CHAPTER III

RESEARCH/METHODOLOGY

This chapter describes three parts, the required research equipment, Linear Programming (LP) and applying matrix-based Genetic Algorithm (m-GA) for Logistics Chain Network and testing problems.

Required Research Environment

The properties of a personal computer for this thesis have a processor of Intel Pentium III, 930 MHz and 256 MB of RAM

Package software such as What'sBest! (Student version), MATLAB and MINITAB were used in this research. The What'sBest! which based on Linear Programming method is the add-in software for MS Excel (What'sBest!, 2004). The What's Best! has a limitation on capacity constraints of 150, variables of 300 and integers of 30. The developments of m-GA program were written in MATLAB (Stephen, 2002). The Analyses of Variance of all experimental results were investigated on MINITAB (Ryan, et al., 2005).

Linear Programming (LP) for Logistic Chain Network (LCN)

Formulate the mathematical model of LCN problem and solve it by using LP. For LCN problems from Figure 1, assuming that the number of suppliers, plants, distribution centers (DCs) and customers including their demands and capacities are known in advance, the objective function of total costs to be minimized can be formulated as shown in equation (1) (Pongcharoen, et al., 2005) and equation (2).

The equation (1), the objective function was aimed to minimizing the total transportation costs. It was assumed that the number of products from suppliers was equal to the customer demand. The equation (2), the objective function was aimed to minimizing the total costs. It was assumed that the number of products from supplier was more than the customer demand. Both of the objective functions needed to find the amount of raw material flow from suppliers to plants, the amount of finished goods move from plants to DCs and the amount of finished goods deliver from DCs to customers.

$$\text{Min. } \sum_{i=1}^{I}\sum_{j=1}^{J} a_{ij}x_{ij} + \sum_{j=1}^{J}\sum_{k=1}^{K} b_{jk}y_{jk} + \sum_{k=1}^{K}\sum_{l=1}^{L} c_{kl}z_{kl} \quad (1)$$

Subject to:

$$\sum_{j=1}^{J} x_{ij} \le S_i \quad \text{for all } i. \quad (1.1)$$

$$\sum_{k=1}^{K} y_{jk} \le P_j \quad \text{for all } j. \quad (1.2)$$

$$\sum_{l=1}^{L} z_{kl} \le D_k \quad \text{for all } k. \quad (1.3)$$

$$\sum_{k=1}^{k} z_{kl} = C_l \quad \text{for all } l. \quad (1.4)$$

$$\sum_{i=1}^{I}\sum_{j=1}^{J} x_{ij} = \sum_{j=1}^{J}\sum_{k=1}^{K} y_{jk} = \sum_{k=1}^{K}\sum_{;l=1}^{L} z_{kl} = \sum_{l=1}^{L} C_l \quad (1.5)$$

$$x_{ij}, y_{jk}, z_{kl} \ge 0 \quad \text{for all } i, j, k, l. \quad (1.6)$$

$$\text{Min. } \sum_{i=1}^{I}\sum_{j=1}^{J}(a_{ij}+r_i)x_{ij} + \sum_{j=1}^{J}\sum_{k=1}^{K}(b_{jk}+m_j)y_{jk} + \sum_{k=1}^{K}\sum_{l=1}^{L}(c_{kl}+h_k)z_{kl} + \sum_{j=1}^{J} f_j t_j + \sum_{k=1}^{K} f_k t_k \quad (2)$$

Subject to:

$$\sum_{j=1}^{J} x_{ij} \le S_i \quad \text{for all } i. \quad (2.1)$$

$$\sum_{i=1}^{I} x_{ij} \le P_j t_j \quad \text{for all } j. \quad (2.2)$$

$$\sum_{k=1}^{K} y_{jk} \le P_j \quad \text{for all } j. \quad (2.3)$$

$$\sum_{j=1}^{J} y_{jk} \le D_k t_k \quad \text{for all } k. \quad (2.4)$$

$$\sum_{l=1}^{L} z_{kl} \le D_k \quad \text{for all } k. \quad (2.5)$$

$$\sum_{k=1}^{k} z_{kl} = C_l \quad \text{for all } l. \quad (2.6)$$

$$\sum_{i=1}^{I}\sum_{j=1}^{J}x_{ij}=\sum_{j=1}^{J}\sum_{k=1}^{K}y_{jk}=\sum_{k=1}^{K}\sum_{l=1}^{L}z_{kl}=\sum_{l=1}^{L}C_l \qquad (2.7)$$

