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The Production-Distribution Problem in the Supply Chain Network using Genetic Algorithm

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Abstract

This study deals with finding an optimal solution for minimizing the total cost of production and distribution problems in supply chain network. First, we presented an integrated mathematical model that satisfies the minimum cost in the supply chain. To solve the presented mathematical model, we used a genetic algorithm with an excellent searching ability for complicated solution space. To represent the given model effectively, the matrix based real-number coding schema is used. The difference rate of the objective function value for the termination condition is applied. Computational experimental results show that the real size problems we encountered can be solved within a reasonable time.

Keywords: Supply chain network – Genetic algorithm – Production and distribution problem

INTRODUCTION

As the organization of companies becomes more complicated and diversified, and as the competition among companies is becoming more intense, the interest for supply chain is increasing. The supply chain is largely divided into the supply stage where raw materials are supplied to, the production stage where products are produced and assembled, and the distribution stage where the products are transported to the DCs(Distribution Centers) and customers according to demand. The previous studies have mainly investigated each stage separately without considering the complex interactions between production and distribution activities in the supply chain network. Recently, an integrated production and distribution problem, which concerns each stage in supply chain network simultaneously, is widely investigated. The integrated production and distribution problem is a very complicated problem due to its many variables and constraints. Therefore, many techniques were applied to find the best solution for this problem within a reasonable time. We shall introduce some studies that deal simultaneously with production and distribution problems. Bylka (1999) presented a distribution and inventory decision model under single-vendor, multi-buyer, single-product, and multi-period circumstances. Moreover, Erengüç et al. (1999) reviewed the study of the integrated production/distribution planning in supply chains. They proposed the framework for analyzing supply chains and identified the relevant decisions at each stage of the supply chain. Chandra and Fisher (1994) performed studies on the production scheduling and vehicle routing problems in order to minimize the fixed, inventory and delivery costs in the single production facility, multi-product circumstances. Flipo and Finke (2001) performed studies by modeling the production-distribution problems as a multi-facility, multi-product, multi-period network flow problem. Burn et al. (1985) performed studies on the shipment of the completed products in order to minimize the production, maintenance, and delivery costs for the simplified manufacturing system. Williams (1981) developed the heuristic algorithm of the joint production-distribution scheduling, which decides the batch size in order to minimize the average inventory maintenance cost in a given period. Cohen (1998) studied on the stochastic demand in the multi stage production-distribution system. Zuo (1991) studied on the heuristic model which assigns products to the production plant from the large scale agricultural production and distribution system. Kim and Lee (2000) presented a multi-stage production and distribution-planning problem under the capacity restriction conditions. Sim and Park (2000) used a heuristic method to solve similar problems. Also, Syarif et al. (2002) used a GA to solve the supply network problems.

This study focuses the inventory, production and transportation problems in the supply chain network. This problem is well known as an NP-hard problem. We presented mathematical models to solve the integrated production and distribution problem in the supply chain network. As the solution method, the matrix-based genetic algorithm is proposed. We implemented our proposed model using a commercial genetic algorithm-based optimizer, Evolver for Microsoft Excel, and showed that the solution can be obtained within a relatively reasonable time. This paper is organized as follows: In Section 2, details of the problem are described and the mathematical model for this problem is given. We describe the structures of the genetic algorithm and the problem solving process in Section 3. In Section 4, computational experiment results are provided and discussed for this problem. Finally, some concluding remarks are presented in Section 5.

MATHEMATICAL MODEL

In order to satisfy the customer's demand for various products with a minimum cost, we should determine how many products are produced and transported. Fig. 1 is an example of the integrated supply chain model. Our study represents the problem with three stages for an effective cost analysis. The first stage is a supplier stage. At the supplier stage, suppliers produce raw materials. The second stage is a factory stage. At the factory stage, the raw materials from the suppliers are transformed into the final products. The last stage is a distribution center stage. In the integrated supply chain model, the production plants are determined and the proper amount of production and transportation that can satisfy all capacities and demands with a minimum cost is assigned to each plant. In this study, the model using a mixed integer linear programming is proposed. The model is represented as follows.

