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공급사슬에서 실제 시설물 운영시간을 고려한 시설배치계획에 관한 연구

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Facility Location Planning with Realistic Operation Times in Supply Chain

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■ Abstract ■

Facility location planning (FLP) problem is the strategic level planning in supply chain. The FLP is significantly affected by the operation time of each facility. In most of the FLP researches, operation time of facility has been treated as a fixed value. However, the operation time is not a static factor in real situations and the fixed operation time may lead unrealistic FLP. In this paper, a mixed integer programming (MIP) model is proposed for solving the 3-stage FLP problem and operation times are adjusted by the results from the simulation model and an iterative approach combining the analytic model and simulation model is proposed to obtain more realistic operation plans for FLP problems.

Keyword : Supply Chain, Facility Location Planning, Mixed Integer Programming, Iterative Approach, Operation Time

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1. Introduction

Where to locate facilities such as supply points, plants, warehouses to satisfy fixed customer zones is very essential for optimal design of a supply chain. In the planning of supply chain, three levels of planning can be distinguished: strategic, tactical and operational. Strategic supply chain decisions may include: plants or warehouse openings and closing, allocation of equipment to manufacturing facilities, selection of a location or locations for manufacture of a new product, and evaluation of changes in the flow of a particular product through the supply chain. Therefore, locating facilities in a supply chain is included in the strategic level. We consider a multi-item, multi-facility, multi-stage, multi-period version of the supply point, plant and warehouse logistics problem with limited capacities in this paper.

There are some models to solve various facility location planning. Prikul and Jayaraman [8] developed a mixed integer programming (MIP) model for the plant and warehouse location problem with 2-stage, multi-product, multi-plant, multi-warehouse, multi-customer zone, multi-period system where the objective is to minimize the total transportation, distribution costs, the fixed costs for opening and operating plants, and warehouses. They employed Lagrangean relaxation to the model, and also presented a heuristic to produce an effective feasible solution for the problem. Barbarosoğlu and Ozgür [1] applied the method of Lagrangean relaxation in the hierarchical design of an integrated model of production-distribution functions in a 2-echelon system ; multi-product, one plant, multi-depot, multi-customer, multi-period. They proposed MIP model to decide the optimal quantities of production and distribution and the optimal amount of inventory. Mohamed [7] studied the modeling of production planning and logistics decisions for multi-national company operating under varying inflation and exchange rates. They incorporated decision parameters regarding when to open, retain, and close facilities into the optimal production-distribution plans regarding one-stage, multi-national company, multi-product, multi-facility, multi-market, multi-period. Their results indicate profit reduces by as much as 45.77% depending on the exchange rates, initial capacities, and restrictions imposed on the more profitable facilities. Korpela and Lehmusvaara [5] presented a customer oriented approach to the evaluation and selection of alternative warehouse operators in 2-stage, one plant, multi-warehouse, multi-customer system configuration. The analytic hierarchy process (AHP) is used for analyzing the customer-specific requirements for logistics service and for evaluating the alternative warehouse operators. A mixed integer linear programming model is used for maximizing the overall service performance of the warehouse network under relevant restrictions. Lee and Kim [6] proposed a hybrid approach combining the analytic model and simulation model to obtain realistically optimal operation time for optimal realistic production-distribution plans. The proposed model is LP model with 2-stage, multi-product, multi-plant, multi-warehouse, multi-customer, multi-period.

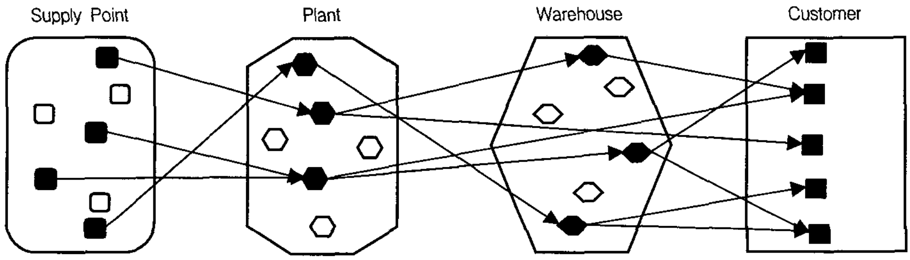
From these previous researches, we know that most of models deal with 2-stage (plant-warehouse), multi-product, multi-facility, multi-period and their objective functions have mostly been expressed by single measure : one of cost, profit, throughput, time etc. However, for more realistic supply chain design, 3-stage system including supply points, plants, warehouses, customers should be considered in the integrated environment of supply chain. The facility should be opened and operated until all required products are made and delivered. Thus, distribution times also should be regarded as importantly as cost factors because delivering products to customers on time is a critical factor. These delivery times affect significantly the locations of facilities in supply chain. The sum of all delivery times in a certain facility is equal to the operation time of that facility.

