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The Development of Simulator for Supply Chain Design and Planning

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Abstract

To satisfy and respond quickly to customers' demand, many companies are now aggressively focusing on supply chain management in order to strengthen their competitiveness. The modeling and analysis of supply chain environment have been widely studied. This study is concerned with the development of supply chain simulator which deals with stochastic natures existing in the supply chain environment. We proposed the mathematical model for the efficient cost analysis and developed the supply chain simulator based on the proposed mathematical model with object-oriented language C++. The simple experiment which find the best combination of policies considering the whole cost shows the possibility and reasonability of the developed simulator.

Key Words: Supply Chain Simulator, Production and Distribution Problem, Simulation

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1. Introduction

With the increasing interest in supply chain management (SCM), most companies are speeding up to develop a solution that can efficiently support SCM. However, it is not easy matter to find the most appropriate management policy for the combination management of the SCM, and the overall management policy for SCM is required from raw material purchase, production and storage of products, and to the transportation (Ganeshan et al., 2000). Therefore, in this study, the supply chain simulator is developed. The characteristics of complex problems in SCM were defined as the proposed mathematical model and their appropriate solutions were founded by using the simulation.

The modeling and analysis of supply chain environment has been an active area of research for many years. Vidal et. al. (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 uncertain environment. Lee and Kim (2002) obtained the more realistic optimal production-distribution plans for the integrated supply chain system reflecting stochastic natures by performing the iterative hybrid analytic-simulation procedure. Thomas and Griffin (1996) developed supply chain models to support both strategic supply chain planning and operational control of the supply chain. Cohen and Lee (1988) represented mathematical models that consider the whole supply chain networks.

However, existing mathematical models could not represent the stochastic properties of the supply chain. Simulation is an effective analysis tool for dynamically changing variables of internal supply chains. Moreover, simulation can work for the global optimization of planning entire supply chain optimal values of each component (Lee et al., 2002).

Companies also promoted the development of simulator for SCM analysis. 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. However, previous simulation studies focused not the integrated SCM analysis but some parts of SCM analysis because of the difficulty developing the integrated model including the complex relation of many factors within network and the unlike network form and organization of each company.

This paper is consisted of as follows. In chapter 2, mathematical model that can support the understanding of decision process is proposed. In chapter 3, the developed supply chain simulator is introduced. In chapter 4, experiments and results for the developed simulator are shown. Concluding remark is shown in chapter 5.

2. Mathematical Model

We present a comprehensive mathematical

model that can support the developed supply chain simulator. The model was 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 raw material i at supplier s
- h_{if} : unit cost of inventory of raw material 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

$$\min z = \sum_t \sum_i \sum_s I_{is}^t h_{is} + \sum_s S_s Z_s + \sum_t \sum_i \sum_s P_{is}^t CP_{is} + \sum_s M_s Z_s$$

s.t.

$$I_{is}^{t-1} + P_{is}^t - \sum_f T_{isf}^t = I_{is}^t \qquad \forall i, \forall s, \forall t \quad (1)$$

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

$$I_{is}^t, P_{is}^t, T_{isf}^t \ge 0 \qquad \forall i, \forall s, \forall t \quad (3)$$

The object function in supplier stage is to minimize the sum of production cost, inventory cost, maintenance cost, and fixed cost of raw materials. Constraint (1) is the equation related to raw material inventory at supplier during period t.

Factory stage

$$\min z = \sum_t \sum_p \sum_f I_{pf}^t h_{pf} + \sum_t \sum_i \sum_f I_{if}^t h_{if} + \sum_f S_f Z_f + \sum_f M_f Z_f + \sum_t \sum_p \sum_f P_{pf}^t CP_{pf} + \sum_t \sum_i \sum_f \sum_s B_{ifs}^t CB_{ifs}$$

s.t.

$$\sum_f B_{ifs}^t = T_{isf}^t \qquad \forall i, \forall f, \forall s, \forall t \quad (4)$$

$$I_{pf}^{t-1} + P_{pf}^t - \sum_d T_{pfd}^t = I_{pf}^t \qquad \forall p, \forall f, \forall t \quad (5)$$

$$I_{if}^{t-1} + \sum T_{isf}^t - P_{if}^t = I_{if}^t \qquad \forall i, \forall f, \forall s, \forall t \quad (6)$$

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

$$I_{if}^t, I_{pf}^t, B_{ifs}^t, T_{isf}^t, T_{pfd}^t \ge 0 \qquad \forall i, \forall d, \forall f, \forall p, \forall s, \forall t \quad (8)$$

The object function in 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 factory must be equal to the amount of transportation. 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.

