
43	474	105	369	96.967	581	465	116	112	96
44	465	97	368	96.933	581	480	101	96	112
45	480	86	394	96.533	579	490	89	80	96
46	490	97	393	96.5	579	473	106	96	80
47	473	89	384	96.2	577	480	97	96	96
48	480	108	372	96.533	579	468	111	96	96
49	468	104	364	96.733	580	460	120	112	96
50	460	95	365	96.633	579	477	102	96	112
51	477	90	387	96.367	578	483	95	80	96
52	483	103	380	96.533	579	460	119	112	80
53	460	97	363	96.5	579	475	104	96	112
54	475	104	371	96.7	580	467	113	112	96
55	467	99	368	96.733	580	480	100	96	112
56	480	97	383	96.7	580	479	101	96	96
57	479	105	374	96.933	581	470	111	96	96
58	470	92	378	96.733	580	474	106	96	96
59	474	97	377	96.7	580	473	107	96	96
60	473	103	370	96.867	581	466	115	112	96
61	466	86	380	96.667	580	492	88	80	112
62	492	95	397	97.1	582	477	105	96	80
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

Table 2: Summary of Parameters in Three Modules

Module	No.	Items	No.	Items	No.	Items	No.	On/Off
General	1	Number of kinds of products						
	2	Number of sources						
	3	Number of sinks						
	4	Beginning day number						
	5	Ending day number						
	6	Individual products	1	Individual products	1	Product number		
					2	Number of cases per pallet		
				(Repeat)				
Source	1	Source number						
	2	Number of kinds of products						
	3	Number of sinks						
Sink	1	Sink number						
	2	Number of kinds of products						
	3	Number of sources						
	4	Number of sinks						
	5	Individual products	1	Individual products	1	Product number		
					2	Check	1	On
							2	Off
					3	Number of days in the bank		
					4	Number of days for finding average demand		
					5	Demand during day I		
				(Repeat)				
	6	Sources	1	Sources	1	Source number		
					2	Number of pallets per truck		
					3	Leadtime in days		
				(Repeat)				
	7	Percentage	1	Percentage	1	Product number		
					2	Source number		
					3	Percentage		
				(Repeat)				

papers (Takakuwa, 1996, Takakuwa 1997). The template system in this system comprises the following three modules:

(1) General. This module is designed to specify the overall characteristics of the system.

(2) Source. This module is designed to specify the parameters on each source.

(3) Sink. This module is designed to specify the parameters on each sink.

3.2 Building A Simulation Model

Figure 3 shows an illustrative example of Arena template and a series of associated modules for the transportation-inventory systems. 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.

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. Furthermore, all necessary "routes" should be connected between the associated pairs of sources and sinks. 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 movement system is modeled using the SIMAN/Arena simulation language constructs. 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 additional files are used for keeping information on transportation and inventories in the system. The number of external files in each file group is indicated in parentheses.

(1) File Group 1: Initial conditions. (Number of products times number of sinks.)

[PURPOSE] To prepare all of the past data on the demand and inventory for each product at each sink as the initial conditions of the simulation experiment.

[CONTENTS] i, $QB(i)$, $D(i)$, $QE(i)$, $DAVE(i)$, $BANK(i)$, $AVAIL(i)$, $C(i)$, $REP(i)$, $REPADD(i)$

(2) File Group 2: Generated inventory-bank results. (Number of products times number of sinks.)

[PURPOSE] To generate iterative inventory-bank-replenishment results in performing simulation, and keep the record on the status of each product at each sink.

[CONTENTS] i, $QB(i)$, $D(i)$, $QE(i)$, $DAVE(i)$, $BANK(i)$, $AVAIL(i)$, $C(i)$, $REP(i)$, $REPADD(i)$

(3) File Group 3: Record of transported products loaded on each truck. (Number of sources.)

[PURPOSE] To record the detailed contents of products transported by each truck.