We consider a facility location planning (FLP) problem regarding suppliers, manu-facturers, customers, multi-product, multi-supplier, multi-plant, multi-warehouse, multi-customer, and multi-period system to decide location of open facilities. The objectives of this research are to develop an integrated multi-period, multi-product, multi-facility location model in supply chain to satisfy retailers' demands and formulate the problem as an analytic model which minimizes the sum of various costs and delivery times subject to various constraints and propose an iterative approach combining an analytic and simulation model to solve the FLP problem in more realistic situation. Through experiments by the proposed solution approach, more realistically optimal facility location plans are obtained.

2. Problem Statement

In the capacitated supply point, plant and warehouse location model, customers typically demand multiple products that are distributed to customer outlets from open warehouses or open plants while warehouses receive these products from several manufacturing plants. Supply point is regarded as a separated facility and raw materials in supply point are supplied to plants for making products.

However, assigning the operation times for each facility in supply chain is a difficult task. Operation times have been fixed or disregarded in most of analytic models. But in real situations, tremendous differences exist between facility operation times and the required times to achieve the facility location plan. Because the consumed time to realize the facility location plan is complex and has stochastic natures. More realistic operation time derives more realistic plan. Therefore, we use a simulation model to accommodate real operation times in the analytic model of the system. The model structure dealt with in this research is illustrated in [Figure 1]. Planning for multi-stage supply chain systems



[Figure 1] A proposed supply chain for facility location planning are strategic level planning. Facilities are dispersed on the supply chain. Black colored boxes represent open facilities while non-black colored boxes represent closed facilities.

3. Model Development

The proposed model is to locate a number of supply points, plants and warehouses subject to their various restrictions and decide the optimal quantities of flow of raw materials and products among facility locations. Customers demand multiple products in each time period. Products are distributed to customers from open warehouses or open plants. In fact, concepts like supply chain management(SCM) and logistics network engineering include the suppliers of the manufacturer into the same framework and aims to coordinate the activities of suppliers, manufacturers, wholesalers, and retailers. Raw materials in supply points are supplied to open plants to make products satisfying customer demands. Warehouses receive products from open plants.

The locations of customers and their demands for multiple products are known. Backlogging of demand is not allowed. Maximum holding capacities of supply points, plants and warehouses are also known. Setup and operating cost for each facility includes the general expenditure of management for each facility. Delivery times and costs are fixed previously. Under these assumptions, two objectives are established: minimizing total cost of setup, manufacturing, transportation and minimizing total delivery time from the proposed plant/warehousing facility to its suppliers and customers are considered.

The hypothetical system under this study is a multi-product, multi-supplier, multi-plant, multi-warehouse, multi-customer, multi-period, 3-stage system and its facility location problem is formulated as a MIP. Through this model, the facility location decision addresses the following issues :

(1) Where and when to locate which supply point or plant or warehouse facility which can minimize cost and delivery time?
(2) How much of raw material or product should be transported among facilities (logistic flow)?
(3) How does weighting rate of two major objective function values : cost and delivery time affects the solutions?

Given the proposed model framework, the following mathematical notation and formulation are presented.

- **Index**

j : product, i : supply point, m : plant, k : warehouse, l : customer, n : raw material, t : period

- **Parameter**

D_{jlt} : demand of product j from customer l in period t

O_{it} : setup and operating cost for supply point i in period t

P_{mt} : setup and operating cost for plant m in period t

Q_{kt} : setup and operating cost for warehouse k in period t

C_{imnt} : supply cost for a unit raw material n from an open supply point i to an open plant m in period t

T_{mkjt} : transportation cost for a unit product j from an open plant m to an open warehouse k in period t

R_{kljt} : distribution cost for a unit product j from an open warehouse k to a customer l in period t

S_{mljt} : distribution cost for a unit product j from an open plant m to a customer l in period t

CA_{imnt} : supply time for a unit raw material n from an open supply point i to an open plant m in period t

TA_{mkjt} : transportation time for a unit product j from an open plant m to an open warehouse k in period t

RA_{kljt} : distribution time for a unit product j from an open warehouse k to a customer l in period t

SA_{mljt} : distribution time for a unit product j from an open plant m to a customer l in period t

