A Modeling Framework of Supply Chain Simulation

Beom-cheol Park
Kwangwoon University, Seoul, Korea

Sukjae Jeong*
Kwangwoon University, Seoul, Korea

To satisfy and respond quickly to customer's demands, many companies are now aggressively focusing on supply chain management in order to strengthen their competitiveness. Thus, the modeling and analysis of supply chain environment have been widely studied for the better management of supply chain functions. This study is to develop a supply chain simulator that deals with stochastic characteristics of the supply chain environment. We propose a mathematical model for an efficient cost analysis and present a supply chain simulator in an object-oriented language C++ based on the proposed mathematical model. A simple experiment is conducted to show the usefulness and applicability of the developed simulator.

* Corresponding Author. E-mail address: sjjeong@kw.ac.kr

I. INTRODUCTION

With the increasing interest in supply chain management (SCM), most companies are speeding up to develop a solution that can efficiently support SCM. From an operational perspective, SCM is to effectively integrate supplier, manufacturers, warehouses, and stores, so that products are produced and distributed at the right quantities, to the right locations, and at the right time, in order to minimize system wide cost while satisfying service requirements. However, it is not easy to coordinate the operations of individual supply chain members and improve system profit (Ganeshan et al., 2000).

The modeling and analysis of supply chain environment have been active research agenda in the SCM field for many years. Vidal and Goetschalckx (1997) reviewed the strategic production-distribution model. They focused on global supply chain models with emphasis on mixed integer programming models. Petrovic et al. (1999) described fuzzy modeling and simulation of a supply chain in an uncertain environment. Lee and Kim (2002) obtained more realistic optimal production-distribution plans for the integrated supply chain system reflecting stochastic natures by using iterative simulation procedures. Thomas and Griffin (1996) developed supply chain models to support both strategic supply chain planning and operations control of the supply chain activities. Cohen and Lee (1988) represented mathematical models that consider the whole supply chain networks.

However, the existing mathematical models could not represent the stochastic properties of the supply chain. Simulation is an effective analysis tool for dynamically changing environments of internal supply chains. Moreover, simulation can be used to achieve an optimization of planning an entire supply chain system (Lee et al., 2002).

Industry has promoted the development of simulators for supply chain system analyses.

IBM developed SCA (Supply Chain Analyzer) based on Simprocess and provided inventory optimizer and supply planning (Bagchi et al, 1999). Also, Compaq developed CSCAT (Compaq Supply Chain Analyzer Tool) based on Arena. Nokia developed LOGSIM based on ProModel. LOGSIM consists of the five components - supplier, buffer, production and assembly process, customer, material requirement planning. In this paper, we developed an integrated simulator supporting multi-periods, multi-products, multi-facilities production and distribution model in supply chain environment.

This study developed a supply chain simulator which can reflect stochastic phenomena of supply chain activities into the modelling and analyses of a supply chain system. The characteristics of complex problems in SCM are defined in a mathematical model, and then a supply chain system is analysed by using the simulator. This paper is organized as follows: In chapter 2, a mathematical model that can support decision making is proposed. In chapter 3, a supply chain simulator developed using the mathematical model is introduced. In chapter 4, experiments and results for the developed simulator are shown. Concluding remarks are provided in chapter 5.

II. MATHEMATICAL MODEL

We present a comprehensive mathematical model that can support a supply chain simulator to be presented in the next section. The model is consisted of supplier, factory, DC (distribution center), customer, and transport stages in order to help the efficient cost analysis.

Indices

i : number of raw materials (i = 1, 2, … , i)
p : number of products (p = 1, 2, …, p)
t : number of periods (t=1, 2, …, t)
s : number of suppliers (s = 1, 2, …, s)
f : number of factories (f = 1, 2, …, f)
d : number of distribution centers (d = 1, 2, …, d)
c : number of customers (c = 1, 2, …, c)

Parameters

S_s : fixed cost at supplier s
S_f : fixed cost at factory f
S_d : fixed cost at DC d
S_c : fixed cost at customer c
M_S : maintenance cost at suppler s
M_f : maintenance cost at factory f
M_d : maintenance cost at DC d
M_c : maintenance cost at customer c
Z_s : 1, if production takes place at supplier s,
: 0, otherwise
Z_f : 1, if production tacks place at factory f
: 0, otherwise
Z_d : 1, if DC d is opened
: 0, otherwise
Z_c : 1, if customer c is opened
: 0, otherwise
P^t_{is} : production amount of raw material i at supplier s during period t
P^t_{pf} : production amount of product p at factory during period t
P^t_{if} : input amount of Material i at factory f during period t
CP_{is} : unit cost of producing of raw material i at supplier s
CP_{pf} : unit cost of producing of product p at factory f
T^t_{isf} : transportation amount of raw material i at supplier s to factory f during period t
T^t_{pfc} : transportation amount of product p at factory f to customer c during period t