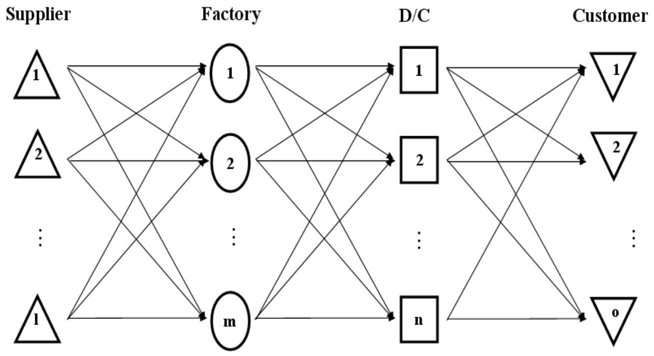

Figure 1: The supply chain network

Problem assumptions, parameters and variables

Assumption

We impose the following assumptions to design the mathematical model. First, multi-product and multi-period are considered. Second, the customer's demand at each period is given.

Indices

i : number of sources ($i = 1, 2, \ldots , i$)

p : number of products ($p = 1, 2, \ldots, p$)

s : number of suppliers ($s = 1, 2, \ldots, s$)

f : number of factories ($f = 1, 2, \ldots, f$)

d : number of distribution centers ($d = 1, 2, \ldots, d$)

c : number of customers ($c = 1, 2, \ldots, c$)

t : number of periods($t=1,2\ldots, t$)

Parameters

S_s : fixed cost at supplier s

S_f : fixed cost at factory f

S_d : fixed cost at DC d

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

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

CP_{is} : unit cost of producing of source i at supplier s

CP_{pf} : unit cost of producing of product p at factory f

K_{pd} : capacity for product p at DC d

K_{pf} : capacity for product p at factory f

K_{is} : capacity for the source i at supplier s

TD : capacity for all DCs

TF : capacity for all factories

TS : capacity for all suppliers

Variables

P^t_{is} : production amount of raw material i at supplier s at end of period t

P^t_{pf} : production amount of product p at factory f at end of period t

I^t_{is} : inventory amount of raw material i at supplier s at end of period t

I^t_{if} : inventory amount of raw material i at factory f at end of period t

I^t_{pf} : inventory amount of product p at factory f at end of period t

I^t_{pd} : inventory amount of product p at DC d at end of period t

T^t_{isf} : transportation amount of raw material i at supplier s to factory f at end of period t

T^t_{pdf} : transportation amount of product p at factory f to DC d at end of period t

T^{t}_{pdc} : transportation amount of product *p* at DC *d* to customer *c* at end of period *t*

B^{t}_{ifs} : demand of raw material *i* at factory *f* to supplier *s* at end of period *t*

B^{t}_{pdf} : demand of product *p* at DC *d* to factory *f* at end of period *t*

$$Z_s = \begin{cases} 1, & \text{if production takes place at supplier } s \\ 0, & \text{otherwise} \end{cases}$$

$$Z_f = \begin{cases} 1, & \text{if production takes place at factory } f \\ 0, & \text{otherwise} \end{cases}$$

$$Z_d = \begin{cases} 1, & \text{if DC } d \text{ is opened} \\ 0, & \text{otherwise} \end{cases}$$

Mathematical model formulation

Supplier stage

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

s.t.

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

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

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

At the supplier stage, the objective function is to minimize the production, inventory, maintenance and fixed costs of raw materials. The constraint (1) is concerned with the raw material inventory at suppliers during any given period. Constraint (2) is the binary variable of the supplier.

Factory stage

$$\min z = \sum_t \sum_p \sum_f I^t_{pf} h_{pf} + \sum_t \sum_i \sum_f I^t_{if} h_{if} + \sum_f S_f Z_f$$
$$+ \sum_t \sum_p \sum_f P^t_{pf} CP_{Pf} + \sum_t \sum_p \sum_f \sum_d T^t_{pdf} CT_{pdf}$$

s.t.

