

FLEXIBLE MODULE-BASED MODELING AND ANALYSIS FOR LARGE-SCALE TRANSPORTATION-INVENTORY SYSTEMS

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ABSTRACT

A method of modeling large-scale transportation-inventory systems is proposed as an attempt to describe the systems flexibly. Such a system has a lot of items that are ordered, transported, and stored at the warehouses of the distribution centers. The system consists of any required numbers of “sources” and “destinations” as the need arises to build a simulation model. The order by a destination is made toward the associated source, based on the inventory policy at the distribution center. A more flexible module-based method is proposed to generate simulation models for transportation-inventory systems and by adopting Excel VBA. The proposed method is applied to the actual system. It was found that the time to build simulation models could be drastically reduced. Furthermore, the proposed method was 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 (e.g., factories) and multiple destinations (e.g., warehouses) in terms of linear programming (Ignizio 1982). Source nodes are used to describe a terminal at which a supply of discrete items exists. On the other hand, destination nodes are used to represent 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 destination nodes represent warehouses in the distribution centers.

In the real world, however, there are a lot of products or items to be handled. For this study, a modeling method was developed to generate simulation models for the transportation-inventory systems and by adopting the simulation together with Excel. A flexible module-based modeling method is proposed to generate simulation models for the

large-scale transportation-inventory systems. The proposed method is applied to an actual system for illustrating the procedure.

2 TRANSPORTATION-INVENTORY MODEL

2.1 Outline of the System

Figure 1 provides a convenient illustration of the practical transportation-inventory problem 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 the destinations. The branches connecting the source nodes to the destination nodes represent paths of transmission, or transportation routes between each individual source and destination. The system comprises two major phases that is, inventory controls at each distribution center and transportation of products from the factory to the distribution center. First, inventory controls are performed on each product based on the inventory-bank-replenishment policy at each distribution center. Then, the order to ship products is released to the factory by the distribution center. The single objective of the traditional transportation problem is to find the minimum cost pattern of shipment. Second, the factory ships requested products to the designated distribution center after receiving the order from the distribution center.

In the proposed system, the capacity of a truck is to be specified in building the simulation model. In addition, any number of both sources and destinations can be specified with as many as required. Contrary to the traditional transportation problem in terms of linear programming, multiple kinds of products are actually considered in the model. Furthermore, whether the same kinds of products would be delivered from the different sources to the specific destination depends on the actual situation. In the proposed method, the various types of systems comprise any number

of products, sources, and destinations that can be modeled, and performed by simulation.

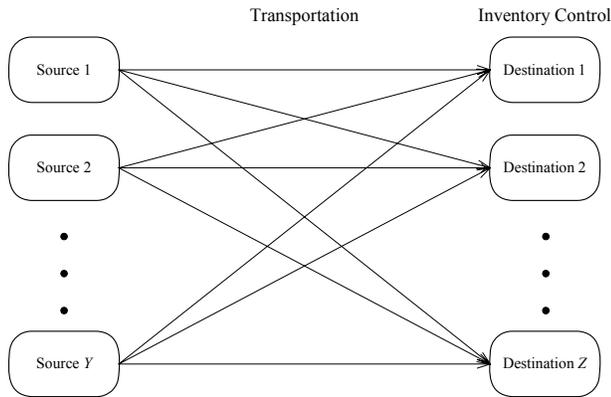


Figure 1: Schematic Model of a Practical Transportation-Inventory

2.2 The Units of Transportation

In the traditional transportation problem, the main issue is the cost pattern of shipment, while the form or the unit of transportation is not taken into consideration. In the actual case of transportation concerns, however, the form 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 include a unit of product, in a corrugated carton, on a pallet, and on a truck. The certain number of pieces of the product is packed in one corrugated carton. The number of pieces for each product is predetermined, considering the size of both the product and the corresponding corrugated carton. Then, numerous corrugated cartons are put on one pallet, and the palletized cartons might be handled by a forklift truck. Finally, a specified number of pallets, with the corrugated cartons are being put, are loaded onto one truck, and transported to the destination. Therefore, in constructing the associated simulation model, it is necessary that the total number of products for one corrugated carton, the number of cartons for one pallet, and the number of pallets for one truck respectively should be determined for each product type transported. In addition, the capacity in terms of the number of pallets to be loaded on a truck should be decided for each combination of the source and the destination.