T^t_{pfd} : transportation amount of product p at factory f to DC d during period t
T^t_{pdc} : transportation amount of product p at DC d to customer c during period t
CT_{isf} : unit cost of transportation from supplier s to factory f
CT_{pfd} : unit cost of transportation from factory f to DC d
CT_{pdc} : unit cost of transportation from DC d to customer c
I^t_{is} : inventory amount of raw material i at supplier s during period t
I^t_{if} : inventory amount of raw material i at factory f during period t
I^t_{pf} : inventory amount of product p at factory f during period t
I^t_{pd} : inventory amount of product p at DC d during period t
h_{is} : unit cost of inventory of source i at supplier s
h_{if} : unit cost of inventory of source i at factory f
h_{pf} : unit cost of inventory of product p at factory f
h_{pd} : unit cost of inventory of product p at DC d
B^t_{ifs} : demand of raw material i at factory f to supplier s during period t
B^t_{pdf} : demand of product p at DC d to factory f during period t
B^t_{pcd} : demand of product p at customer c to DC d during period t
CB_{ifs} : unit cost of demanding of raw material i at factory f to supplier s
CB_{pdf} : unit cost of demanding of product p at DC d to factory f
CB_{pcd} : unit cost of demanding of product p at customer c to DC d
K_{pd} : capacity of product p at DC d
TK : capacity of all DCs

Supplier stage

$$\min z = \sum_t \sum_i \sum_s I^t_{is} h_{is} + \sum_s S_S Z_S + \sum_t \sum_i \sum_s P^t_{is} CP_{is} + \sum_s M_S Z_S$$

s.t.

$$I^{t-1}_{is} + P^t_{is} - \sum_f T^t_{isf} = I^t_{is} \qquad \forall i, \forall s, \forall t \qquad (1)$$

$$Z_S \in \{0,1\} \qquad \forall s \qquad (2)$$

$$I^t_{is}, P^t_{is}, T^t_{isf} \geq 0 \qquad \forall i, \forall s, \forall t \qquad (3)$$

The objective function in the supplier stage is to minimize the sum of production cost, inventory cost, maintenance cost, and fixed cost of raw materials. Constraint (1) represents inventory balanced equations that define the inventory levels at the end of period t at supplier stage resulting from the production and transportation. Constraint (2) is the binary variable to decide whether or not that each supplier can be operated.

Factory stage

$$\min z = \sum_t \sum_p \sum_f I^t_{pf} h_{pf} + \sum_t \sum_i \sum_f I^t_{if} h_{if} + \sum_f S_f Z_f + \sum_f M_f Z_f + \sum_t \sum_p \sum_f P^t_{pf} CP_{pf} + \sum_t \sum_i \sum_f \sum_s B^t_{ifs} CB_{ifs}$$

s.t.

$$\sum_f B^t_{ifs} = T^t_{isf} \qquad \forall i, \forall f, \forall s, \forall t \qquad (4)$$

$$I^{t-1}_{pf} + P^t_{pf} - \sum_d T^t_{pfd} = I^t_{pf} \qquad \forall p, \forall f, \forall t \qquad (5)$$

$$I^{t-1}_{if} + T^t_{isf} - P^t_{if} = I^t_{if} \qquad \forall i, \forall f, \forall s, \forall t \qquad (6)$$

$$Z_f \in \{0,1\} \qquad \forall f \qquad (7)$$

$$I^t_{if}, I^t_{pf}, B^t_{ifs}, T^t_{isf}, T^t_{pfd} \geq 0 \qquad \forall i, \forall d, \forall f, \forall p, \forall s, \forall t \qquad (8)$$

The objective function in the factory stage is to minimize the sum of fixed cost, maintenance cost, inventory cost of raw material and product, production cost, and purchase cost. Constraint (4) means that all demands of raw materials from each factory must be equal to the transportation amount of the raw materials to the factory. Constraint (5) is the equation related to the inventory of product during period t. Constraint (6) is the equation related to the inventory of raw material. Constraint (7) is the binary variable for deciding whether open or not at each factory.

Distribution Center stage

$$\min z = \sum_t \sum_d \sum_p I^t_{pd} h_{pd} + \sum_d S_d Z_d + \sum_d M_d Z_d + \sum_t \sum_p \sum_c \sum_d B^t_{pdf} CB_{pdf}$$

$$s.t. \quad \sum_f B^t_{pdf} = T^t_{pdf} \qquad \forall d, \forall f, \forall p, \forall t \qquad (9)$$

$$I^{t-1}_{pd} - \sum_c T^t_{pdc} = I^t_{pdc} \qquad \forall c, \forall d, \forall p, \forall t \qquad (10)$$

$$\sum_p \sum_c T^t_{pdc} \le K_{pd} \qquad \forall d, \forall p, \forall t \qquad (11)$$

$$Tk \ge \sum_p K_{pd} \qquad \forall d \qquad (12)$$

$$Z_d \in \{0,1\} \qquad \forall d \qquad (13)$$

$$I^t_{if}, B^t_{pdf}, T^t_{pcd}, T^t_{pdf} \ge 0 \qquad \forall c, \forall d, \forall f, \forall i, \forall p, \forall t \quad (14)$$

The objective function of the DC stage is to minimize the sum of fixed cost, maintenance cost, inventory cost, and purchase cost. Constraint (9) means that all demands of DC must be equal to the amount of transportation. Constraint (10) is the equation related to the inventory of products at DC during period *t*. Constraint (11) prevents the transportation amount of product p at DC d from exceeding its storage capacity at the DC. Constraint (12) means that total capacity must be bigger than the sum of each. Constraint (13) is the binary variable.

Customer stage

$$\min z = \sum_c S_c Z_c + \sum_c M_c Z_c + \sum_t \sum_p \sum_c \sum_d B^t_{pcd} CB_{pcd}$$

$$s.t. \quad \sum_c B^t_{pcd} = T^t_{pcd} \qquad \forall c, \forall d, \forall p, \forall t \qquad (15)$$

$$Z_c \in \{0,1\} \qquad \forall c \qquad (16)$$

$$B^t_{pcd}, T^t_{pcd} \ge 0 \qquad \forall c, \forall d, \forall p, \forall t \qquad (17)$$

At customer stage, the objective function is to minimize the sum of fixed cost, maintenance cost, and purchase cost. Constraint (15) means that all demands of customer must be equal to the amount of transportation.