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

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

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

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

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

At the factory stage, the objective function is to minimize the sum of the fixed, inventory, production, and transportation costs. Constraint (4) means that the total amount of purchasing at factories equals the total amount of transportation at suppliers. Constraint (5) is concerned with the inventory of products at factory during any given period, and Constraint (6) is concerned with the inventory of raw materials at factory during any given period. Constraint (7) is the binary variable of the factory.

Distribution center stage

$$\min z = \sum_t \sum_d \sum_p I^t_{pd} h_{pd} + \sum_d S_d Z_d + \sum_t \sum_p \sum_f \sum_d T^t_{pcd} CT_{pcd}$$

s.t.

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

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

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

$$Z_d \in \{0,1\} \qquad \forall d \qquad (12)$$

$$I^t_{pd}, B^t_{pdf}, T^t_{pcd}, T^t_{pdf} \geq 0 \qquad \forall f, \forall c, \forall t, \forall p, \forall d \qquad (13)$$

The objective function at the DC stage is to minimize the sum of the fixed, inventory, and transportation costs. Constraint (9) means that the total amount of purchasing at DCs equals the total amount of transportation at factories. Constraint (10) is concerned with the inventory of products at DC during any given period, and constraint (11) ensures that the transportation amount should not exceed the capacity of DCs. Constraint (12) is the binary variable of DC.

It can be the optimal supply chain network that minimizes the inventory, production and transportation costs if each stage model can be integrated into one.

GENETIC ALGORITHM

Genetic algorithm is widely used as a method to solve the complicated optimization problems. The algorithm is easily applied to all optimization problems, and it has an excellent searching ability for complicated solution spaces. It is very suitable for solving large-scale mathematical problems with many variables and constraints and has merits of easily adding constraints or altering objective functions. A general procedure of a genetic algorithm is as follows.

```
begin
   t ← 0;
   initialize P(t);
   evaluate P(t) ;
   while (not termination condition) do
   begin
      recombine P(t) to yield C(t);
      evalutate C(t);
      select P(t+1) from P(t) and C(t);
      t ← t + 1 ;
   end
end
```

Representation of the chromosome

The first step in building a genetic algorithm is to present the potential solution as a genetic representation. The representation may be dependent on the problem to be solved. In this study, real encoding is applied to design constraints easily. Chromosomes of real encoding were presented as a matrix-based representation. This study considered 3 suppliers, 3 factory, 3 distribution centers and 3 customers.

Figure 2 shows the representation of chromosome at the period *t*. The first, second and third sub-strings are the binary variables at suppliers, factories, and DCs. The fourth is a decision variable for the total amount of transportation to customer. The fifth and sixth are the decision variables for the total amount of transportation to DCs and the total inventory at DCs. The next 3 sub-strings represent the decision variables for the amount of transportation to factories and the amount of production and inventory at factories. The last two sub-strings represent the decision variables for the amount of production of raw materials and the total inventory at suppliers.

Genetic operations

Crossover

The crossover operation used in this study is a uniform crossover. When selecting a pair of parent chromosomes, the uniform crossover produces a template, exchanges parental genes on '1' in the template, and produces their offsprings. The exchanged genes are determined by a template, and the template is randomly produced. In Fig. 3, the crossover operation in this study is shown.