U_t : maximum number of supply points that can be open

V_t : maximum number of plants that can be open

W_t : maximum number of warehouses that can be open

o_{it} : maximum capacity of supply point i in period

p_{mt} : maximum capacity of plant m in period t

q_{kt} : maximum capacity of warehouse k in period t

a_{nj} : amount of raw material n to make a unit of product j

$CACAPA_{it}$: total operation time for supply point i in period t

$TACAPA_{it}$: total operation time for plant m in period t

$RACAPA_{kt}$: total operation time for warehouse k in period t

$Budget_t$: total amount of budget available in period t

- **Variables**

X_{imnt} : total number of units of raw material n supplied from supply point i to plant m in period t

Y_{mkjt} : total number of units of product j transported from plant m to warehouse k in period t

Z_{kljt} : total number of units of product j distributed from warehouse k to customer l in period t

W_{mljt} : total number of units of product j distributed from plant m to customer l in period t

$$B_{it} = \begin{cases} 1, & \text{if supply point } i \text{ is open in period } t \\ 0, & \text{otherwise} \end{cases}$$

$$E_{mt} = \begin{cases} 1, & \text{if plant } m \text{ is open in period } t \\ 0, & \text{otherwise} \end{cases}$$

$$F_{kt} = \begin{cases} 1, & \text{if warehouse } k \text{ is open in period } t \\ 0, & \text{otherwise} \end{cases}$$

- **Objective Function :**

Minimize [Total Cost + Total Delivery Time]

Total Cost =

$$\left[\begin{array}{l} \sum_i^I\sum_m^M\sum_n^N\sum_t^T C_{imnt}X_{imnt} + \\ \sum_m^M\sum_k^K\sum_j^J\sum_t^T T_{mkjt}Y_{mkjt} + \\ \sum_k^K\sum_l^L\sum_j^J\sum_t^T R_{kljt}Z_{kljt} + \\ \sum_m^M\sum_l^L\sum_j^J\sum_t^T S_{mljt}W_{mljt} + \sum_i^I\sum_t^T B_{it}O_{it} \\ + \sum_m^M\sum_t^T E_{mt}P_{mt} + \sum_k^K\sum_t^T Q_{kt}F_{kt} \end{array}\right] \quad (1)$$

Total Delivery Time =

$$\left[\begin{array}{l} \sum_i^I\sum_m^M\sum_n^N\sum_t^T CA_{imnt}X_{imnt} + \\ \sum_m^M\sum_k^K\sum_j^J\sum_t^T TA_{mkjt}Y_{mkjt} + \\ \sum_k^K\sum_l^L\sum_j^J\sum_t^T RA_{kljt}Z_{kljt} + \\ \sum_m^M\sum_l^L\sum_j^J\sum_t^T SA_{mljt}W_{mljt} \end{array}\right] \quad (2)$$

- **Constraints :**

$$\left[\begin{array}{l}\sum_{i}^{I}\sum_{m}^{M}\sum_{n}^{N}C_{imnt}X_{imnt}+\sum_{m}^{M}\sum_{k}^{K}\sum_{j}^{J}T_{mkjt}Y_{mkjt}+\sum_{k}^{K}\sum_{l}^{L}\sum_{j}^{J}R_{kljt}Z_{kljt} \\ +\sum_{m}^{M+}\sum_{l}^{L}\sum_{j}^{J}S_{mljt}W_{mljt}+\sum_{i}^{I}B_{it}O_{it}+\sum_{m}^{M}E_{mt}P_{mt}+\sum_{k}^{K}Q_{kt}F_{kt}\end{array}\right. \le Budget_t \qquad (3)$$

$$\sum_{m}^{M}\sum_{n}^{N}CA_{imnt}X_{imnt}\le CACAPA_{it},\ \forall i,t \qquad (4)$$

$$\sum_{k}^{K}\sum_{j}^{J}TA_{mkjt}Y_{mkjt}+\sum_{l}^{L}\sum_{j}^{J}SA_{mljt}W_{mljt}\le TACAPA_{mt},\ \forall m,t \qquad (5)$$

$$\sum_{l}^{L}\sum_{j}^{J}RA_{kljt}Z_{kljt}\le RACAPA_{kt},\ \forall k,t \qquad (6)$$

$$\sum_{k}^{K}Z_{kljt}+\sum_{m}^{M}W_{mljt}=D_{jlt},\ \forall j,l,t \qquad (7)$$

$$\sum_{i}^{I}B_{it}\le U_t,\ \forall t \qquad (8)$$

$$\sum_{m}^{M}\sum_{n}^{N}X_{imnt}\le o_{it}B_{it},\ \forall i,t \qquad (9)$$

$$\left[\sum_{m}^{M}\sum_{k}^{K}\sum_{j}^{J}a_{nmj}Y_{mkjt}+\sum_{m}^{M}\sum_{l}^{L}\sum_{j}^{J}a_{nmj}W_{mljt}\right]=\sum_{m}^{M}\sum_{i}^{I}X_{imnt},\ \forall n,t \qquad (10)$$