2.3 The Inventory-Bank System

In the inventory-bank replenishment system, every t units of time a decision is made with respect to replenishment (Naddor 1966). It is assumed that a truck can transport

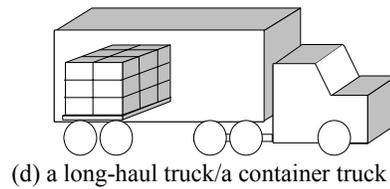
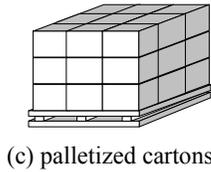
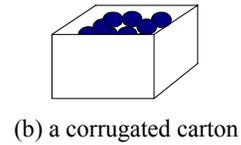
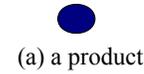


Figure 2: Units of Transportation

products only when the prescribed number of pallets are loaded onto the truck to full capacity (Takakuwa 1998; Takakuwa and Fujii 1999). In this section, a specific product is taken up to describe the system. The notation to describe the essential elements is summarized as follows:

- $AV(i)$: the available inventory as of end of day i before ordering a replenishment (i.e., the amounts on hand and on order),
- $BA(i)$: the bank as of end of day i , based on equation (3),
- $C(i)$: the quantity given by equation (1),
- $D(i)$: the demand during day i ,
- $DA(i)$: the average demand as of end of day i , based on equation (4),
- i : day number,
- L : lead time,
- M : the number of days to calculate the mean demand,
- N : the number of days to calculate $BA(i)$,
- NP : the number of corrugated cartons put on one pallet,
- $QB(i)$: the inventory on hand at the beginning of day i ,
- $QE(i)$: the inventory on hand at end of day i ,
- $RE(i)$: the replenishment quantity ordered at the end of day i , based on equation (2),
- $RD(i)$: the replenishment added to inventory at end of day i , available at beginning of day $i+1$.

The amount to be replenished at time i raises the avail-

able inventories $AV(i)$ to a bank $BA(i)$. No returns are allowed. Thus, the basic quantity $C(i)$ ordered for replenishment of inventory is formally given by

$$C(i) = \max[BA(i) - AV(i), 0]. \quad (1)$$

Then, two conditions must be satisfied to ship the product by a truck. The first condition is that $C(i)$ is more than or equal to the specified number of the corrugated cartons to put on one pallet. The second condition is that the cumulative number of pallets over all designated products is more than the capacity (in pallets) of a truck. In addition, these two conditions are necessary as some products cannot be shipped because of the constraint of the capacity of the truck as some cases, even if these two conditions are satisfied for the products.

The actual replenishment quantity ordered at the end of day i is given by

$$RE(i) = k \times NP, \quad (2)$$

where k is a natural number, and is decided on the capacity of the 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 $BA(i)$ which is subject to control by a decision maker. The bank may be viewed as composed of several days of average demand,

$$BA(i) = N \times DA(i), \quad (3)$$

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

Several methods may be used to determine the average demand $DA(i)$. 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 :

$$DA(i) = (1/M) \sum_{j=i-M+1}^i D(j). \quad (4)$$

The parameters N and M thus completely specify how decisions may be reached in the inventory system. Then, the equations can be obtained:

$$QE(i) = QB(i) - D(i), \quad (5)$$

$$AV(i) = QE(i) + \sum_{j=i-L}^{i-1} RE(j) \quad (L > 0), \quad (6)$$

$$RD(i) = RE(i-L), \quad (7)$$

and

$$QB(i+1) = QE(i) + RD(i). \quad (8)$$

The use of decision rules based on equations (1), (2), and (4) in inventory systems involves many item stems from practical considerations. The decision rule of equation (4) 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 $DA(i)$, and this may lead to excessive inventories or to excessive shortages. The lead times are assumed to be deterministic because the unit of time is measured in days. In addition, an exponential smoothing method could be applied to calculate the average demand as well.

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), lead time is one day, M is 30, and N is 6. The transition of amounts in inventory, demands, orders and replenishments is illustrated in Table 1. In this table, in the 33rd period, 96 units were ordered, and a replenishment of the exact units has been added to inventory in the next period.