Transport stage

$$\min z = \sum_t \sum_i \sum_s \sum_f T^t_{isf} CT_{isf} + \sum_t \sum_p \sum_f \sum_d T^t_{pdf} CT_{pdf} + \sum_t \sum_p \sum_f \sum_d T^t_{pfd} CT_{pfd} + \sum_t \sum_p \sum_d \sum_c T^t_{pdc} CT_{pdc}$$

$$s.t. \quad T^t_{isf}, T^t_{pdf}, T^t_{pcd}, T^t_{pfc} \ge 0 \qquad \forall c, \forall d, \forall f, \forall i, \forall p, \forall s, \forall t \quad (18)$$

The objective function of transport stage is to minimize the sum of transport cost to factory, to DC, and to customer. It can be defined as the optimal mathematical equation that minimizes the inventory cost, production and transportation cost, fixed cost, and maintenance cost.

III. SUPPLY CHAIN SIMULATOR

There are many uncertain variables with stochastic property in a supply chain environment. It is not easy to find an optimal solution with the existing analytical methods like LP (Linear Programming) and DP (Dynamic Programming). However, simulation is known as the most efficient method for dealing with stochastic variables existing within the supply chain environment. The supply chain simulation which could represent an overall supply chain system with mathematical model is efficient in finding solutions under many constraints, and reflects all the uncertainties existing in a supply chain system such as the demand of customers, delivery time of products and raw materials, and service rates for customers.

We developed a supply chain simulator usin object-oriented modeling. The most important reason for the widespread appeal of object oriented modeling is the natural mapping paradigm. This allows one to one mapping among objects, which is the abstraction standing for a real-world entities in the system. Object-oriented modeling also affects simulation implementation through its facilitation of modular design and software reusability.

3.1. Simulation Internal Process

3.1.1. Event

An event is defined as something that happens at an instant of simulated time. The event has information such as time, object, production and transportation volume, priority and due date. An event function is defined as something that processes the information of event. The event function is activated by the event during simulated time. The event functions are consisted of order-arrival function, process function, production function, inventory function, and transport function according to each object. The simulator engine consists of event function, event calendar, event creation function, output function. Fig. 1 shows the engine of the simulation.