$$\sum_{m}^{M}E_{mt}\le V_t,\ \forall t \qquad (11)$$

$$\sum_{k}^{K}\sum_{j}^{J}Y_{mkjt}+\sum_{l}^{L}\sum_{j}^{J}W_{mljt}\le P_{mt}E_{mt},\ \forall m,t \qquad (12)$$

$$\sum_{l}^{L}Z_{kljt}\le\sum_{m}^{M}Y_{mkjt},\ \forall j,k,t \qquad (13)$$

$$\sum_{k}^{K}F_{kt}\le W_t,\ \forall t \qquad (14)$$

$$\sum_{l}^{L}\sum_{j}^{J}Z_{kljt}\le q_{kt}F_{kt},\ \forall k,t \qquad (15)$$

$$B_{it},\ E_{mt},\ F_{kt}=\{0,1\},\ \forall i,m,k,t \qquad (16)$$

$$X_{imnt},\ Y_{mkjt},\ Z_{kljt},\ W_{mljt}\ge 0,\ \forall i,m,k,l,j,n,t \qquad (17)$$

Equation (1) is a measure of total cost. The model minimizes the sum of: the costs to supply raw materials from supply points to plants; the costs for transporting units of different products from plants to warehouses and customers; the costs for distributing units of different products from warehouses to customers; the fixed cost associated with locating and operating facilities. Equation (2) is a measure of total delivery time. The model minimizes the sum of the time to supply raw materials from supply points to plants; the time for transporting units of different products from plants to warehouses and customers. Equation (3) ensures that total cost needed in a certain period of time should not excess the budget limit in that period. Equation (4), (5) and (6) ensure that total time required to deliver units of raw materials or units of products in a certain period of time should be less than or equal to the available time in each facility in that period. Equation (7) ensures that all the demand of customers are satisfied by open plants and open warehouses. Equation (8) ensures that total number of supply points can be open cannot excess the maximum number of potential supply points. Equation (9) ensures that total number of units of raw materials supplied from supply points to plants in a certain period of time should not excess the maximum number of raw materials available in that period. Equation (10) ensures that total number of units of raw materials required to make finished products demanded from all customers should be equal to the total number of units of raw materials supplied from supply points to plants. Equation (11) ensures that total number of plants can be open may not excess the maximum number of potential plants. Equation (12) ensures that total number of units of products transported from plants to warehouses or customers directly in a certain period of time should not excess the maximum number of products produced in that period. Equation (13) ensures that total number of units of products transported from plants to warehouses is less than or equal to the available number of units of products in warehouses. Equation (14) ensures that total number of warehouses can be open may not excess the maximum number of potential warehouses. Equation (15) ensures that total number of units of products distributed from plants to warehouses or customers in a certain period of time should not excess the maximum number of products stored in warehouses in that period. Equation (16) enforces the binary nature of decision variables and (17) enforces the non-negativity restriction on the decision variables.

4. Iterative Analytic-Simulation Approach

The iterative analytic-simulation approach is proposed to solve the problem in this paper. This approach uses a simulation model to support the analytic model of the system. The simulation can describe dynamic situations in real system. This procedure will reflect the effects of operational characteristics on the analytic model. Furthermore, the influence of probabilistic characteristics of the system can easily be included in the model. It leads to derive more realistic solutions with respect to the analytic solutions. The operation time constraints in the analytic model for facility location planning problems have been regarded as fixed values. However, in the real situations, operation times can not be considered as fixed values due to their stochastic natures.

Simulation model can accommodate realistic operation time to the analytic model providing simulation flow time to perform the results from the analytic model. The iterative approach, which is based on imposing adjusted operation times derived from the simulation model results, is recursive in structure and consists of the following steps :

Step 1 : Generate optimum facility location plan from the analytic model.

Step 2 : Assign the optimum plan from the analytic model as inputs to the simulation model.

Step 3 : Run simulation model subject to realistic operation policies.

Step 4 : If the simulation model results indicate that the optimum facility location plan obtained from step 1 can be performed within the operation time, then go to step 7, otherwise go to step 5.