Distribution Center stage

$$\min z = \sum_t \sum_d \sum_p I_{pd}^t h_{pd} + \sum_d S_d Z_d + \sum_d M_d Z_d + \sum_t \sum_p \sum_c \sum_d B_{pdf}^t CB_{pdf}$$

s.t.

$$\sum_f B_{pdf}^t = T_{pdf}^t \qquad \forall d, \forall f, \forall p, \forall t \quad (9)$$

$$I_{pd}^{t-1} + \sum T_{pdf}^t - \sum T_{pdc}^t = I_{pdc}^t \qquad \forall c, \forall d, \forall f, \forall p, \forall t \quad (10)$$

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

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

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

$$I_{if}^t, B_{pdf}^t, T_{pcd}^t, T_{pdf}^t \ge 0 \qquad \forall c, \forall d, \forall f, \forall i, \forall p, \forall t \quad (14)$$

The object function of distribution center 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. Constraints (11) shows not to exceed the storage capacity at DC. Constraint (12) means that total capacity must be bigger than the sum of each.

Customer stage

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

s.t.

$$\sum_c B_{pcd}^t = T_{pcd}^t \qquad \forall c, \forall d, \forall p, \forall t \quad (15)$$

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

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

The object function of customer stage 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

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

s.t.

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

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

3. Supply chain simulator

There are many uncertain variables with stochastic property in supply chain environment. It is not easy matter to find the 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 represents the overall supply chain with mathematical model is efficient in finding solutions under many constraints, and reflects all the uncertainties existing on the SCM such as the demand of customers, delivery time of products and raw materials, and service rate for customers. We developed the supply chain simulator that is designed to the 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 effects on 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.

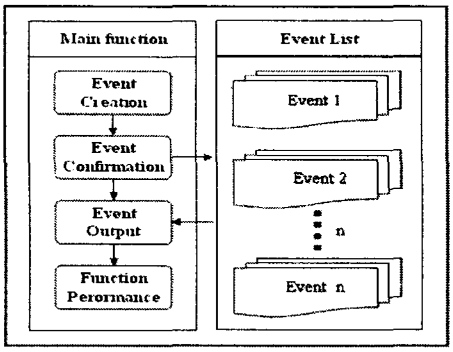

Fig.1. The simulator engine

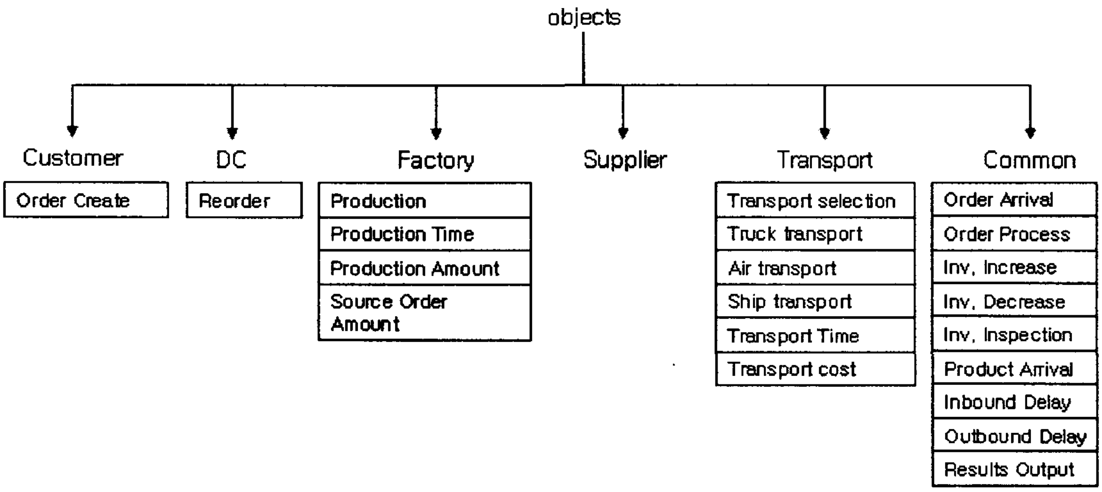

Fig. 2. The taxonomy of objects model in supply chain

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.