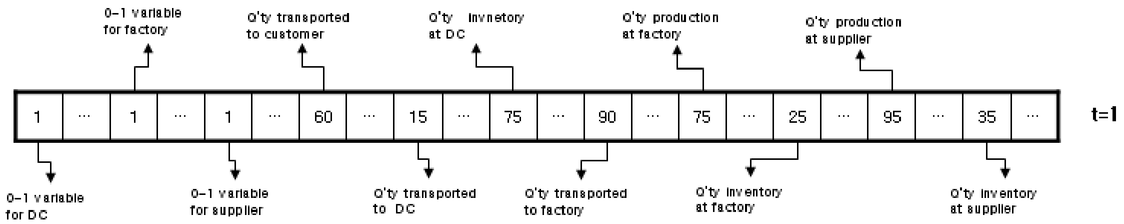

Figure 2: The illustration of representation

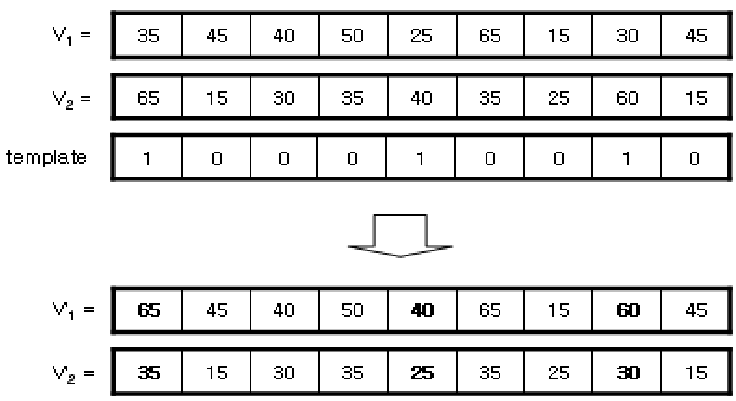

Figure 3: The illustration of crossover operation

Mutation

The mutation randomly alters genes during the process of copying a chromosome from one generation to the next. After producing random variable between 0 and 1 for each gene, if a variable gets a number that is less than or equal to the mutation rate, then that variable is mutated. The chromosome genes are real numbers. If mutated, the number of swapping exchanged into randomly occurred values between the upper and lower limit of constraints. In Fig. 4, the mutation operation in this study is shown.

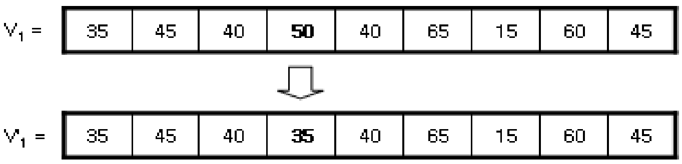

Figure 4: The illustration of mutation operation

Selection

The selection in this study uses a rank-based selection which is known as the simplest and most effective way to control selection. This is designed to improve the problems of the early convergence of roulette wheel selection (Whitely, 1989). In the selection, the rank is determined according to the fitness size, and an individual is selected through a stochastic universal sampling.

Constraints

When applying a genetic algorithm for complicated optimization problems, it is important to consider how to deal with the constraints. Because the presented problem in this study has many constraints, the genetic operator can produce an infeasible solution. Recent studies have proposed a few strategies dealing with the constraints. The strategies are classified into rejecting strategy, repairing strategy, modifying genetic operator strategy, penalty strategy (Michalewicz 1991, Michalewicz 1996, Gen 1997). The strategy in this study is a repairing strategy. When the produced offspring chromosome violates the constraints, it is sent to the parent chromosome until being a feasible solution.

Termination condition

Generally, the 2 cases are used as the termination conditions. First, the GA is terminated when reaching the given generation. Secondly, When there is no change in solution improvement during the given computation time, the generation is terminated. This study considers the second case as the termination condition. The generation stops when the difference rate between the preceding best solution and the current best solution is close enough to be acceptable. Then, we assume that we found the optimal solution.

EXPERIMENTS AND RESULTS

Computational experiments have been provided in order to demonstrate the effectiveness and reasonability of the proposed mathematical model. Considering the complexity of solving such a model, we have applied a genetic algorithm. We implement our proposed model using a commercial genetic algorithm-based optimizer, Evolver for Microsoft Excel. The proposed model is tested by using the conditions for the test problem given in Table 1. The initial inventory at each stage for the test problem is given in Table 2. The capacity, demand and the fixed cost are given in Table 3, and the related costs at each stage are given in Tables 4 through 10. As for the genetic operator parameters, the crossover rate is set to 0.5 and the mutation rate is set to 0.1. The population size is 30 and the number of the generation is set to perform every 1000 times.