$x_{ij}, y_{jk}, z_{kl} \geq 0$ for all *i*, *j*, *k* and *l*. (2.8)

$t_j, t_k = \{0,1\}$ for all *j* and *k* (2.9)

Notation:

i number of suppliers ($i = 1, 2, \ldots, I$)

j number of plants ($j = 1,2, \ldots, J$)

k number of distribution centers ($k = 1, 2, \ldots, K$)

l number of customers ($l = 1, 2, \ldots, L$)

a_{ij} transportation cost per unit of raw material flow from supplier i^{th} to plant j^{th}

b_{jk} carrying cost per unit of finished goods move from plant j^{th} to DC k^{th}

c_{kl} transportation cost per unit of finished goods deliver from DC k^{th} to customer l^{th}

r_i raw material cost per unit of material requirement from suppliers i^{th}

m_j manufacturing cost per unit of production process at plants j^{th}

f_j fixed cost for operating at plants j^{th}

f_k fixed cost for operating at DC k^{th}

h_k holding cost per unit of holding products at DC k^{th}

x_{ij} amount of raw material flow from supplier i^{th} to plant j^{th}

y_{jk} amount of finished goods move from plant j^{th} to DC k^{th}

z_{kl} amount of finished goods deliver from DC k^{th} to customer l^{th}

S_i upper limit of supplier i^{th} can supply

P_j production capacity of plants j^{th}

D_k storage limit of DC k^{th}

C_l is the demand of customer l^{th}

$t_j = \begin{cases} 1 \text{ if production takes place at plant } j \\ 0, \text{otherwise} \end{cases}$

$t_k = \begin{cases} 1 \text{ if DC } k \text{ is opened} \\ 0, \text{otherwise} \end{cases}$

For equation (1), Constraint (1.1), (1.2), (1.3) and (1.4) are capacity limitations for the suppliers, plants, DCs and customers respectively. Constraint (1.5) ensures that the same amount of items is transported in each stage and also meets customer demand. In the case of unbalancing of supply and demand, a dummy supplier or customer may be introduced. The last constrain (1.6) ensures that all variables are not negative value.

For equation (2), Constraints (2.1), (2.3), (2.5) and (2.6) are capacity limitations for the suppliers, plants, DCs and customers respectively. Constraints (2.2) and (2.4) are the capacity constraints for the plants and DCs respectively. Constraint (2.7) ensures that the same amount of items is transported in each stage and also meets customer demand. In the case of unbalancing of supply and demand, a dummy supplier or customer may be introduced. Constrain (2.8) ensures that all variables are not negative value. The last constrain (2.9) ensures that the subset of plants and DCs to be opened or closed.

Matrix-based Genetic Algorithms (m-GA) for LCN.

In this work, matrix-based genetic algorithm (m-GA) is applied to solve three stages logistics chain network problem. The general process of m-GA that mainly included chromosome representation and initialization, genetic operations and chromosome evaluation and selection can be described in followings sub-sections.

1. Chromosome representation and initialization

Matrix-based chromosome representation is used to represent the transportation matrices between parties in the logistics chain network (LCN). For example, in Figure 1, three stages LCN problem consists of four suppliers, six plants, six distribution centres (DCs) and four customers. This give raise three transportation matrices (M) of suppliers to plants (M_{4x6}), plants to DCs (M_{6x6}) and DCs to customers (M_{6x4}). Each matrix is then stretched into a single array called sub-chromosome. Figure 14 shows sub-chromosome representation of a matrix size of 4x6. Considering three stages logistics system, each chromosome representation is therefore integrated of three parts of sub-chromosomes, each of which represents a transportation matrix.

$X_{11}, X_{12}, \ldots, X_{16}$	$X_{21}, X_{22}, \ldots, X_{26}$	$X_{31}, X_{32}, \ldots, X_{36}$	$X_{41}, X_{42}, \ldots, X_{46}$

Figure 14 Sub-chromosome representation for a matrix 4x6.

(Pongcharoen, et al., 2005).

In LCN problem, the process of chromosomes initialization is quite difficult since the first group of chromosomes generated can be infeasible solutions due to capacities constrains for each matrix. Therefore propose a process of chromosome initialization by ensuring all chromosomes generated to be feasible solutions. The process is performed matrix by matrix with considering constrains in each row and column as follows:

Procedure: Sub-chromosome initialization.