[FORMAT] i, Sink No., Arrival period, Product No.,…

4 APPLICATION

The proposed modeling method is applied to a little simplified system based on an actual case. The number of sinks and the number of products are fewer than in the real case, but the actual figures are used for the parameters in the model. In this system, daily commodities are delivered from the warehouses of the factories to the warehouses of business offices. The system is characterized as followed:

(1) Number of sources: 2.
(2) Number of sinks: 4.
(3) Number of kinds of products transported from source 1 to each sink: 10.
(4) Number of kinds of products transported from source 2 to each sink: 8.
(5) Leadtime in days: 1 through 4 (specified for each source-sink combination).
(6) Capacity of the truck in pallets: 20 or 40 (specified for each source-sink combination).
(7) Number of corrugated cardboard boxes put on one pallet: 16 through 85 (specified for each product).

An associated simulation model is already shown in Figure 3. In this case, 72 external files are required for File Group 1, and 72 external files are generated as File Group 2. One file in File Group 2 is already shown in Table 1. This table is one part of the list of the file on Product No. 2 at Sink No. 1. In addition, two external files of File Group 3 are generated to record the detailed contents of products transported from each source, as shown in Table 3. This table is one part of the list of transportation from Source No. 1.

Furthermore, the transition of the inventory on hand on Product No.2 at Sink No.1 at both the beginning and end of each day is shown in Figure 4. The cumulative amount of transportation at each source is indicated on the screen, as shown in Figure 5. These figures might be used as occasion demands. The system described in this section is rather simple. No matter how many sources, sinks and products may be required to define the system, however, the corresponding numbers of these items can be specified in a simulation model, by using the proposed module-based system.

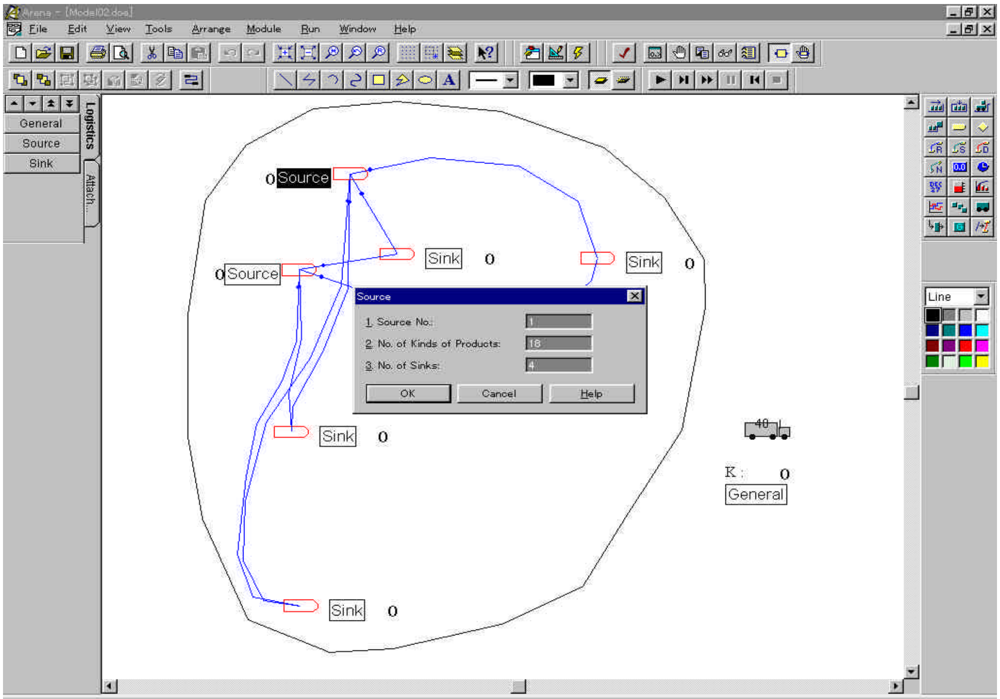


Figure 3: Illustrative Simulation Model Using Special-Purpose Modules

Table 3: Resultant External File (Listing of Transportation at Source No.1)