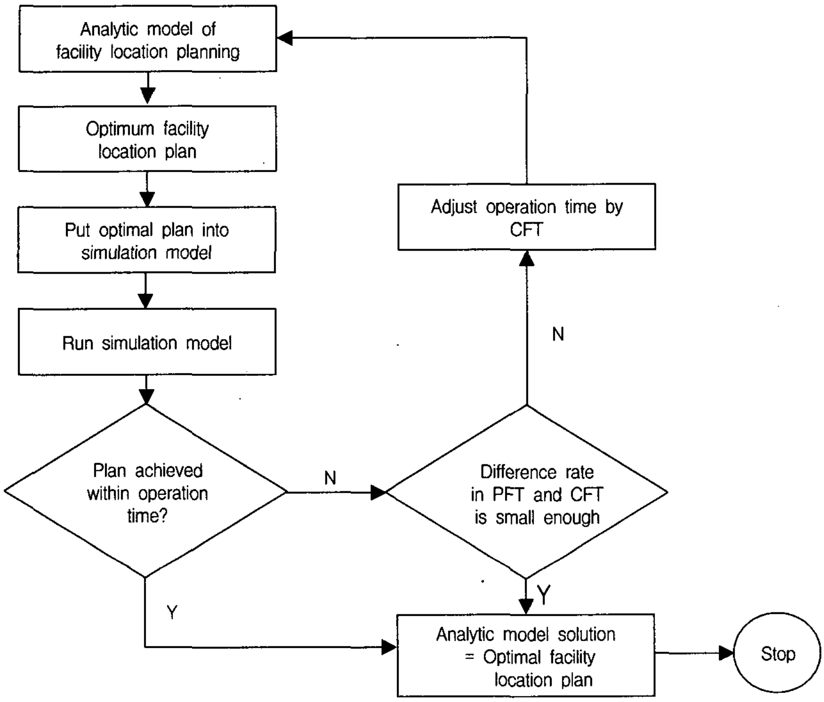
Step 5 : If the difference rate in preceding simulation flow time (PFT) and current simulation flow time(CFT) is closely enough to be accepted, then go to step 7, otherwise go to step 6.

Step 6 : Adjust operation time in the analytic model with current simulation flow time and go to step 1.

Step 7 : Current facility location plan given by the analytic model is considered to be realistically optimal solutions.

Step 8 : Stop

Operation times are the right hand side values of constraint equations (4), (5) and (6) in the analytic model. As stated in step 6, these operation times are adjusted with simulation flow times. Therefore, operation times of each constraint are



[Figure 2] A proposed iterative approach

replaced by simulation flow times which are derived from the simulation model. Initial operation times of each facility are considered to be deterministic and fixed for each planning period. This solution procedure is illustrated in [Figure 2]. The procedure uses independently developed analytic and simulation models together to solve the problem. The simulation model is employed as a sub-model. Although it has not been proved that the procedure will always converge, convergence does occur within a reasonable number of iterations through many experimental experiences.

5. Experiments

The proposed MIP model is applied to a minimization of objective function of a 2 period, 3 supply point, 3 plant, 3 warehouse, 4 customer facility location with 2 product, 2 raw material problem in supply chain under various constraints. The cost and delivery time coefficients, demand matrix and various given data are in <Table 1> to <Table 12>.

⟨Table 1⟩ Demands from customers

Period(t)	1								2							
Customer(L)	1		2		3		4		1		2		3		4	
Product(j)	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
	50	60	70	80	60	75	80	90	50	50	70	70	80	80	50	50

〈Table 2〉 Setup and operating costs for each facility

Period(t)		1	2	Period(t)		1	2	Period(t)		1	2
Supply Point(I)	1	200	240	Plant(M)	1	300	320	Warehouse(K)	1	250	270
	2	210	230		2	350	310		2	220	280
	3	220	220		3	300	290		3	230	270

〈Table 3〉 Supplying costs for raw materials from supply points to plants

Period (t)		1		2	
Raw material (n)		1	2	1	2
Supply Point (I)	Plant(M)				
1	1	5	8	6	4
2		6	9	4	5
3		5	6	8	5
1	2	7	5	5	6
2		5	6	8	5
3		7	5	5	6
1	3	5	8	6	4
2		6	9	4	5
3		5	6	8	5

〈Table 4〉 Transportation costs for products from plants to warehouses

Period (t)		1		2	
Product (j)		1	2	1	2
Plant(M)	Warehouse(K)				
1	1	8	7	8	7
2		9	8	8	9
3		8	9	8	9
1	2	9	8	8	9
2		8	9	8	9
3		9	8	8	9
1	3	8	9	8	9
2		9	8	8	9
3		9	8	8	9