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. The object plays a role of mutually exchanging information of each object.

Input data of common object

we shows the input data of common object are commonly used in factory, DC and supplier in Table 1.

Function of common object - 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 Hyper geometric 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.

Table 1. 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
LotOrderSize	- information for lot size of ordering
Unit cost of order	- input data for unit cost of order
CallDelay	- the time taken for ordering raw material and product
Capacity	- capacity for raw material and product

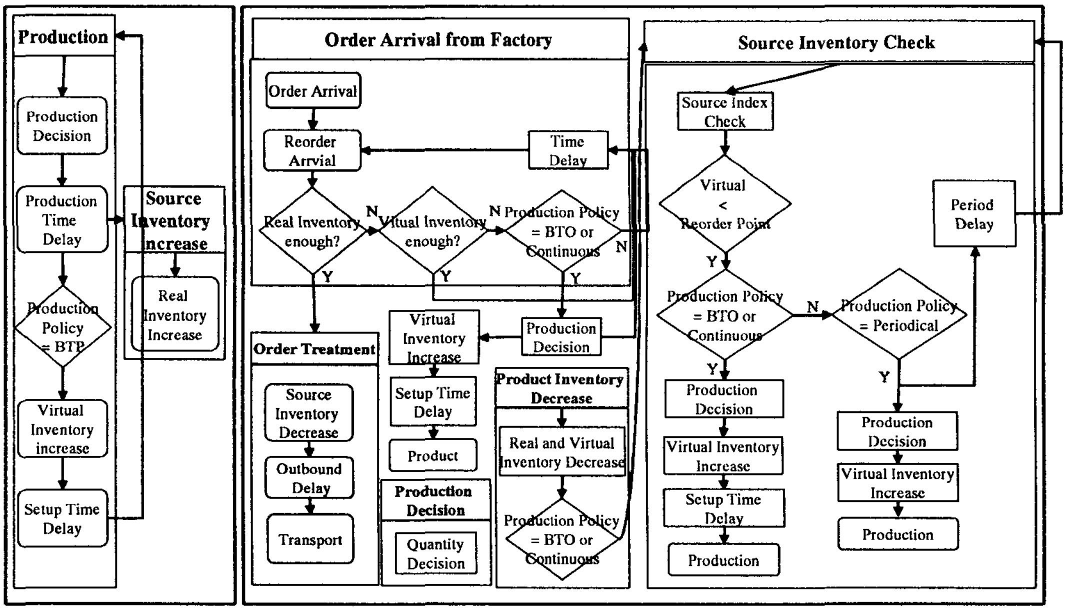

Fig.3. The procedure of the order process in supplier object

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.