I	Sink No.	Truck No.	Arrival	Product 1	Product 2	Product 3	Product 4	Product 5	Product 6	Product 7	Product 8	Product 9	Product10
31	1	1	32	0	5	0	15	0	0	0	0	0	0
31	1	2	32	0	0	0	8	10	0	0	1	1	0
32	1	1	33	0	5	0	15	0	0	0	0	0	0
32	1	2	33	0	0	0	9	11	0	0	0	0	0
32	3	1	34	0	6	0	14	0	0	0	0	0	0
32	3	2	34	0	0	0	6	11	0	0	0	3	0
33	1	1	34	0	6	1	13	0	0	0	0	0	0
33	1	2	34	0	0	0	12	8	0	0	0	0	0
33	3	1	35	1	3	0	10	6	0	0	0	0	0
33	4	1	36	0	7	0	24	9	0	0	0	0	0
34	1	1	35	0	5	0	15	0	0	0	0	0	0
34	1	2	35	0	0	0	10	10	0	0	0	0	0
34	1	3	35	0	0	0	0	9	0	0	3	8	0
34	2	1	36	0	3	0	12	5	0	0	0	0	0
34	3	1	36	0	3	0	12	5	0	0	0	0	0
35	1	1	36	2	7	1	10	0	0	0	0	0	0
35	1	2	36	0	0	0	16	4	0	0	0	0	0
35	1	3	36	0	0	0	0	10	1	1	1	7	0
35	3	1	37	0	3	1	10	6	0	0	0	0	0
35	4	1	38	1	5	0	17	14	0	0	1	2	0
36	1	1	37	0	6	0	14	0	0	0	0	0	0
36	1	2	37	0	0	0	15	5	0	0	0	0	0
36	3	1	38	1	4	0	13	2	0	0	0	0	0
37	1	1	38	0	7	0	13	0	0	0	0	0	0
37	1	2	38	0	0	0	9	11	0	0	0	0	0
37	1	3	38	0	0	0	0	7	0	0	2	11	0
37	2	1	39	0	3	0	11	6	0	0	0	0	0
37	3	1	39	0	3	0	12	5	0	0	0	0	0
37	3	2	39	0	0	0	0	7	0	0	3	10	0
37	4	1	40	0	5	1	19	9	0	0	1	5	0
38	1	1	39	12	6	1	1	0	0	0	0	0	0
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