〈Table 5〉 Distribution costs for products from warehouses to customers

Period (t)		1		2	
Product (j)		1	2	1	2
Warehouse(K)	Customer(L)				
1	1	12	11	11	12
2		11	12	13	11
3		12	15	11	11
1	2	13	11	12	12
2		12	11	11	12
3		11	12	13	11
1	3	12	15	11	11
2		13	11	12	13
3		13	11	12	13

〈Table 6〉 Distribution costs for products from plants to customers

Period (t)		1		2	
Product (j)		1	2	1	2
Plant (M)	Customer (L)				
1	1	15	18	16	15
2		17	15	17	16
3		16	14	19	19
1	2	15	19	17	20
2		15	18	16	15
3		17	15	17	16
1	3	16	14	19	19
2		15	19	17	20
3		15	19	17	20

〈Table 7〉 Supplying times for raw materials from supply points to plants

Period (t)		1		2	
Raw material (n)		1	2	1	2
Supply Point (I)	Plant(M)				
1	1	0.3	0.4	0.2	0.3
2		0.6	0.4	0.4	0.4
3		0.4	0.5	0.4	0.5
1	2	0.4	0.5	0.5	0.3
2		0.3	0.3	0.2	0.2
3		0.6	0.4	0.6	0.4
1	3	0.3	0.4	0.3	0.2
2		0.6	0.4	0.5	0.4
3		0.4	0.3	0.4	0.5

〈Table 8〉 Transportation times for products from plants to warehouses

Period (t)		1		2	
Product (j)		1	2	1	2
Plant(M)	Warehouse(K)				
1	1	0.8	0.4	0.4	0.6
2		0.5	0.5	0.3	0.4
3		0.4	0.4	0.8	0.4
1	2	0.8	0.5	0.7	0.3
2		0.8	0.4	0.6	0.4
3		0.9	0.7	0.7	0.5
1	3	0.5	0.3	0.4	0.5
2		0.5	0.5	0.7	0.4
3		0.5	0.5	0.7	0.7

〈Table 9〉 Distribution times for products from warehouses to customers

Period (t)		1		2	
Product (j)		1	2	1	2
Warehouse(K)	Customer(L)				
1	1	0.9	1.1	0.9	0.9
2		0.8	0.9	0.9	0.8
3		0.7	0.8	0.7	0.7
1	2	0.9	0.7	0.8	0.7
2		1.0	0.9	0.9	0.8
3		0.9	1.0	1.1	0.9
1	3	0.8	0.9	1.0	0.8
2		0.9	0.8	0.9	1.0
3		0.9	0.9	1.0	0.9
1	4	0.6	0.6	0.6	0.6
2		0.6	0.6	0.6	0.6
3		0.6	0.6	0.6	0.6

〈Table 10〉 Distribution times for products from plants to customers

Period (t)		1		2	
Product (j)		1	2	1	2
Plant (M)	Customer (L)				
1	1	1.6	1.4	1.9	1.9
2		2.0	2.1	1.7	1.9
3		1.4	1.5	1.3	1.0
1	2	1.1	1.2	1.4	1.7
2		1.6	1.4	1.9	1.9
3		2.0	2.1	1.7	1.9
1	3	1.4	1.5	1.3	1.0
2		1.1	1.2	1.4	1.7
3		1.1	1.2	1.4	1.7
1	4	1.0	1.0	1.0	1.0
2		1.0	1.0	1.0	1.0
3		1.0	1.0	1.0	1.0

〈Table 11〉 Maximum number of each facility

Period (t)	1	2
Supply point (I)	7	7
Plant (M)	3	3
Warehouse (K)	3	4

〈Table 12〉 Amount of raw materials used to produce a unit of product

Plant(M)	1				2				3			
Product(j)	1		2		1		2		1		2	
Raw material(n)	1	2	1	2	1	2	1	2	1	2	1	2
	4	3	3	4	3	3	5	4	2	3	4	5

The analytic model is solved using the weighting method with equal weights for the two objectives. However, notice that weights may not be meaningful unless the objectives are of the same order of magnitude.