3 MODULE-BASED MODELING SYSTEMS

3.1 Procedures for Modeling

Microsoft Visual Basic for Applications represents a powerful development in technology that rapidly customizes software applications and integrates them with existing data and systems. The Integrated Development Environment (IDE) of VBA is available with Microsoft Visio, Excel, Word, and Power Point and in a wide variety of other software including Arena (Seppanen 2005). In recent studies, this approach has been applied to build simulation models for various fields of research including manufacturing systems, logistics and supply chain systems, and health care management (Grabau and Clay 1999; Alvarez and Centeno 1999; Seppanen 2000; Goldsman and Kang. 2002; Marasini and Dawood 2002; Enns and Suwanruji 2003).

In this study, the simulation model was developed with Arena and incorporated with Microsoft Excel (Kelton et al. 2004). In the proposed procedure, only one step was required to build a simulation model. The step required the input of the data associated with the transportation-inventory system into the Excel worksheets.

In addition, the modeling approach incorporated the module-based system, by using the template-building features of Arena (Takakuwa 1996; Takakuwa 1997; Nomura

Table 1: Inventory-Bank-Replenishment System

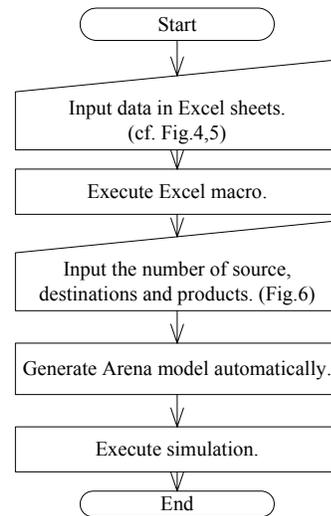
Period	Inventory at the beginning	Demand	Inventory at the end	Average demand	Replenishment level	Inventory +order quantity	Difference	Order quantity	Replenishment quantity
i	$QB(i)$	$D(i)$	$QE(i)$	$DA(i)$	$BA(i)$	$AV(i)$	$BA(i)-AV(i)$	$RE(i)$	$RD(i)$
31	96	20	76	21.6	172	76	96	0	0
32	76	20	56	21.2	169	56	113	0	0
33	56	23	33	21.4	171	33	138	96	0
34	33	23	10	21.6	172	106	66	0	96
35	106	25	81	22.2	177	81	96	0	0
36	81	23	58	22.8	182	58	124	0	0
37	58	20	38	22.8	182	38	144	0	0
38	38	24	14	23	184	14	170	0	0
39	14	25	-11	23.4	187	-11	198	192	0
40	-11	19	-30	22.2	177	162	15	0	192
41	162	25	137	22.6	180	137	43	0	0

and Takakuwa 2004). Module-based system drastically reduces time and effort for modeling drastically and increases efficiency of constructing models and changing it only by setting a series of designated parameters. Furthermore, using Excel VBA saves time and labor for inputting all required parameters.

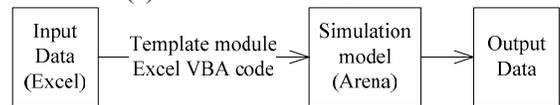
A new template system on this system was designed and developed, and it comprising the three modules termed General, Source, and Destination modules. In Arena, simulation models were built by placing modules in a working area of a model window, providing data for these modules, and specifying the flow of entities through modules. In this procedure, the simulation model using the three modules was constructed automatically by using Excel VBA. All placed modules with inputted data in a simulation model include macro-codes in Excel.

Figure 3 shows the procedure of the modeling system proposed in this study. First, all associated data need to be inputted in the corresponding Excel worksheets. The macro-code is executed by pressing a button on the worksheet. When the user form appears, the number of sources, destinations, and products are inputted. Then the new Arena model window is automatically opened, and all necessary modules in the model are placed in the working model window. The corresponding values in the modules have been provided for their operands from each worksheet. In addition, because external files are required to run the simulation model, these files are made by Excel VBA as well. After the Excel macro has been executed, a simulation can be performed.

If an animation is needed for a corresponding simulation model, all required “routes” should be connected between the associated pairs of sources and destinations. In addition, entity pictures should be edited for the numerical sizes of the trucks.