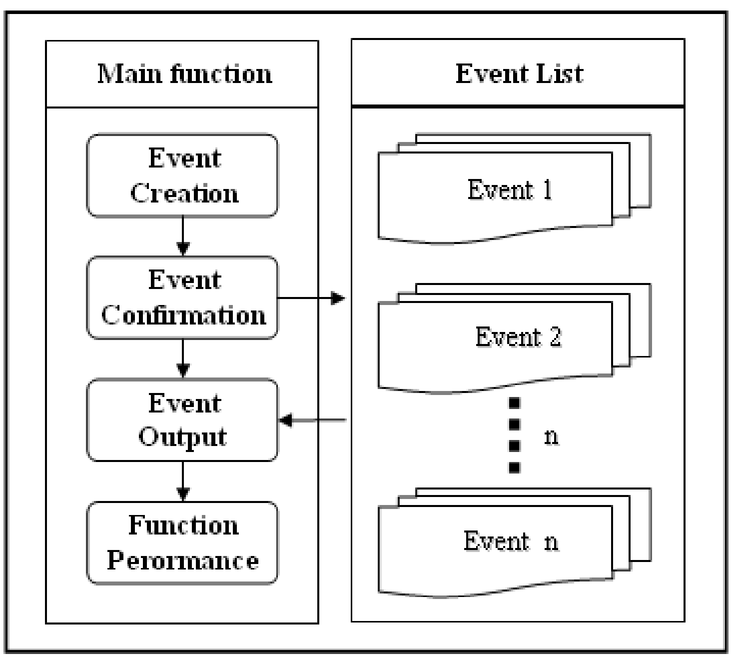

FIGURE 1. THE OVERVIEW OF THE SIMULATOR ENGINE

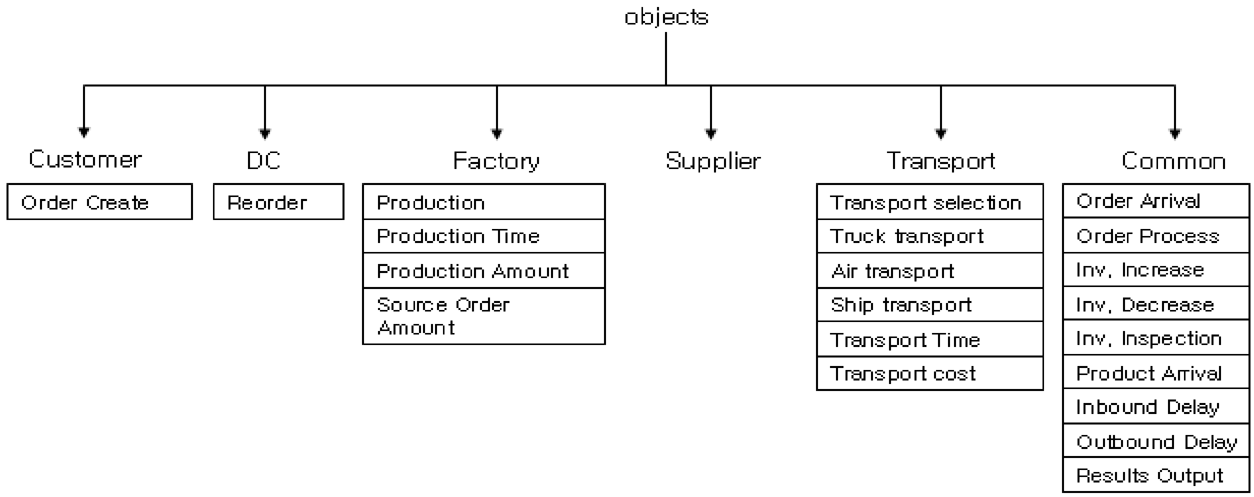

FIGURE 2. THE TAXONOMY OF OBJECTS MODEL IN SUPPLY CHAIN

3.1.2. Objects Model of Supply Chain

Fig. 2 shows the classes representing the taxonomy of objects model in supply chain. The developed simulator consists of the external objects like customer, DC, factory, supplier and internal object like the common object.

3.1.2.1. Internal Object

A common object has common information for external objects, which play a role of mutually exchanging information of individual objects.

Input data of common object

■ *Product and Material*

Input data of common object are commonly used in factory, DC and supplier.

Unit Cost of Inventory	- input data for unit cost of raw material and product
Virtual Inventory	- product and raw material producing during any given period
Real Inventory	- the inventory of raw material and product during any given period
Order Policy	- order policy for each product and raw material
Order Point	- reorder point for raw material and product (r,Q) or (r,S) policy : reorder point (s,S) policy : reorder point inspection cycle
Order Volume	- order quantity at reorder point (r,Q) policy : order quantity (s,S) policy : target inventory
Lot Order Size	- information for lot size of ordering
Unit Cost of Order	- input data for unit cost of order
Call Delay	- the time taken for ordering raw material and product
Capacity	- capacity for raw material and product

Function of common object

■ Delay (Inbound Delay, Outbound Delay)

Delay is a function for calculating delay time. The delay consists of Inbound Delay and Outbound Delay function. It can select various probability distributions (Exponential, Uniform, Normal, Gamma, Beta, Binomial, Geometric, and Hypergeometric Distribution) to consider the stochastic property in supply chain environment

3.1.2.2. External Objects

External objects are consisted of supplier, factory, distribution center and transport object. The roles of each object are as follows.

Supplier object

The input data of supplier object are consisted of production policy that determines production of raw materials, setup time, production time per lot size and delay time of outbound. The function of supplier object is consisted of order arrival function, order processing function, production function of raw materials and inventory function.

The procedure of the order process in supplier object is listed as:

Step 1 : Orders from factory object arrive.
Step 2 : Check the amount of real inventory to satisfy orders.
Step 3 : If satisfies, the order process is started immediately.
Otherwise, check the virtual inventory.
Step 4 : If the virtual inventory satisfies orders, the order process is started.
Otherwise, produce according to production plans generated in supplier object.

Fig 3 shows the order process occurred in supplier object.