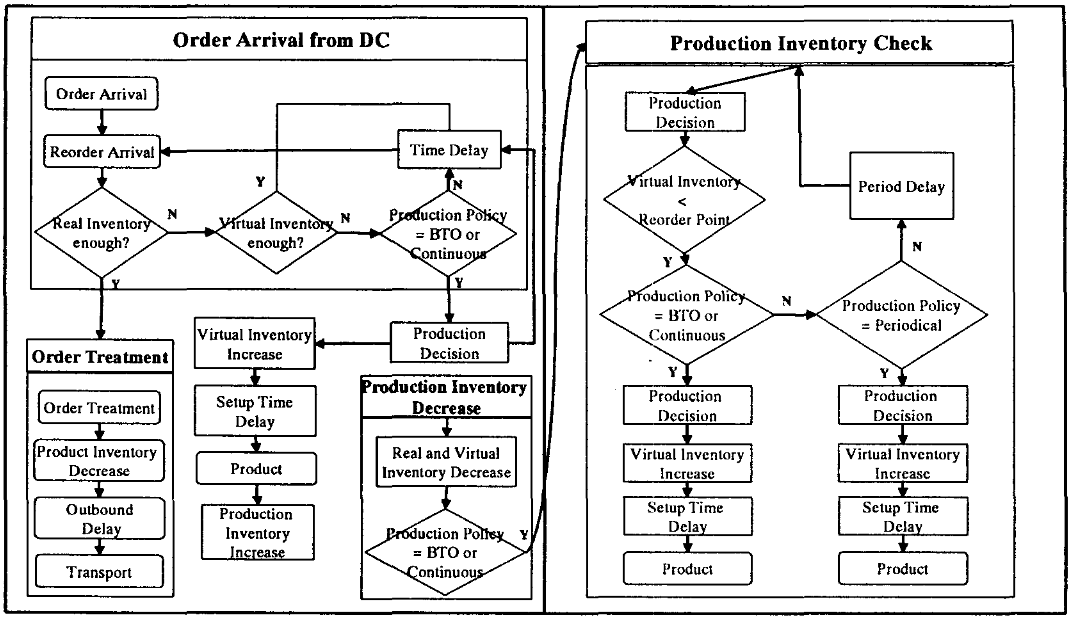

Fig. 4. The procedure of the order process in factory object

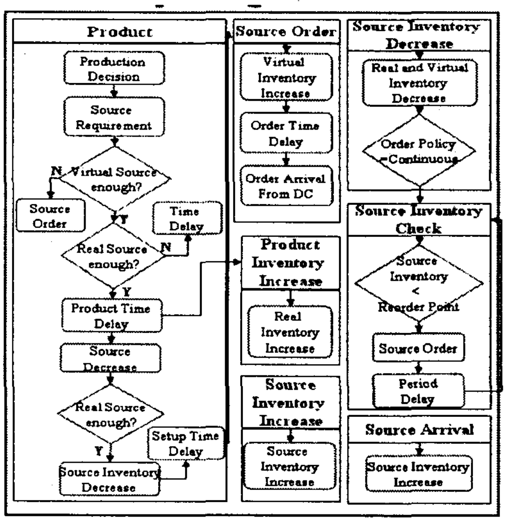

Fig. 5. The procedure of the production process in factory object

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. Fig 6 shows the order process occurred in DC object.