The process of sub-chromosome initialization can be divided into two parts; creating sequence number (s/n) and assigning the values for each element (X_{ij}) in the matrix.

Part 1: Creating s/n for all elements (X_{ij}) in the matrix.

Step 1 Generate random value (V_{ij}) between 0 to 1 all elements (X_{ij}) in matrix (M_{IxJ}) (i=1, 2, ...I; j = 1, 2, ..., J).

Step 2 Find an ascending sequence started from 1 to IxJ for all X_{ij} by considering the value of V_{ij}. The X_{ij} with smallest value of V_{ij} will be assigned a sequence number (s/n) = 1 whilst s/n of IxJ will be assigned to the X_{ij}, which has the largest value of V_{ij}. (see Figure 15).

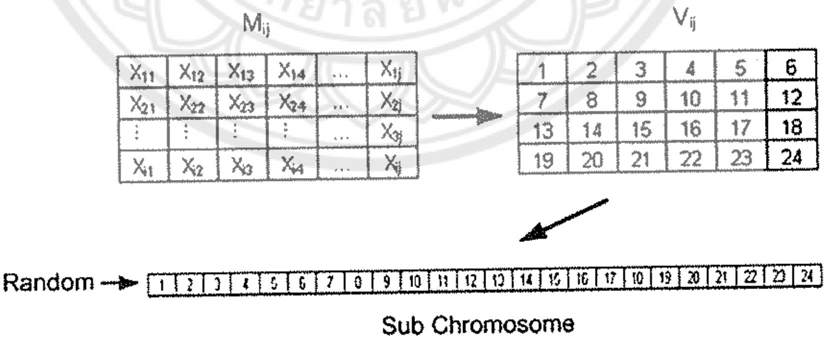

Figure 15 Sub-chromosome initialization in part I (Pongcharoen, et al., 2005).

Part 2: Assigning the values of X_{ij} in the matrix.

Step 1 Set the values of all X_{ij} initially equal to zero

Step 2 Start from the element X_{ij} with s/n = 1, then repeat the following steps until s/n = IxJ.

Step 3 Compare the capacity constraints of row I (ri) and column j (c_j). If $r_i \leq c_j$, then $X_{ij} = X_{ij} + r_i$, $c_j = c_j - r_i$, and set $r_j = 0$. Otherwise, $X_{ij} = X_{ij} + c_j$, $r_i = r_i - c_j$, and set $c_j = 0$.

Step 4 Then increasing the sequence number; s/n = s/n+1.

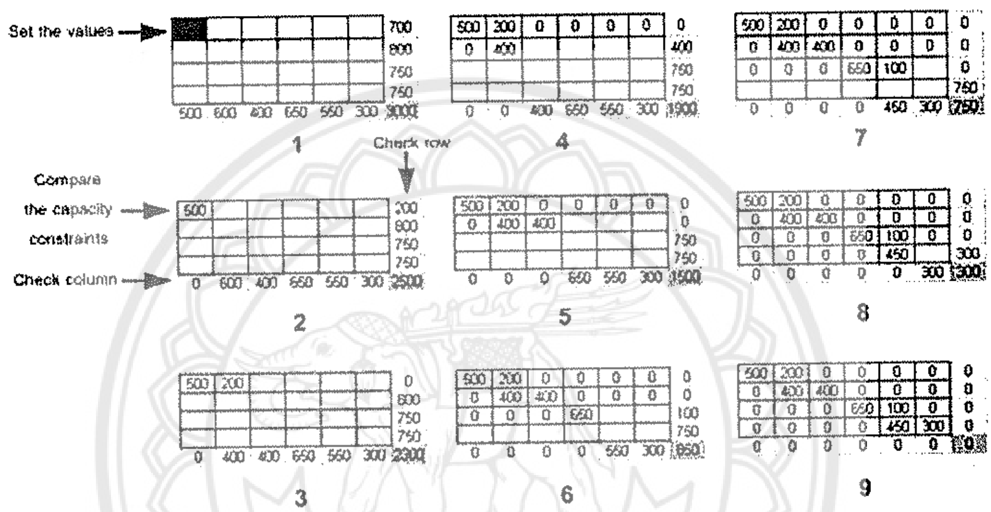

Figure 16 Sub-chromosome initialization in part II (Pongcharoen, et al., 2005).