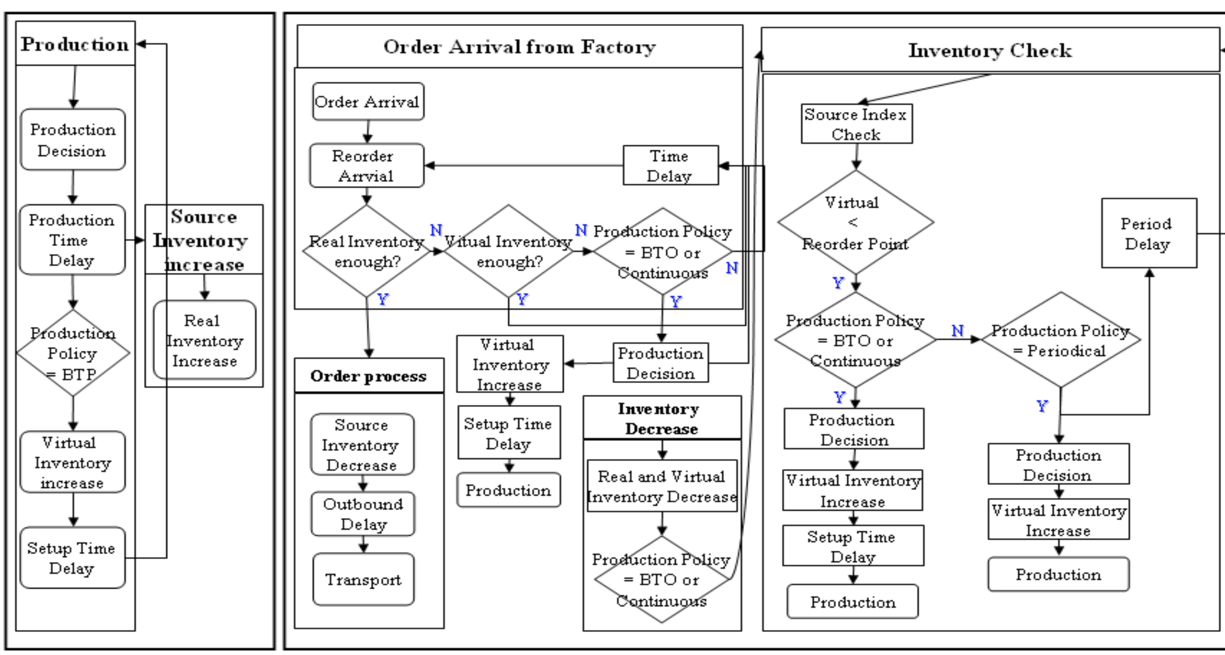

FIGURE 3. THE PROCEDURE OF THE ORDER PROCESS IN SUPPLIER OBJECT

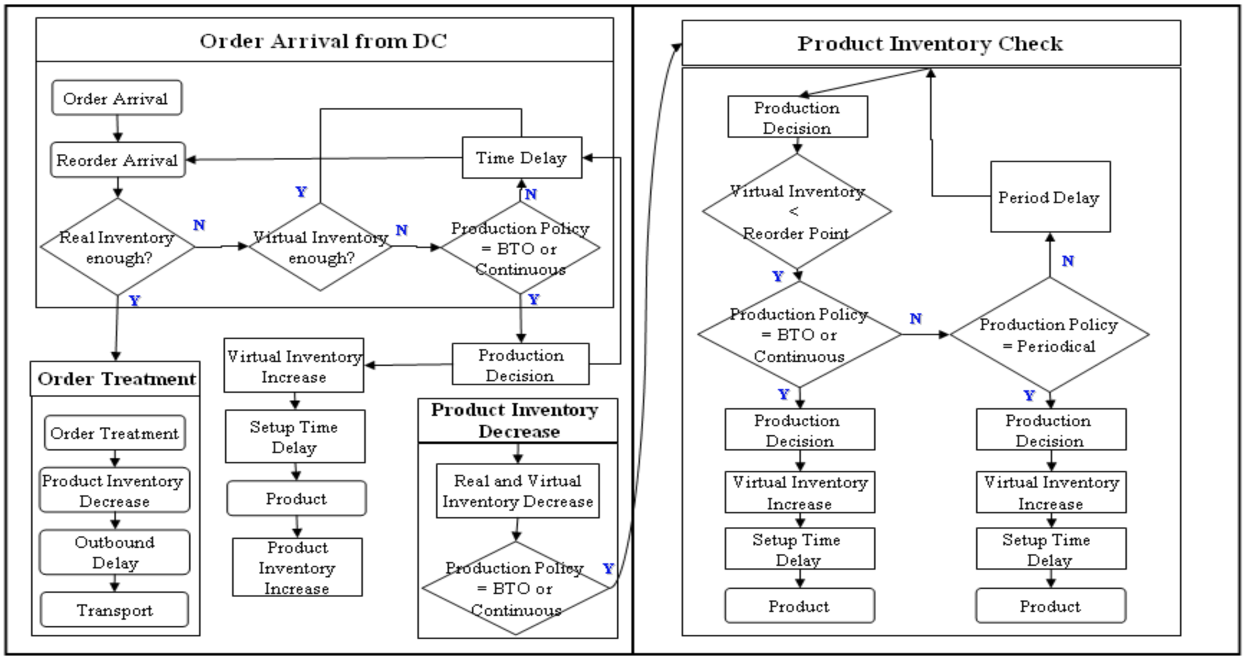

FIGURE 4. THE PROCEDURE OF THE ORDER PROCESS IN FACTORY OBJECT

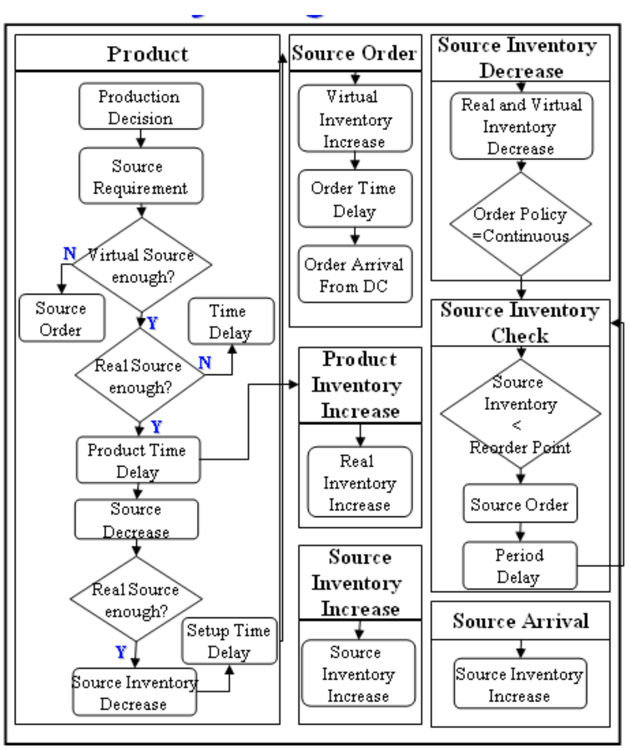

FIGURE 5. THE PROCEDURE OF THE PRODUCTION PROCESS IN FACTORY OBJECT

Factory object

The input data of factory object are consisted of production policy that determines production of product, setup time, production time per lot size and delay time of inbound and outbound. The function of factory object is consisted of order arrival function, order processing function, production function of product and inventory function of raw material and product.

The procedure of the order process in factory object is listed as:

Step 1 : Orders from DC objects arrive
Step 2 : Check the amount of real inventory to satisfy orders
Step 3 : If satisfies, the order process is started immediately.
Otherwise, check the virtual inventory.
Step 4: If the virtual inventory satisfies orders, the order process is started.
Otherwise, produce according to production plans generated in factory objects.