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

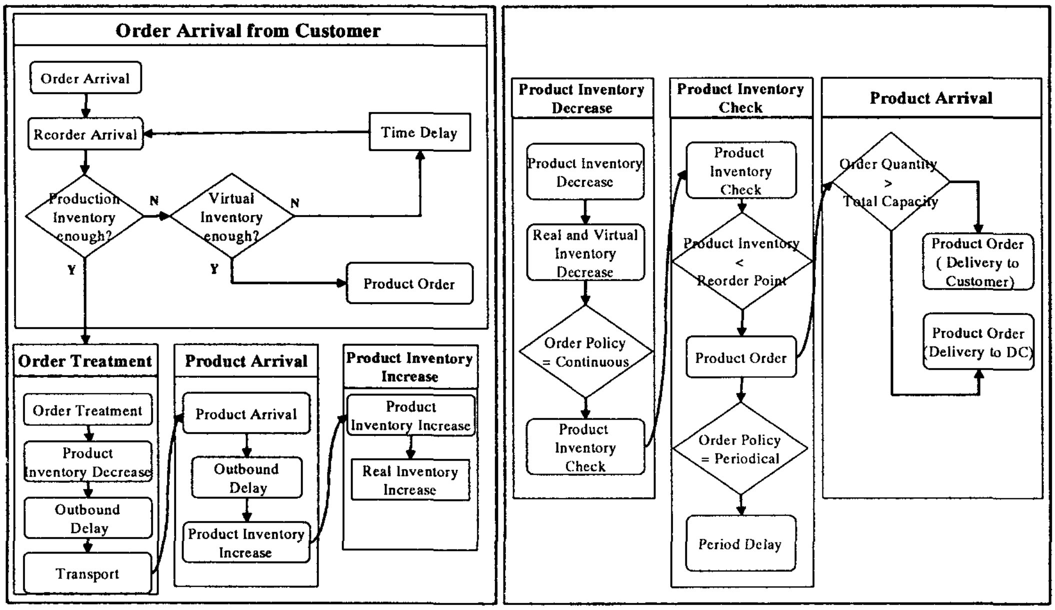

Fig. 6. The procedure of the order process in DC object

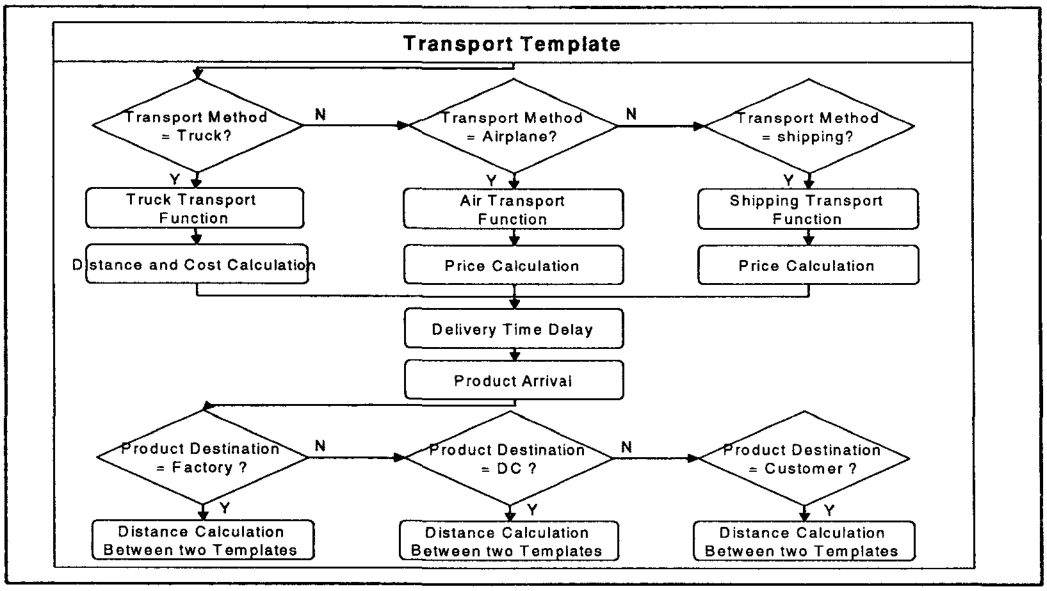

Fig. 7. The procedure of the transportation process in transport object

transportation time between them. 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.