5.1 Scaling the Objective Functions

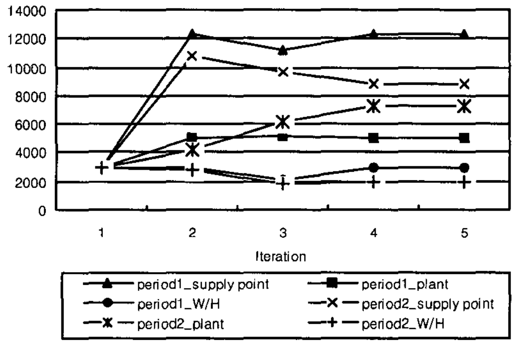
In general, three philosophies are available for re-scaling the objective functions: (a) normalization, (b) use of 10 raised to an appropriate power, and (c) the application of range equalization factors (Steuer [10]). Our purpose is numerical (i.e., to bring all objective function coefficients into the same order of magnitude). In this case, normalization is likely to change the coefficients to unrecognizable numbers. The recognition of each coefficient is retained with 10 raised to an appropriate power because only the decimal point moves. All the objective functions re-scaled by using 10 raised to an appropriate power. The first objective is re-scaled by 10^{-2} and the second objective by 10^{-1}. In this way, all objective function coefficients are brought into the same order of magnitude, yet the recognition of the objective function coefficients is retained.

5.2 Experimental Results

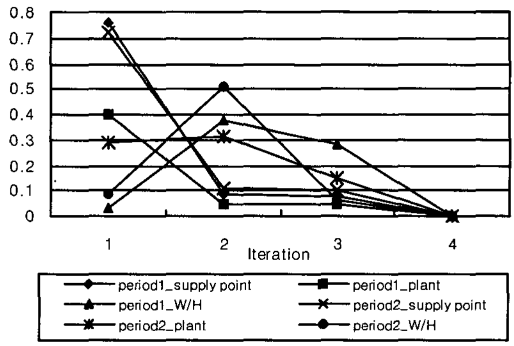
For random machine and vehicle operations, it is supposed that mean time between failure (MTBF) for each vehicle follows exponential distributions with mean of 100 unit times and mean time to repair (MTTR) follows normal distribution with mean of 10 unit times and variance of 1 unit time. Operation time of the each facility is 3,000 unit time per period, which is assumed from a simple calculation by multiplying the initial unit processing time(transportation or distribution) for a unit product by the number of that product. The analytic model provides the optimal solutions with initially given operation time. Then, simulation model performs the solutions from the analytic model and provides the simulation flow time. These simulation times are used as new operation times for the analytic model. The analytic model with new operation times provides new optimal solutions which will be run by the simulation model.

When we consider random failures into the simulation model, we need to simulate more than one run in order to estimate mean flow times. The independence of replications is accomplished by using different random numbers for each replication. In the research, results from 10 runs of the simulation model are averaged to calculate mean flow times. Although convergence is not guaranteed in general, this procedure resulted in convergence of expected rate with reasonable number of iterations. The results derived by the proposed iterative approach in the case of simulated random failures and repair times are displayed in <Table 13> and plotted in [Figure 3] and [Figure 4].

From <Table 13> and [Figure 3], it is noted that initially given operation times are not realistic. Through the proposed approach, it is verified that there exist big differences between



[Figure 3] Operation times by the proposed approach



[Figure 4] Difference rates in operation times

<Table 13> Operation times from the proposed approach

Iteration #	Period 1			Period 2		
	Supply point	Plant	Warehouse	Supply point	Plant	Warehouse
Initial	3000	3000	3000	3000	3000	3000
1	12271	4979	2901	10762	4236	2755
D.R.	0.76	0.40	0.03	0.72	0.29	0.09
2	11242	5222	2095	9709	6171	1826
D.R.	0.09	0.05	0.38	0.11	0.31	0.51
3	12271	4979	2901	8854	7235	1940
D.R.	0.08	0.05	0.28	0.10	0.15	0.06
4	12271	4979	2901	8854	7235	1940
D.R.	0	0	0	0	0	0

D.R. : Difference Rate

〈Table 14〉 Optimal plan from the proposed approach

		Supply point			Plant point			Warehouse point		
		*I*1	*I*2	*I*3	*M*1	*M*2	*M*3	*K*1	*K*2	*K*3
Period 1	Open	O	O	O		O	O	O	O	
	R.M.	780	1525	780		1525	1560			
	P.					305	260	150	60	
Period 2	Open	O	O			O	O	O		O
	R.M.	2000	750			1250	1500			
	P.					250	250	80		120

R.M. : Raw Material, P : Product, O : Open facility

assumed operation times and realistic operation times.

In [Figure 4], difference rates in operation times are rapidly reduced as iteration is increased.

Note that, the difference rate is 0 after 4 iterations. Because analytic model solutions are exactly the same after iteration 4 and the facility location plan with operation times of the iteration 4 is accepted as the optimal plan.