Table 1: The condition for the test problem

Number of suppliers	Number of factories	Number of DCs	Number of customers	Number of products and raw materials
3	3	3	3	2

Table 2: Initial Inventory

Products(Sources)	DCs			Factories			Suppliers		
	1	2	3	1	2	3	1	2	3
1	200	200	130	240	220	250	180	160	120
2	250	200	140	240	180	150	300	280	300

Table 3: Capacity, demand and fixed cost

Suppliers			Factories			DCs		
Source capacity		Fixed cost	Product capacity		Fixed cost	Product capacity		fixed cost
1	2		1	2		1	2	
200	200	25000000	150	150	60000000	150	150	15000000
200	200	30000000	150	150	70000000	150	150	20000000
200	200	20000000	150	150	80000000	150	150	10000000

Table 4: Shipping cost to factory

Source1	Factories			Source2	Factories		
Suppliers	1	2	3	Suppliers	1	2	3
1	4000	1000	6000	1	1500	1500	3000
2	2000	3500	2500	2	5000	4000	3000
3	2500	3500	4000	3	3000	3000	2000

Table 5: Shipping cost to DC

Product1	DCs			Product2	DCs		
Factories	1	2	3	Factories	1	2	3
1	9000	13000	6000	1	9500	10500	12000
2	6000	4500	5000	2	6500	6500	6000
3	3000	4500	12000	3	7500	5000	5500

Table 6: Shipping cost to customer

Product1	Customers			Product2	Customers		
DC	1	2	3	DC	1	2	3
1	6000	1000	2000	1	6000	1000	2000
2	1400	5400	2500	2	1400	5400	2500
3	3500	1000	5000	3	3500	1000	5000

Table 7: Production cost at supplier

Supplier 1		Supplier 2		Supplier 3	
Source1	Source2	Source1	Source2	Source1	Source2
300	100	400	300	200	400

Table 8: Production cost at supplier

Supplier 1		Supplier 2		Supplier 3	
Source1	Source2	Source1	Source2	Source1	Source2
400	500	300	600	200	400

Table 9: Inventory cost at supplier

Supplier 1		Supplier 2		Supplier 3	
Source1	Source2	Source1	Source2	Source1	Source2
8	13	10	15	15	10

Table 10: Inventory cost at supplier

Supplier 1		Supplier 2		Supplier 3	
Source1	Source2	Source1	Source2	Source1	Source2
30	25	50	40	35	30

Table 11: Experiment results

Generation #	Total cost	Difference rate	Generation #	Total cost	Difference rate
1000	730,476,890	·	11000	540,821,425	0.00222
2000	607,104,570	0.20321	12000	539,746,845	0.00199
3000	589,426,960	0.02999	13000	538,711,050	0.00192
4000	577,370,155	0.02088	14000	537,689,005	0.00190
5000	568,806,500	0.01506	15000	536,699,550	0.00184
6000	561,638,350	0.01276	16000	535,765,565	0.00174
7000	553,160,350	0.01533	17000	534,897,015	0.00162
8000	548,274,785	0.00891	18000	534,057,485	0.00157
9000	544,196,230	0.00749	19000	533,210,470	0.00159
10000	542,023,840	0.00401	20000	532,371,795	0.00158

Table 11 shows the experiment results of the total cost and difference rate. Fig. 5 shows the change of objective function values. Fig. 6 shows the change of the difference rates in objective function values. When the difference rate is less than 0.2% after 12000 generations, the generation is terminated. The optimal solution for this experiment is 539,746,845.