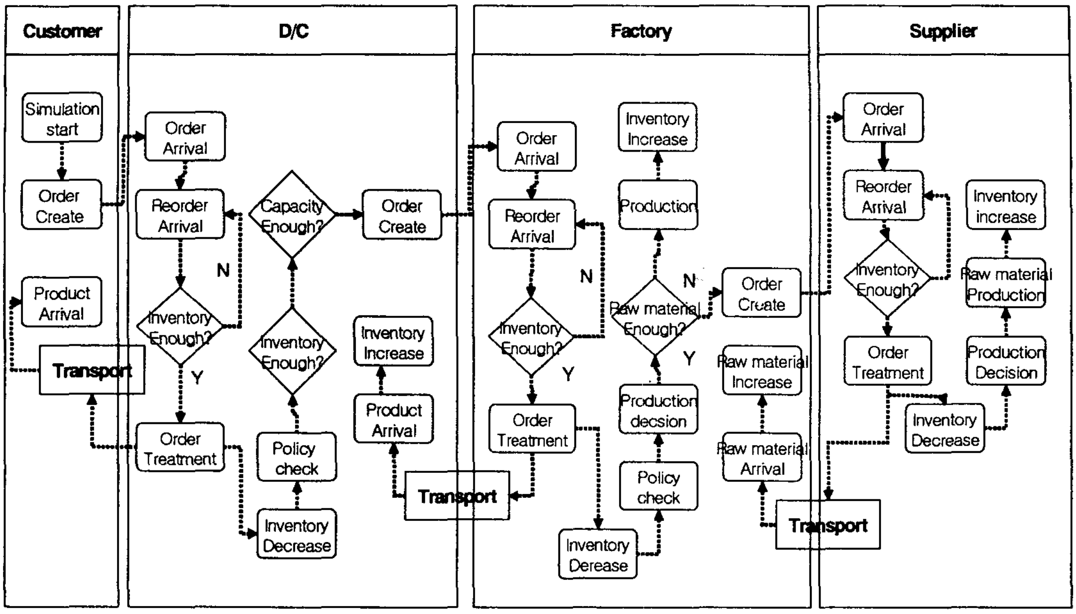

Fig. 8. The simple procedure of supply chain process

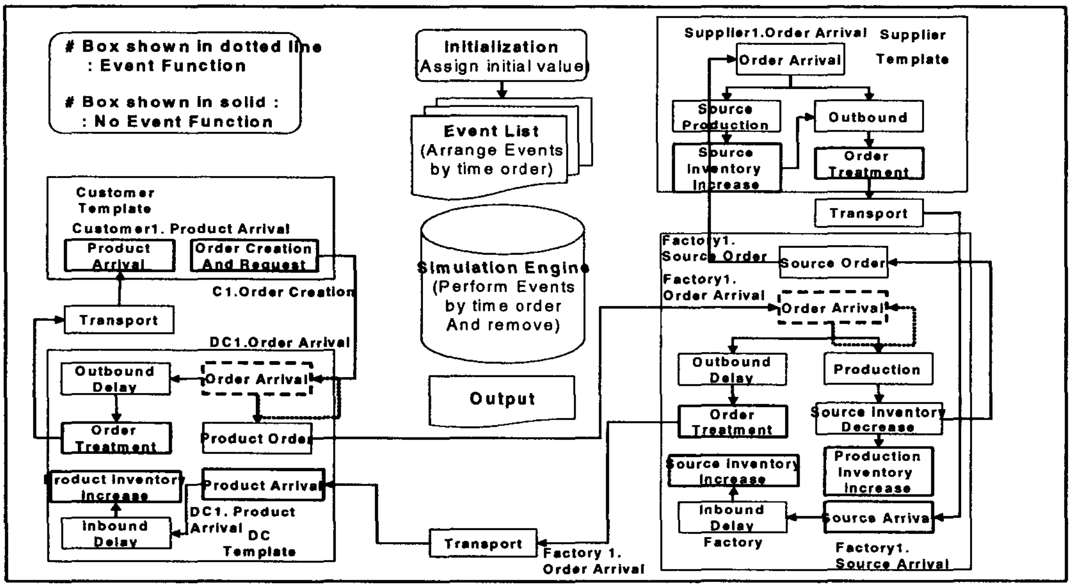

Fig. 9. The architecture of the integrated supply chain simulator

3.2 Inventory replenishment policy

The inventory replenishment policy determines when an object will generate a replenishment order to restock its capacities. The following four policies are suggested and they are applied to the order policy of DC, the order policy of factory and the production plicy of factory.

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.

4. Experiment and Result

The experiments have been provided in order to demonstrate the effectiveness and reasonability of the developed simulator. The performance of the simulator was tested by using the input data as given table 2. Each of experiment is 7 times.

Firstly, we find the combination of replenishment policies to minimize the total cost in factories and DCs. and we implement the sensitive analysis of the total cost according to order cost, production cost and inventory cost in each policies. The input data of the experiment is shown in table 2. simulation tims is set at one year and warm-up period is given in ten days. The conditions for the experiments are given as

Table 2. The input data of experiment

	Input data	Input value			
			DC	Max inventory	2000 units
Customer	Order interval	24 hr		InBound delay	Nor(1, 0.1)
	Order amount	Poison(100)		OutBound delay	Nor(1, 0.1)
	Due date	48 hr		Reorder point	200 units
Factory	Initial Invnetory	500 units		Safety stock	100 units
	Max inventory	1500 units		Periodic Review	4 days
	Production time	Nor(3, 0.3)		BTP Review	7 days
	InBound delay	Nor(1, 0.1)		BTP production	700 units
	OutBound delay	Nor(1, 0.1)	Transport time	Sup -> Fac	Nor(5, 0.5)
	Reorder	200 units		Fac -> DC	Nor(20, 2)
	Safety stock	100 units		DC -> Cus	Nor(10, 1)
	Periodic Review	4 days	Product	price	100
	BTP Review	7 days		inventory cost	20
	BTP Production	700 unis		order cost	2
DC	Initial inventory	1000 units		transportation cost	20

follows. The number of each external object is consisted of 3 customers, 2 DCs, 2 facotories and 2 suppliers. Table 3 and Fig 10 show the experiment results when order policies of factories are BTO policies. the best combination is that the production policies of factories are BTO and order policies of DCs are continuous. We can confirm that this combination reduces at least costs of 30%. Fig 11 shows the graph of the respective cost when the order policies of factories are BTO policies. In this case, production cost does not become different, but the inventory, transportation, backorder cost are appeared differently by the respective combination of policies. Table 4 and Fig 12 show the output when order policies of factories are continuous policies. the optimal combination is that the production. Fig 13 shows the graph of the respective cost when the order policies of factories are continuous policies. policies of factories are BTO and order policies of DCs are continuous. This result shows that the selection of the proper combination of policies using simulation can affect the benefit of the enterprise largely.