(a) Flow of Procedure



(cf. Fig.4,5 and 6) (cf. Fig.7) (cf. Fig.8) (cf. Table 1 and 4)

(b) Flow of Executing Programs

Figure 3: General Flow of Proposed Simulator

3.2 Input Data

All required data is inputted in the two kinds of Excel worksheets: General_Data and Des_(number).

1. General_Data; The data of the beginning inventory at the destination and the number of cases per pallet for product is inputted in worksheet General_Data. Figure 4 shows the worksheet, after inputting the sample data.

- Des_(number); Each destination data is inputted in each worksheet of destination. Figure 5 shows the data of destination No. 1. The name of worksheet is Des_1. The contents comprise each product data, truck size, and lead time and percentage.

Figure 6 shows the user form and the beginning of Excel macro. The contents comprise a number of sources, destinations, and products.

3.3 Modules

The three modules, General, Source, and Destination were used to build a simulation model. The number of Source and Destination modules corresponded to those of the fac-

tory and the distribution center within the transportation system.

3.3.1 General Module

This module was designed to specify the overall characteristics of the system. This module performed two functions: one, checking of the simulation time, and two, to write the resultant output data into the file of the truck data.

3.3.2 Source Module

This module was designed to specify the parameters of each source. This module sent an entity to both the Destination module associated and the General module.

	A	B	C	D	E	F	G	H
1	Number of kinds of products	Number of cases per pallet	Inventory (Des_1)	Inventory (Des_2)	Inventory (Des_3)	Inventory (Des_4)	Inventory (Des_5)	Inventory (Des_6)
2	1	96	96	96	96	96	96	96
3	2	96	96	96	96	96	96	96
4	3	96	96	96	96	96	96	96
5	4	40	40	40	40	40	40	40
6	5	40	40	40	40	40	40	40
7	6	40	40	40	40	40	40	40
8	7	40	40	40	40	40	40	40
9	8	40	40	40	40	40	40	40
10	9	45	45	45	45	45	45	45
11	10	60	60	60	60	60	60	60
12	11	100	100	100	100	100	100	100
13	12	100	100	100	100	100	100	100
14	13	100	100	100	100	100	100	100

Figure 4: Excel Worksheet General_Data

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Destination number	Product number	Check	Number of days in the bank	Number of days for finding average demand	Daily demand (Average)	Daily demand (Standard Deviation)	Source number	Number of pallets per truck	Leadtime in days	Product number	Source number	Percent		
2	1	1	1	8	5	21.73	2.17	1	16	1	1	1	100		
3		2	1	8	5	11.73	1.17				2	1	100		
4		3	1	8	5	8.33	0.83				3	1	100		
5	Model	4	1	8	5	16.67	1.67				4	1	100		
6		5	1	8	5	16.67	1.67				5	1	100		
7		6	1	8	5	20.00	2.00				6	1	100		
8		7	1	8	5	8.33	0.83				7	1	100		
9		8	1	8	5	13.33	1.33				8	1	100		
10		9	1	8	5	11.73	1.17				9	1	100		
11		10	1	8	5	11.73	1.17				10	1	100		
12		11	1	8	5	13.33	1.33				11	1	100		
13		12	1	8	5	11.00	1.10				12	1	100		
14		13	1	8	5	9.00	0.90				13	1	100		