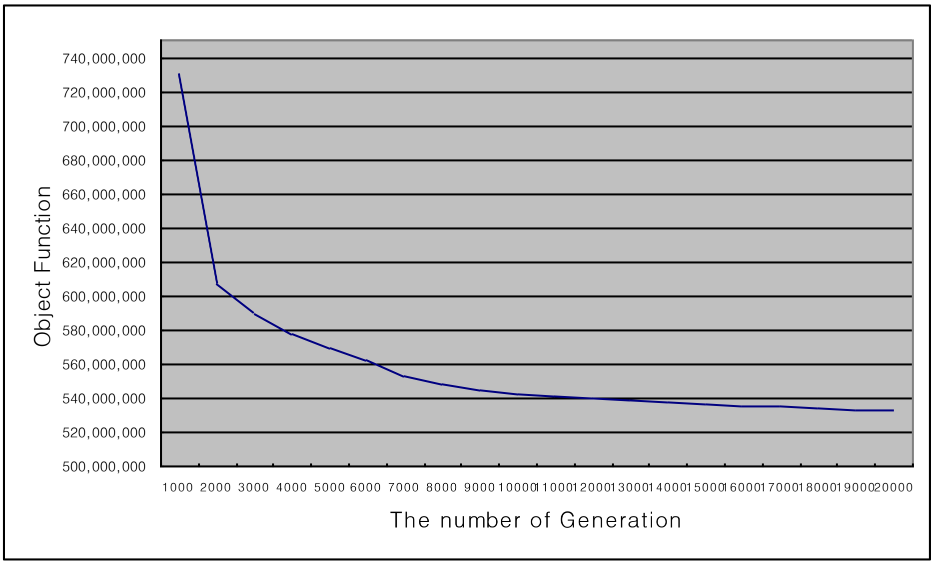

Figure 5: Best solutions in each generation

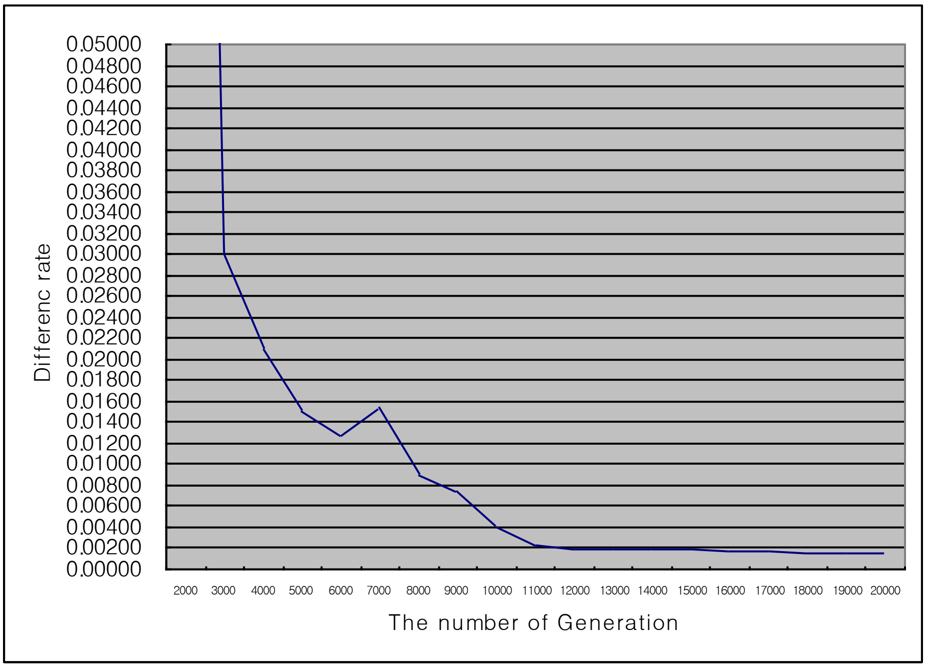

Figure 6: Difference rates of the best solutions in each generation

Table 12 through 19, we show that the best production and distribution planning for this problem is given by our represented model.