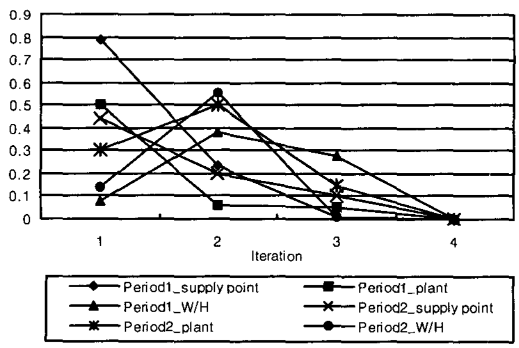
The final optimal solution with realistic operation times obtained by the proposed approach is shown in <Table 14> which suggests that opening of all 3 supply points, plant *M*2 and *M*3, warehouse *K*1 and *K*2 in period 1 and closing of supply point *I*3, plant *M*1, warehouse *K*2 in period 2. The solution also provides logistic flow which is the amount of raw materials and products transported among open facilities.

Although convergence is not guaranteed all the time, we performed additional experiments to ensure the robustness of the proposed hybrid approach in this paper. We could execute many different types of experiments according to the experimental combinations of processing times (transportation, distribution), times of failure and repair, options of routes among each logistic point. Among many options, only MTBF and MTTR of vehicles in the model are considered for convenience and simplicity. Additional experiments executed are shown in <Table 15>.

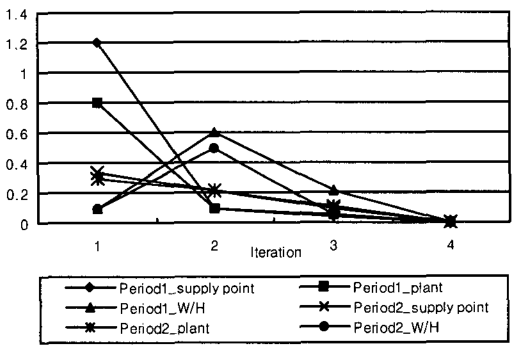
As shown in [Figure 5], [Figure 6] and [Figure 7], different rates in operation times are rapidly decreased as iteration is increased. That is pretty much the same as the initial experiment. Therefore, we are sure that the usefulness of the proposed approach in the field of practice.

〈Table 15〉 Experimental combinations

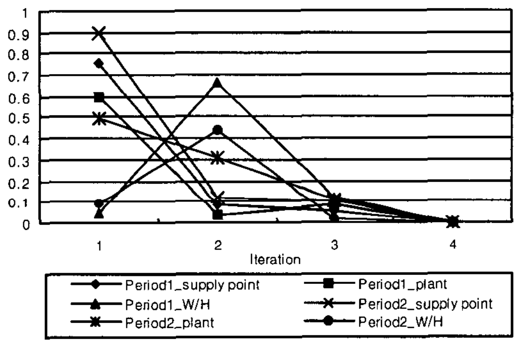
Experiment	MTBF	MTTR
Initial	Exp(100)	N(10, 1)
Option #1	Exp(200)	N(10, 1)
Option #2	Exp(50)	N(10, 1)
Option #3	Exp(100)	N(20, 2)



[Figure 5] Difference rates in operation times of additional experiment(option #1)



[Figure 6] Difference rates in operation times of additional experiment(option #2)



[Figure 7] Difference rates in operation times of additional experiment(option #3)

6. Conclusion

The FLP problem has been considered as one of major subjects for economic management in SCM. Most of analytic models representing FLP problems have dealt with 2-stage, multi- product, multi-facility, multi-period and their objectives functions have mostly been expressed by a single measure. However, for more realistic supply chain design, 3-stage system describing supply points, plants, warehouses and customer zones should be considered in the integrated environment of supply chain and also the delivery time should be treated as one of the measure of objective functions. Because delivering required amount of products to customers on time is a major concern in SCM.

Therefore, in this research, the MIP model is set up for solving 3-stage FLP problem and delivery time has been regarded as one of objective function measure for the MIP model. We recognize that the consideration of delivery time affects heavily the locations of facilities in supply chain.

Operation times in most of analytic models of FLP problem have been previously known or fixed. But for obtaining realistically optimal plan from the analytic model, operation times that are the certain time periods for operating of each facility to produce and distribute required materials or products should be treated as dynamic factors. Therefore, these factors of the proposed MIP model are adjusted by the results from the simulation model in this research.

Through the proposed MIP model representing 3-stage supply chain with considering delivery times and realistic operation times, we show more practically optimal plan for where and when to locate which facilities and how much of each raw material or product should be transported among facilities in supply chain are obtained.

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