Figure 5: Excel Worksheet Des_1

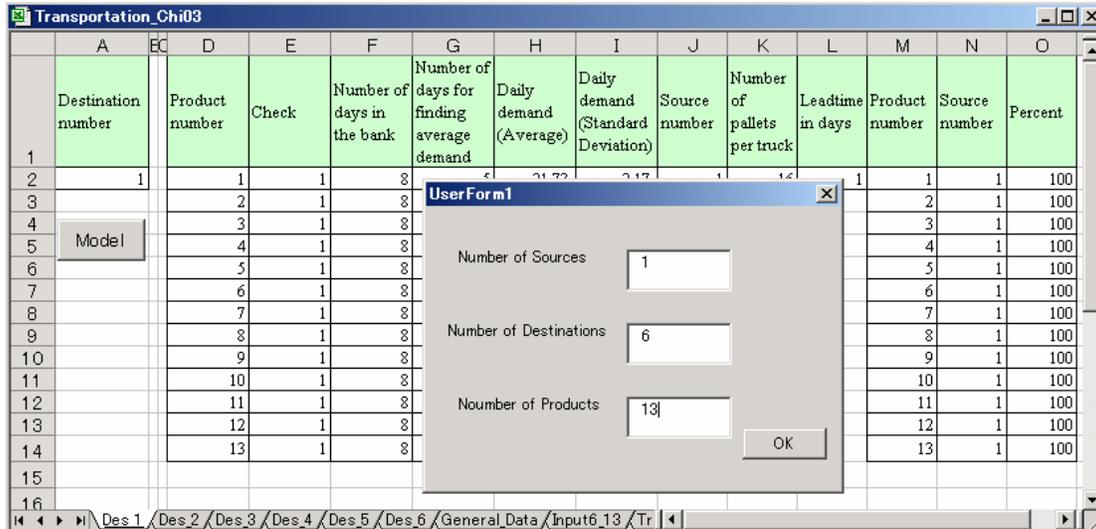


Figure 6: The Start of The Excel VBA Macro

3.3.3 Destination Module

This module was designed to specify the parameters on each destination. Each module created an entity every period and made an inventory control. The results of the inventory control were written into the external file every period.

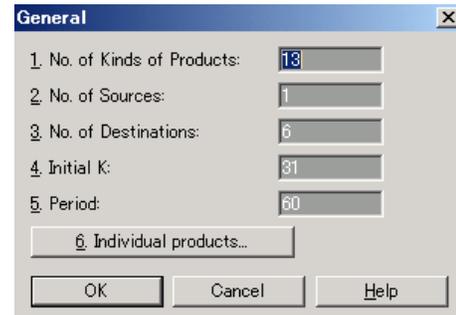
In this module, the inventory-bank system was adopted as an inventory-control policy. The unit of the order quantity was the number of cases per pallet. When an entity was assigned a truck loaded with pallets, an entity was duplicated. The one was sent to an associated source module.

3.3.4 Generated Property Dialog Boxes

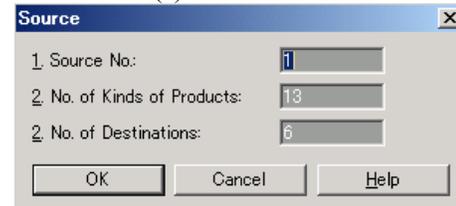
After finishing the input of all required parameters, the resultant dialog boxes were entered automatically. The main property-dialog boxes of the General, Source, and Destination modules are shown in Figure 7. Once all parameters are inputted into Excel worksheets, to build a simulation model, the remaining operation is to enhance the animation of the associated simulation model.

4 APPLICATION

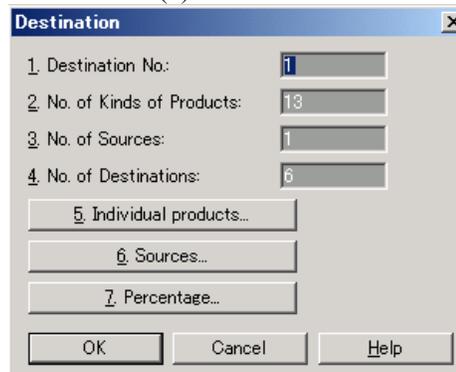
The proposed modeling method was applied to a transportation system based on an actual case. The major products were selected from among those handled at the daily operations, and therefore the resultant model reflected the real situation. In this system, daily commodities were delivered from the warehouses of the factory that is located in the headquarters of the company in Qingtao, China to the warehouses of local distribution centers in Shenyang,



(a) General Module



(b) Source Module



(c) Destination Module

Figure 7: Main Property Dialog Boxes

Shandong, Shanghai, Guangznou, Beijing, and Chengdu. The system is characterized as followed:

1. Number of sources: 1.
2. Number of destinations: 6.
3. Number of kinds of products transported from source No. 1 to each destination: 13.
4. Lead time in days: 1 through 3 (specified for each source-destination combination).
5. Capacity of the truck in pallets: 8, 16, or 30 (specified for each source-destination combination).
6. Number of corrugated cartons put on one pallet: 40 through 100 (specified for each product).
7. Simulation Period: 30 (days).

The list of parameters on demand, lead time and capacity of the truck in pallets are summarized in Table 2. The daily demand for each product at each distribution center are assumed to follow the normal distribution with coefficient of variation 0.1.