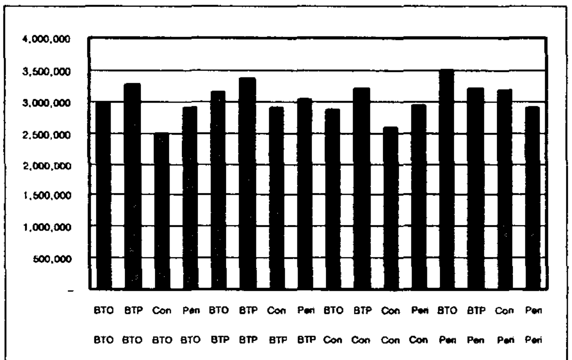

Fig 10. Total cost (Policy of factory - BTO)

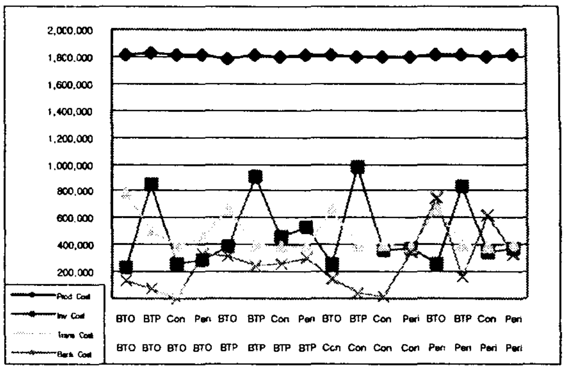

Fig 11. Each cost (Policy of factory - BTO)

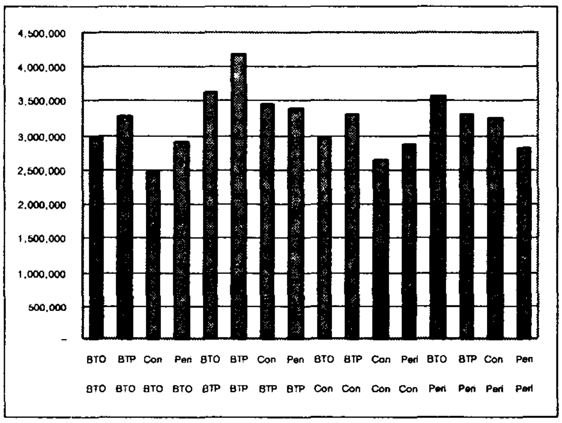

Fig 12. Total cost (Policy of factory - Continuous)

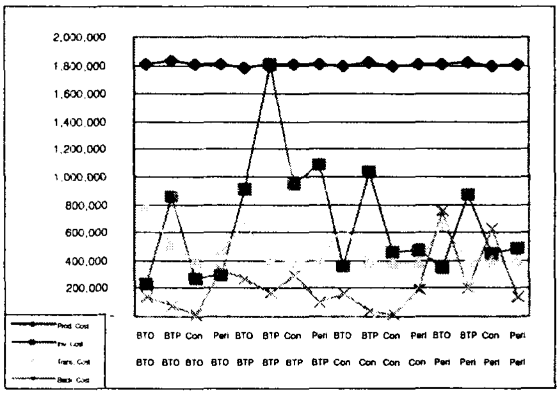

Fig 13. Each cost (Policy of factory - Continuous)

5. 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 are interested in the development of supply chain simulator which considers the stochastic property. Also, we proposed the mathematical model for the efficient cost analysis in process of simulation implementation. The simple experiment which find the best combination of policies in factories and DCs considering the whole cost 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.