Fig 4 and 5 show the order process occurred in factory object.

DC object

The input data of DC object are consisted of the order policy that determine the order planning, and delay time of inbound and outbound. The function of DC object is consisted of order arrival function, order processing function and inventory function.

The procedure of the order process in DC object is listed as:

Step 1 : Orders from customer objects arrive
Step 2 : Check the amount of real inventory to satisfy orders.
Step 3 : If satisfies, the order process is started immediately.
Otherwise, check the virtual inventory.
Step 4 : If the virtual inventory satisfies orders, the order process is started.
Otherwise, generate orders to factories.

Fig 6 shows the order process occurred in DC object.

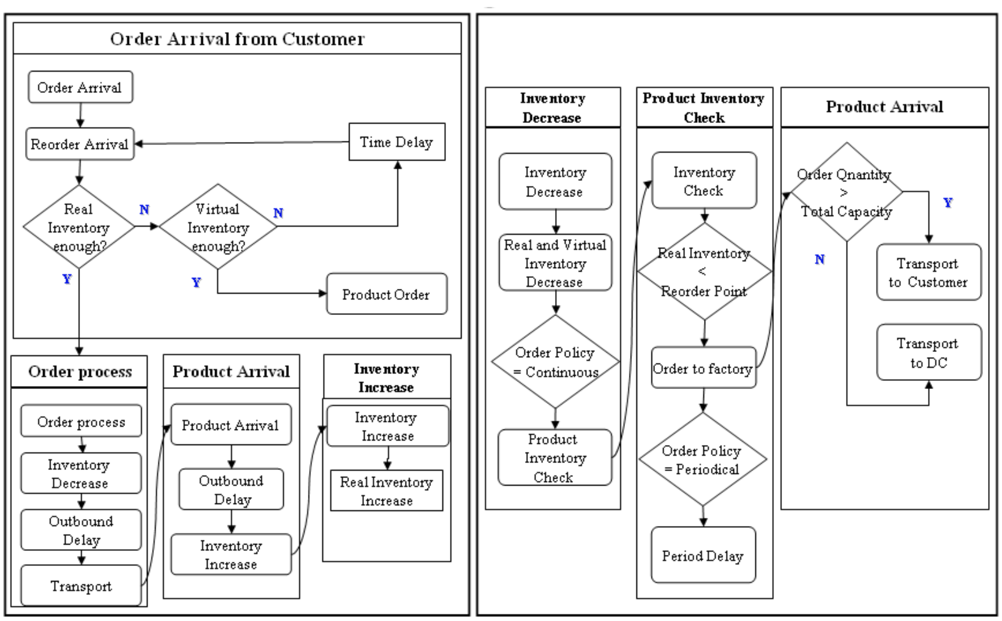

FIGURE 6. THE PROCEDURE OF THE ORDER PROCESS IN DC OBJECT

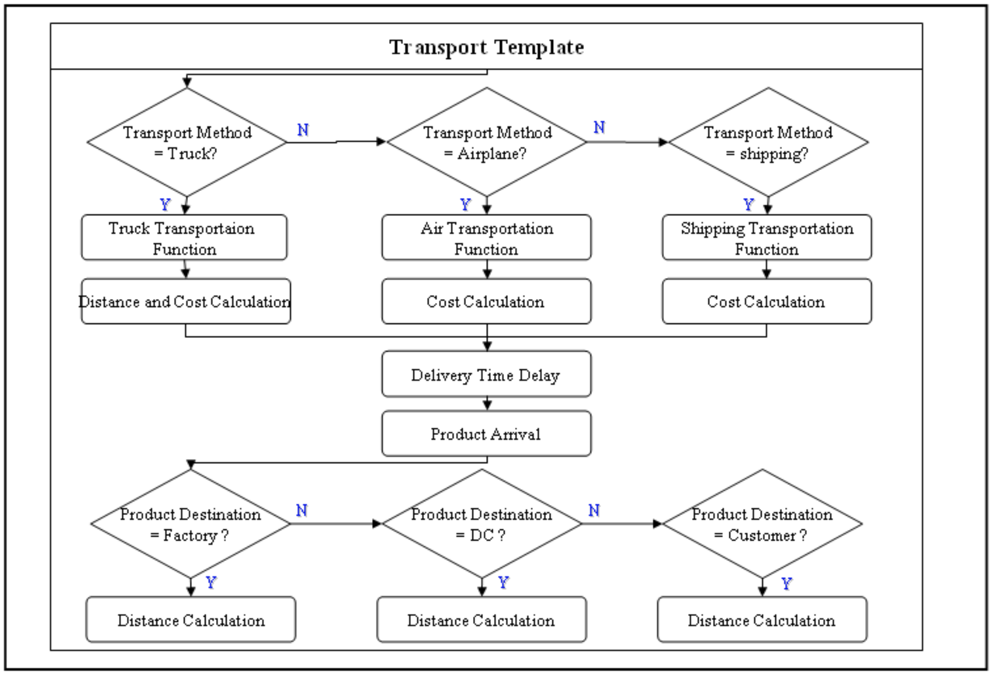

FIGURE 7. THE PROCEDURE OF THE TRANSPORTATION PROCESS IN TRANSPORT OBJECT

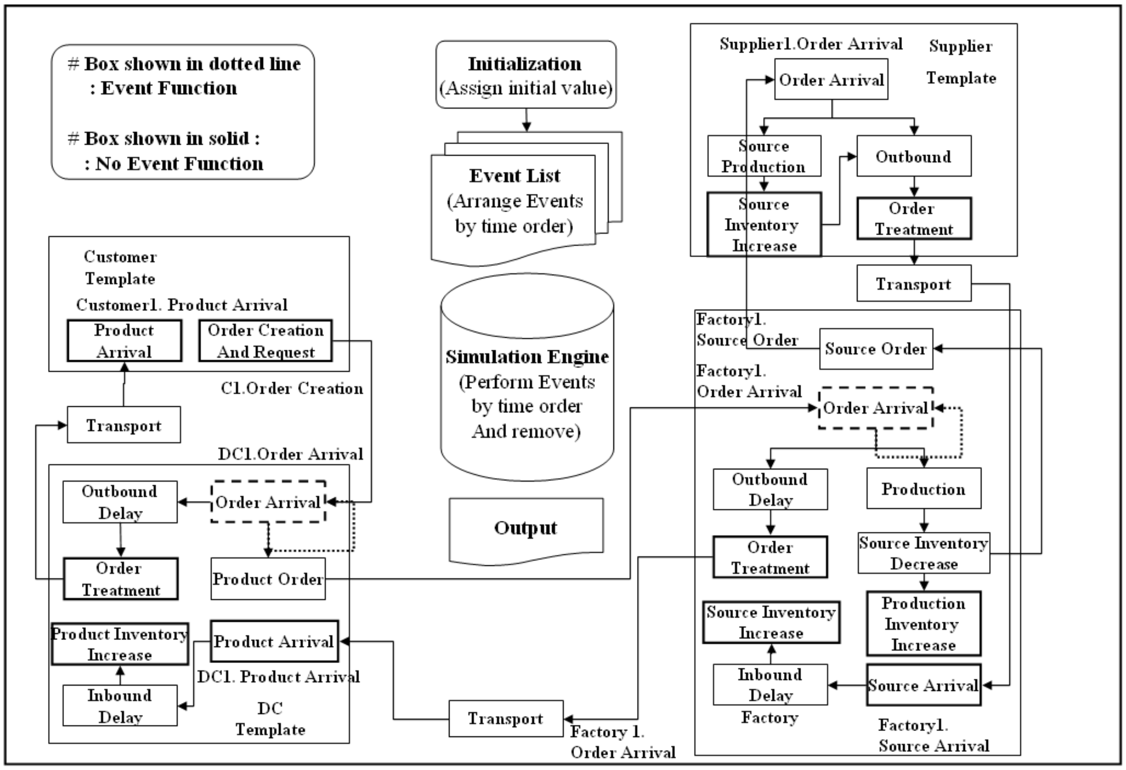

FIGURE 8. THE ARCHITECTURE OF INTEGRATED SCM SIMULATOR

Customer object

The input data of customer object are consisted the amount of order and order time. The function of customer object is consisted of the initial order function and order arrival function.

Transport object

The input data of transport object are consisted of location that indicates location information for all external objects and transportation time between all external objects. The function of transport object is consisted of the initial order function that generates orders firstly and order arrival function.