Other selected parameters that need to be inputted in this model are summarized in Table 3. In this simulation experiment, all number of days in the bank is 8 and all numbers of days for calculating the average demand is 5.

An associated simulation model is shown in Figure8. In this case, 78 external files were generated as a Product File, which can be seen in Table 1. This table shows one part of the list of the file on Product No. 1 at Destination No. 1. In addition, one external file for the Truck File was generated to record the detailed content of products transported from each source, as shown in Table 4. This table displays one part of the list of transportation from Source

No. 1. Furthermore, the number of trucks used for daily transportation is shown in Table 5. From the results of the simulation, 19 trucks were used for 30 days.

The expected value of the number of trucks needed to transport products from the factory to each distribution center is shown in Table 6, which can be compared to the resultant number of them obtained by performing simulation.

The system described in this section was found to reflect the real situation. The required number of parameters might be used as occasion demands. No matter how many sources, destinations and products required to define the system, however, the corresponding number of these items can be specified in a simulation model, by using the proposed module-based system.

Table 2: List of Parameters on Demand and Transportation

Product No.	Expected daily demand (cases)						Number of cases put on one pallet
	Shenyang	Shandong	Shanghai	Guangznou	Beijing	Chengdu	
1	21.73	14.87	13.33	3.33	1.67	0.40	96
2	11.73	11.97	11.67	3.33	0.00	1.40	96
3	8.33	3.33	7.67	5.00	3.33	8.83	96
4	16.67	10.67	6.67	11.67	0.00	0.80	40
5	16.67	13.70	6.67	23.33	0.00	2.83	40
6	20.00	26.93	6.67	13.33	2.67	0.67	40
7	8.33	13.30	1.67	21.67	1.67	5.70	40
8	13.33	29.23	8.33	18.33	0.00	19.17	40
9	11.73	3.40	11.67	8.33	0.00	0.47	45
10	11.73	2.33	10.00	6.67	3.33	1.10	60
11	13.33	8.77	18.33	21.33	5.00	3.80	100
12	11.00	3.27	8.33	14.33	1.00	0.40	100
13	9.00	5.43	11.67	14.33	2.67	0.37	100

	Shenyang	Shandong	Shanghai	Guangznou	Beijing	Chengdu
Lead time (days)	1	1	1	3	1	2
Capacity of the truck (pallets)	16	16	16	30	8	8

Table 3: List of Other Selected Parameters to Be Inputted to Modules

Module	Items	1													6					
General	Number of kinds of products	13																		
	Number of sources	1																		
	Number of destinations	6																		
	Beginning day number	31																		
	Ending day number	60																		
	Individual products	Product number	1	2	3	4	5	6	7	8	9	10	11	12	13					
		Number of cases per pallet	96	96	96	40	40	40	40	40	45	60	100	100	100					
Source	Source number	1																		
	Number of kinds of products	13																		
	Number of destinations	6																		
Destination	Destination number	1														6				
	Number of kinds of products	13														13				
	Number of sources	1														1				
	Number of destinations	6														6				
		Individual products	Product number	1	2	3	4	5	6	7	8	9	10	11	12	13	(Omitted)	1	2	...
			Check	on	on	on	on	on	on	on	on	on	on	on	on	on		on	...	
			Number of days in the bank	8	8	8	8	8	8	8	8	8	8	8	8	8		8	...	
			Number of days for finding average demand	5	5	5	5	5	5	5	5	5	5	5	5	5		5	...	
			Daily demand	(See Table2)														...		
		Sources	Source number	1														1		
		Number of pallets per truck	16														8			
		Lead time in days	1														2			
Percentage	Product number	1	2	3	4	5	6	7	8	9	10	11	12	13		1	2	...		
	Source number	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	...		
	Percentage	100	100	100	100	100	100	100	100	100	100	100	100	100		100	100	...		