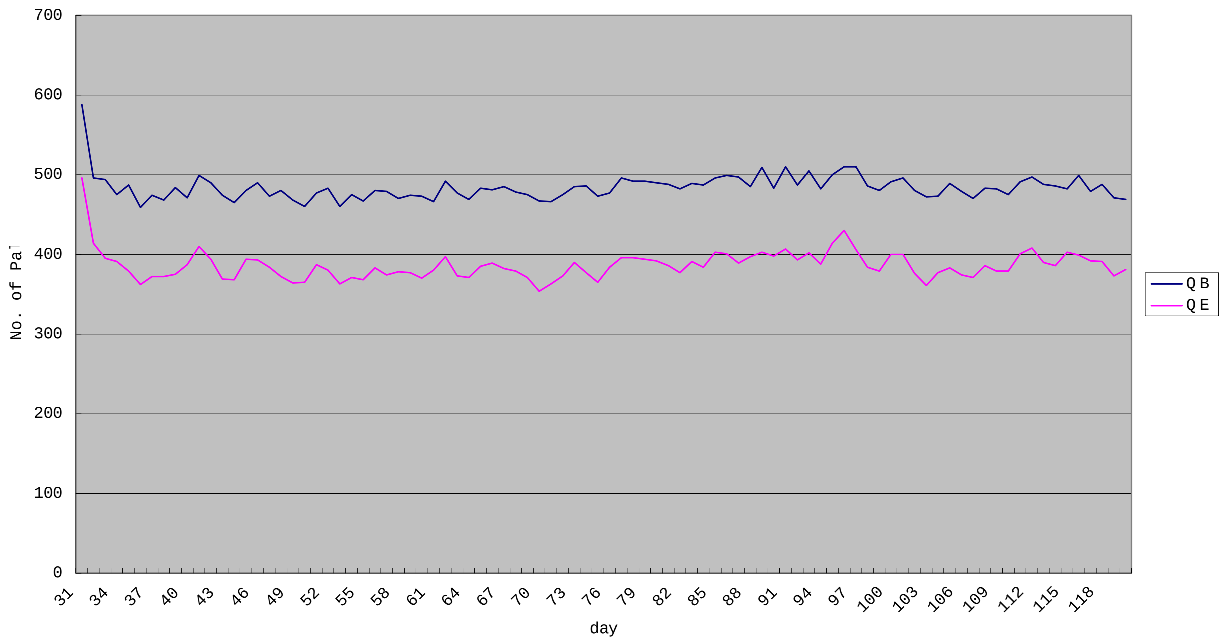


Figure 4: The Inventory on Hand (on Product No.2 at Sink No.1)

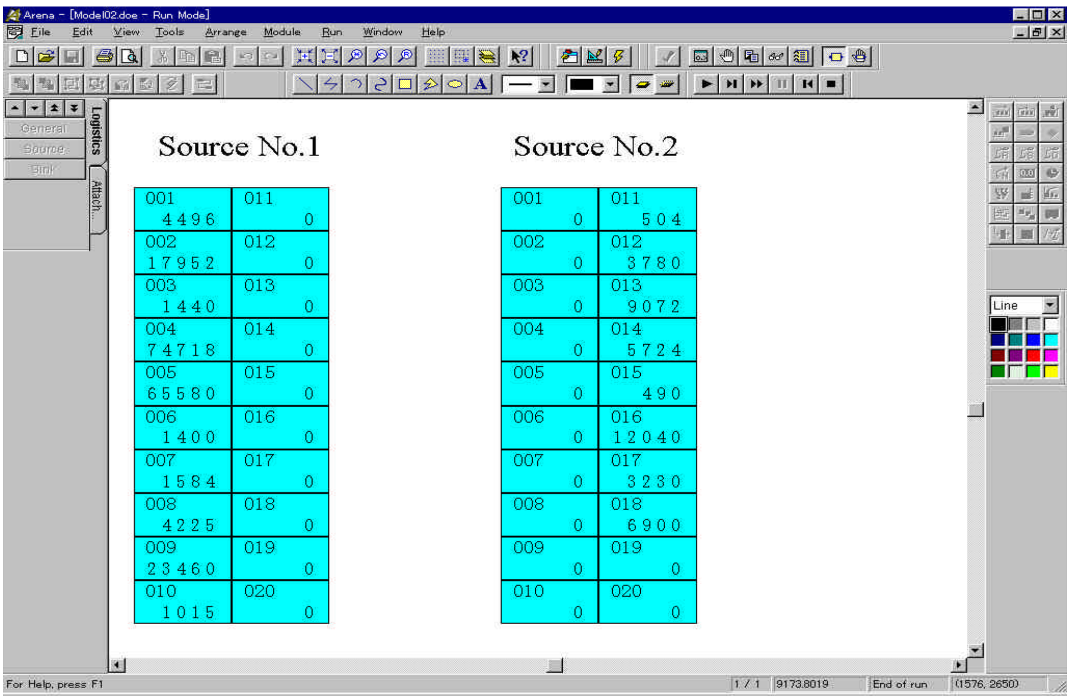


Figure 5: Cumulative Amount of Transportation at Each Source

LP models of the traditional transportation problem are effective in implicitly generating and evaluating large numbers of alternative system configurations (Salvendy 1992). Such models are useful in developing candidate system configurations for further analysis and testing. However, LP models tend to be deterministic in structure and thus cannot capture many of the systems effects that are due to variability in operation. Simulation models are excellent for analyzing the interaction effects due to system variability. Such models can identify queuing effects, bottleneck conditions, and delays.

5 SUMMARY

In this paper, an efficient module-based modeling method is presented for generating simulation programs for practical transportation-inventory systems. The proposed modeling method is presented using a numerical example based on an actual case to demonstrate the applicability to the actual transportation-inventory problems.

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AUTHOR BIOGRAPHY

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 Dr. of Economics from Nagoya University. His research interests include optimization of manufacturing and logistics systems, management information system and simulation. He has prepared the Japanese editions of both *Introduction to simulation using SIMAN* and *Simulation with ARENA.*