2. Genetic operations: crossover and mutation

In this work, two types of crossover operations that guarantee feasible offspring are proposed and described as follows;

Crossover type I aims to perform crossover operation in the randomly selected matrix (sub-chromosome). The idea of this operation is borrowed from the process of chromosome initialization, described in the previous section, in order to ensure that offspring are still feasible. The procedure of type I crossover can be described as follows:

Procedure: Crossover type I.

Step 1 Randomly selected similar sub-chromosomes from both parents.

Step 2 Perform one point crossover of sequence number (s/n), that was created during chromosome initialization and marking on each element (X_{ij}) in a matrix

(M_{IxJ}). This step is therefore reproducing two offspring that have new sequence number for each element (X_{ij}) in the matrix (see Figure 17).

Step 3 Follow the process of assigning the values of X_{ij} in the matrix described in part 2 of chromosome initialization procedure for all offspring obtained from step 2.

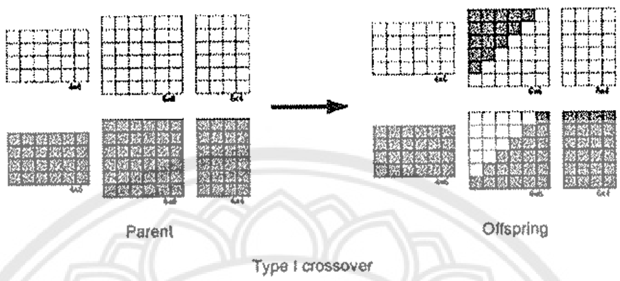

Figure 17 Examples of crossover type I (Pongcharoen, et al., 2005).

Crossover type II is based on the concept of one point crossover by performing between matrices but not in the matrix. For example, two chromosomes are randomly selected as parents, each of which consists of three sub-chromosomes (matrices); M_1, M_2 and M_3 (see Figure 18). A cutting point is randomly generated between matrices and then performing a swap.

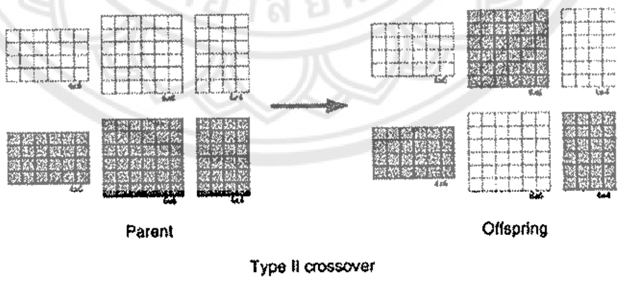

Figure 18 Examples of crossover type II (Pongcharoen, et al., 2005).

Two types of mutation operations that guarantee feasible offspring are proposed in this work and described as follows;

Procedure: Mutation type I.

Step 1 Randomly select a sub-chromosomes in a parent.

Step 2 Randomly choose a gene within the selected sub-chromosome and then perform a swap of sequence number (s/n) between the chosen gene with the successive gene. This step is therefore reproducing an offspring that have new sequence number for each element (X_{ij}) in the matrix (see Figure 19).

Step 3 Perform the process of assigning the values of X_{ij} in the matrix described in part 2 of chromosome initialization procedure for the offspring obtained from step 2.

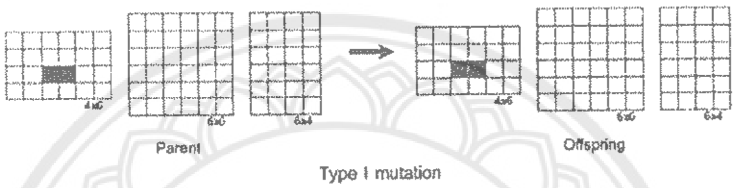

Figure 19 Examples of mutation type I (Pongcharoen, et al., 2005).

Procedure: Mutation type II.

Step 1 Randomly select a sub-chromosomes in a parent.

Step 2 Perform part 1 and 2 of chromosome initialization procedure for the offspring obtained from step 2. This means that a brand new matrix replaces the chosen one (see Figure 20).