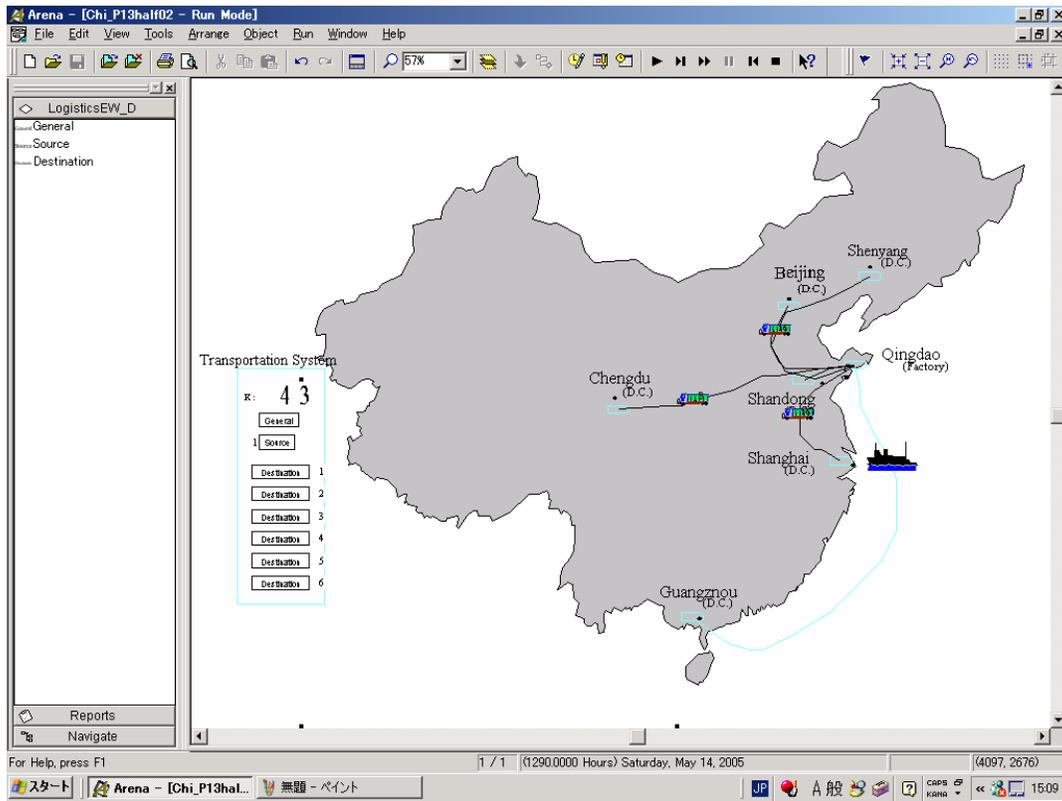


Figure 8: Animation of the Model

Table 4: Resultant External File (Listing of Transportation at Source No.1)

Source No.	Destination No.	Departure	Arrival	Product												
				No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.8	No.9	No.10	No.11	No.12	No.13
1	2	32	33	0	0	0	1	2	5	2	6	0	0	0	0	0
1	1	33	34	1	0	0	3	3	4	1	2	1	1	0	0	0
1	4	38	41	0	0	0	3	7	3	7	5	1	0	2	1	1
1	1	39	40	2	1	0	2	3	3	1	2	2	0	0	0	0
1	2	39	40	1	0	0	2	2	4	2	5	0	0	0	0	0
1	6	39	41	0	0	0	0	0	0	1	7	0	0	0	0	0
1	3	41	42	1	1	0	2	2	1	0	2	3	2	2	0	0
:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:

Table 5: Number of Trucks to Ship Products

Period (day)	32	33	38	39	41	45	46	48	49	50	51	55	57	58	60
Number of trucks	1	1	1	3	1	1	1	1	1	2	1	1	1	1	2

Table 6: Expected Values and Simulation Results on The Number of Trucks

	Expected daily number of pallets	Expected monthly number of trucks	Number of trucks obtained by simulation
Shenyang	3.10	5.81	5
Shandong	2.95	5.53	5
Shanghai	1.90	3.56	3
Guangzhou	3.13	3.13	3
Beijing	0.30	1.13	0
Chengdu	0.91	3.43	2

5 CONCLUSIONS

A flexible module-based modeling method is presented to generate simulation programs for complex and large-scale transportation-inventory systems. By utilizing the proposed module-based modeling procedure, the actual time to build simulations can be drastically reduced.

The proposed modeling method is presented using an actual case to demonstrate the applicability to the areal world transportation-inventory problems. The detailed contents of transported goods by trucks from the factory to each distribution center can be evaluated by inventory management at the distribution center in consideration of sales forecast.

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