Table 3. Order policy of Factory - BTO

Fac Order	Fac Prod	DC Order	Price	Prod. Cost	Inv. Cost	Trans. Cost	Back. Cost	Total Cost	Profit	Profit Rate
BTO	BTO	BTO	3,619,200	1,809,600	236,175	786,110	135,200	2,967,085	652,115	18.0%
BTO	BTO	BTP	3,655,400	1,927,700	853,245	508,601	78,450	3,267,996	387,404	10.6%
BTO	BTO	Con	3,625,200	1,812,600	264,155	394,412	6,750	2,477,917	1,147,284	31.6%
BTO	BTO	Peri	3,616,000	1,808,000	291,230	459,823	330,050	2,889,103	726,898	20.1%
BTO	BTP	BTO	3,581,800	1,790,900	394,755	656,080	311,400	3,153,135	428,665	12.0%
BTO	BTP	BTP	3,616,800	1,808,400	912,915	401,651	243,250	3,366,216	250,584	6.9%
BTO	BTP	Con	3,594,000	1,797,000	464,540	395,215	255,400	2,912,155	681,845	19.0%
BTO	BTP	Peri	3,614,300	1,807,150	525,935	389,187	295,300	3,017,572	596,729	16.5%
BTO	Con	BTO	3,615,300	1,807,650	260,820	658,890	140,500	2,867,860	747,440	20.7%
BTO	Con	BTP	3,602,300	1,801,150	971,695	401,354	36,400	3,210,599	391,701	10.9%
BTO	Con	Con	3,599,400	1,799,700	362,795	400,045	12,000	2,574,540	1,024,860	28.5%
BTO	Con	Peri	3,609,800	1,804,900	373,890	393,669	351,000	2,923,459	686,341	19.0%
BTO	Peri	BTO	3,621,100	1,810,550	260,085	656,450	754,100	3,481,185	139,915	3.9%
BTO	Peri	BTP	3,615,600	1,807,800	834,190	405,201	152,700	3,199,891	415,709	11.5%
BTO	Peri	Con	3,599,700	1,799,850	351,055	393,220	622,100	3,166,225	433,475	12.0%
BTO	Peri	Peri	3,616,900	1,808,450	371,020	398,677	323,800	2,901,947	714,954	19.8%

Table 4. Order policy of Factory - Continuous

Fac Order	Fac Prod	DC Order	Price	Prod. Cost	Inv. Cost	Trans. Cost	Back. Cost	Total Cost	Profit	Profit Rate
Con	BTO	BTO	3,619,200	1,809,600	236,175	786,110	135,200	3,967,085	652,115	18.0%
Con	BTO	BTP	3,655,400	1,827,700	853,245	508,601	78,450	3,267,996	387,404	10.6%
Con	BTO	Con	3,625,200	1,812,600	264,155	394,402	6,750	2,477,907	1,147,294	31.6%
Con	BTO	Peri	3,616,000	1,808,000	291,230	459,823	330,560	2,889,103	726,898	20.1%
Con	BTP	BTO	3,567,100	1,783,550	906,830	660,430	268,050	3,618,860	-51,760	-1.5%
Con	BTP	BTP	3,609,700	1,804,850	1,805,480	411,991	160,950	4,183,271	-573,571	-15.9%
Con	BTP	Con	3,605,000	1,802,500	654,550	397,589	289,850	3,444,489	160,511	4.5%
Con	BTP	Peri	3,606,700	1,803,350	1,092,960	405,577	101,600	3,403,478	203,214	5.6%
Con	Con	BTO	3,595,700	1,797,850	354,955	652,015	164,600	2,969,420	626,280	17.4%
Con	Con	BTP	3,646,900	1,823,450	1,034,540	402,742	36,500	3,297,232	349,668	9.6%
Con	Con	Con	3,599,400	1,799,700	456,425	386,670	12,000	2,654,795	944,605	26.2%
Con	Con	Peri	3,612,400	1,806,200	470,725	390,815	196,400	2,864,140	748,260	20.7%
Con	Peri	BTO	3,621,100	1,810,550	352,355	656,575	754,100	3,573,580	47,520	1.3%
Con	Peri	BTP	3,642,500	1,821,250	869,560	397,574	209,200	3,297,584	344,916	9.5%
Con	Peri	Con	3,599,700	1,799,850	444,410	393,345	622,100	3,259,705	339,995	9.4%
Con	Peri	Peri	3,610,200	1,805,100	482,660	394,640	145,500	2,827,900	782,300	21.7%

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