Fig. 8 shows the architecture of integrated supply chain simulator which includes the simulation engine, internal and external objects.

3.2. Inventory Replenishment Policy

The inventory replenishment policy determines when an object will generate a replenishment order to restock its capacities. The developed simulator is applied to the policy of production and order.

BTO (Build to Order) policy

The build-to-order policy maintains a minimum inventory. The object generates a replenishment order only if a customer order arrives and product is not available to fill the order. The replenishment order requests only the amount of the product needed to satisfy the customer order.

BTP (Build to Plan) policy

Replenishment orders are issued according to production plans generated by the developed simulator.

Continuous review policy

The object generates a replenishment order every time the inventory level falls below its reorder point.

Periodic review policy

This policy is controlled by a periodic review policy instead of a continuous review policy. The Periodic means that the inventory position is inspected at the beginning of each period. The object generates a replenishment order only when the inventory level is below its reorder point.

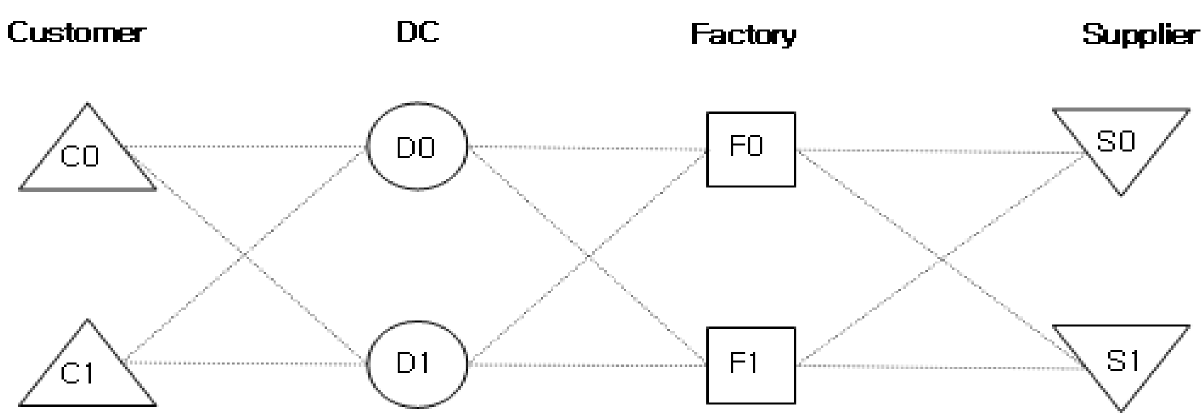

FIGURE 9. THE SCENARIO FOR SUPPLY CHAIN MODEL

IV. EXPERIMENT AND RESULT

Computational experiments have been provided in order to demonstrate the effectiveness and reasonability of the developed simulator. For the experiment of the developed simulator, two-echelon supply chain model was designed