Table 12: Results of the amount of transportation to factory in each period

Periods	Source1	Factories			Source2	Factories		
	Suppliers	1	2	3	Suppliers	1	2	3
t=1	1	96	96	99	1	99	92	113
	2	86	105	103	2	132	98	102
	3	92	118	118	3	90	95	107
t=2	1	104	122	95	1	91	116	101
	2	78	89	103	2	103	103	97
	3	97	117	87	3	94	83	100
t=3	1	84	108	76	1	99	102	78
	2	92	98	112	2	86	78	105
	3	100	104	97	3	101	113	116
t=4	1	111	96	110	1	73	113	97
	2	78	100	113	2	81	89	117
	3	92	101	94	3	102	98	108

Table 13: Results of the amount of transportation to DC in each period

Periods	Product1	Customers			Product2	Customers		
	DCs	1	2	3	DCs	1	2	3
t=1	1	74	55	70	1	77	76	51
	2	13	49	70	2	43	80	62
	3	51	46	82	3	59	54	61
t=2	1	76	65	66	1	51	80	74
	2	39	61	71	2	78	53	56
	3	59	51	32	3	52	77	60
t=3	1	43	73	92	1	79	38	70
	2	104	71	60	2	89	71	76
	3	66	66	78	3	57	44	57
t=4	1	79	83	63	1	71	51	78
	2	96	80	83	2	66	58	73
	3	73	91	72	3	49	58	92

Table 14: Results of the amount of production at supplier in each period

Periods	Supplier 1		Supplier 2		Supplier 3	
	Source1	Source2	Source1	Source2	Source1	Source2
t=1	321	286	161	300	370	227
t=2	306	384	251	274	270	331
t=3	330	391	294	297	266	279
t=4	352	386	291	255	359	214

Table 15: Results of the amount of transportation to customer in each period

Periods	Product1	Customers			Product2	Customers		
	DCs	1	2	3	DCs	1	2	3
t=1	1	107	88	108	1	108	95	84
	2	107	103	88	2	53	83	85
	3	94	68	80	3	73	80	86
t=2	1	71	67	69	1	65	91	97
	2	86	58	85	2	85	63	93
	3	78	78	63	3	87	70	82
t=3	1	80	84	51	1	70	78	85
	2	56	73	80	2	78	89	89
	3	86	89	71	3	90	65	62
t=4	1	61	84	100	1	79	84	83
	2	67	101	81	2	83	67	70
	3	88	82	81	3	82	48	87

Table 16: Results of the amount of production at factory in each period

Periods	Factory 1		Factory 2		Factory 3	
	Product1	Product2	Product1	Product2	Product1	Product2
t=1	153	197	163	176	198	163
t=2	129	112	160	218	191	163
t=3	160	134	150	109	181	139
t=4	152	113	144	142	176	141

Table 17: Results of the amount of inventory at supplier in each period

Periods	Supplier 1		Supplier 2		Supplier 3	
	Source1	Source2	Source1	Source2	Source1	Source2
t=1	210	282	27	248	162	235
t=2	195	358	8	219	131	289
t=3	257	470	0	488	96	238
t=4	292	573	0	456	168	144

Table 18: Results of the amount of inventory at factory in each period

Periods	Factory 1		Factory 2		Factory 3	
	Product1	Product2	Product1	Product2	Product1	Product2
t=1	199	233	251	171	269	139
t=2	121	140	240	182	318	113
t=3	73	87	155	55	289	94
t=4	0	0	40	0	229	36

Table 19: Results of the amount of inventory at DC in each period

Periods	DC 1		DC 2		DC 3	
	Product1	Product2	Product1	Product2	Product1	Product2
t=1	35	142	52	189	110	75
t=2	2	70	0	158	60	46
t=3	0	62	1	55	44	32
t=4	3	2	6	2	11	58

CONCLUDING REMARKS

In this study, we represented the mathematical model considering the multi-stage, multi-product, multi-period in the supply chain network. The given model has many decision variables and constraints and requires lots of computation time. Considering the complexity of the model, the genetic algorithm has been applied for solving this model. We used a real-number coding as the genetic representation to represent the given model effectively. We considered the repair strategy as the constraints and difference rate of the objective function value as termination condition. Computational experimental results show that the real size problems we encountered can be solved within a reasonable time.

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