4.1. Scenario for Experiment

The conditions for the experiments are given as follows. The number of each external object in the supply chain model was 2 respectively, and product and raw material were also 2. The number of order at customer C0 was 3, and C1 was 1, and initial and virtual inventories were randomly given at each DC and factory. Inbound and Outbound time, production time and order time were also randomly given. Simulation time was set at 10000.

4.2. Input Data

TABLE 1. CUSTOMER ORDER

From	To	Product	No. of Order	Order Interval	Due date	Priority
C0	D0	AAA	30	Exp(500)	300	1
C0	D0	BBB	30	300	50	1
C0	D1	BBB	Unif (50,70)	400	200	2
C1	D1	AAA	40	200	100	3

TABLE 2. DC INPUT DATA

DC1	AAA	BBB	Total Capacity
Virtual Inv.	40	50	
Real Inv.	40	50	
Reorder Point	20	20	
Quantity	100	80	
Capacity	150	100	200

TABLE 3. FACTORY INPUT DATA

Product	AAA	BBB	Raw material	aaa	bbb
Virtual Inv.	80	100	Virtual Inv.	40	50
Real Inv.	80	100	Real Inv.	40	50
Reorder Point	40	40	Reorder Point	20	20
Quantity	200	160	Quantity	100	80

TABLE 4. SUPPLIER INPUT DATA

Material	aaa	bbb
Virtual Inv.	480	600
Real Inv.	480	600
Reorder Point	240	240
Quantity	1200	960

4.3. Output Results

The result of the experiment is shown as follows.

TABLE 5. CUSTOMER ORDER OUTPUT

Customer	DC	Product	No. of Order	Quantity of Order	No. of Arrival	Quantity Of Arrival	Arrival in Due date	Service Rate
C0	D0	AAA	25	750	4	120	120	100.0
C0	D0	BBB	34	1020	6	180	150	83.3
C0	D1	AAA	26	1571	6	383	383	100.0
C1	D1	BBB	51	2040	3	120	120	100.0

TABLE 6. DC ORDER OUTPUT

DC	Factory	Product	No. of Order	Quantity of Order	No. of Arrival	Quantity of Arrival	Arrival in Due date	Service Rate
D0	F0	AAA	3	210	2	110	110	100.0
D0	F0	BBB	4	250	0	0	0	0
D0	F1	BBB	1	170	3	170	170	100.0
D1	F0	BBB	6	433	4	383	383	100.0
D1	F1	AAA	3	220	2	120	120	100.0

TABLE 7. DC DELIVERY OUTPUT

DC	Customer	Product	No. of Delivery	Quantity of Delivery	Arrival in due date	Service Rate
D0	C0	AAA	4	120	120	100.0
D0	C0	BBB	6	180	150	100.0
D1	C0	BBB	6	383	383	100.0
D1	C1	AAA	3	120	120	100.0

TABLE 8. FACTORY ORDER OUTPUT

Factory	Supplier	Raw material	No. of Order	Quantity of Order	No. of Arrival	Quantity of Arrival	Arrival in due date	Service Rate
F0	S0	aaa	2	120	1	600	600	100.0
F0	S1	bbb	3	1440	2	960	960	100.0
F1	S0	bbb	2	960	2	960	480	50.0
F1	S1	aaa	1	320	1	320	0	0

TABLE 9. FACTORY DELIVERY OUTPUT

Factory	DC	Product	No. of Delivery	Quantity pf Delivery	Arrival in due date	Service Rate
F0	D0	AAA	2	110	110	100.0
F0	D1	BBB	4	383	383	100.0
F1	D0	BBB	3	170	90	52.9
F1	D1	AAA	2	120	120	100.0

TABLE 10. FACTORY PRODUCTION OUTPUT

Factory	Product	No. of Production	Quantity of Delivery
F0	AAA	2	200
F0	BBB	4	700
F1	AAA	3	200
F1	BBB	3	320

TABLE 11. SUPPLIER DELIVERY OUTPUT

Supplier	Factory	Raw material	No. of Delivery	Quantity of Delivery	Arrival in due date	Service Rate
F0	D0	aaa	1	600	600	100.0
F0	D1	bbb	2	960	480	50.0
F1	D0	bbb	2	960	960	100.0
F1	D1	aaa	1	320	0	0

TABLE 12. SUPPLIER PRODUCTION OUTPUT

Supplier	Raw material	Num of Production	Quantity of Delivery
S0	aaa	2	1200
S0	bbb	2	960
S1	aaa	0	0
S1	bbb	3	960

V. CONCLUSION

The mathematical modeling and analytical method of supply chain environment have been widely studied. However, existing analytical method could not cover all variables with stochastic properties in the supply chain environment. We have developed a supply chain simulator which considers the stochastic property. Also, we proposed the mathematical model for the cost analysis for supply chain activities. A simple experiment was done to show the benefits of the developed simulator.

For further research, it is necessary to develop the simulator for generating graphical output data such that decision makers can see how the supply chain acts over time during simulation.

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