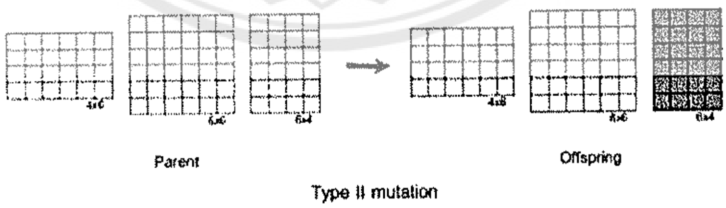

Figure 20 Examples of mutation type II (Pongcharoen, et al., 2005).

3. **Chromosome evaluation and selection**

Chromosome evaluation is usually applied to measure the performance (fitness value) of a candidate solution (individual) by determining an objective (fitness) function. The higher fitness value of individual, the higher its chances to be selected onto the next generation. In this work, the total transportation cost and the total cost between all parties in the logistics chain network as described in section 2 is used as fitness function to measure the performance of the network. The famous chromosome selection called roulette wheel is then applied for randomly choosing the same amount of individual onto the next generation. The m-GA process is repeated until the termination criteria are satisfied.

Testing problems

Testing problems consist three sizes of logistics problems, small, medium and large problem.

1. Small problem

Small problem consists of four suppliers, six plants, six DCs and four customers was considered as a testing problem, where the capacity constraints, customer demand and transportation cost per unit between stages are given in Table 5 and 6. This problem was solved in experiment 1, 2 by LP and GA with two kinds of objective functions. These objective functions are the equation (1) and the equation (2).

Table 5 Capacity constraints and customer demand.

Source	Capacity			Customer Demand
	Supplier	Plant	DC	
1	700	500	400	800
2	800	600	500	700
3	750	400	600	650
4	750	650	350	850
5		550	650	
6		300	500	

Table 6 Transportation cost per unit for each stage.

Suppliers	Plants					
	1	2	3	4	5	6
1	2	5	3	7	5	6
2	4	2	1	3	2	5
3	3	5	4	5	6	2
4	5	3	6	3	4	7
Plants	**Distribution Centres**					
	1	2	3	4	5	6
1	6	5	4	3	4	5
2	4	3	5	2	3	4
3	3	2	2	1	2	3
4	5	4	3	2	4	5
5	3	6	5	4	3	5
6	1	5	7	6	3	4
Distribution Centres	**Customers**					
	1	2	3	4	5	6
1	4	5	6	5	4	5
2	6	3	3	7	6	3
3	4	2	6	8	4	2
4	3	6	4	5	3	6

Table 5 and 6 are the performance of the equation (1). For the performance of the equation (2), the capacity constraints, customer demand and transportation cost per unit between stages are given in Table 7 and 8. Table 9 shows the raw material cost per unit of material requirement from suppliers, manufacturing cost per unit of production process at plants and holding cost per unit of holding products at DCs. Table 10 shows fixed cost for operating at plants and DCs.

Table 7 Capacity constraints and customer demand.

Source	Capacity			Customer Demand
	Supplier	Plant	DC	
1	1000	1000	1000	800
2	1000	1000	1000	700
3	1000	1000	1000	650
4	1000	1000	1000	850
5		1000	1000	
6		1000	1000	

Table 8 Transportation cost per unit for each stage.

Suppliers	Plants					
	1	2	3	4	5	6
1	2	5	3	7	5	6
2	4	2	1	3	2	5
3	3	5	4	5	6	2
4	5	3	6	3	4	7
Plants	**Distribution Centres**					
	1	2	3	4	5	6
1	6	5	4	3	4	5
2	4	3	5	2	3	4
3	3	2	2	1	2	3
4	5	4	3	2	4	5
5	3	6	5	4	3	5
6	1	5	7	6	3	4

Distribution Centres	Customers			
	1	2	3	4
1	4	5	6	5
2	6	3	3	7
3	4	2	6	8
4	3	6	4	5
5	2	5	2	5
6	4	5	3	4

Table 9 The raw material cost per, manufacturing cost and holding cost per unit

Source	Raw material Cost at suppliers	Manufacturing Cost at plants	Holding Cost at DCs
1	2	15	3
2	3	16	4
3	4	14	5
4	5	13	4
5		14	6
6		15	3

Table 10 The fixed cost for operating at plants and Distribution Centres.

Source	Plants	DCs
1	100	300
2	200	200
3	300	200
4	200	100
5	400	300
6	300	400

2. Medium problem

Medium problem consists of eight suppliers, ten plants, ten DCs and eight customers was considered as a testing problem, where the capacity constraints, customer demand and transportation cost per unit between stages are given in Table 11 and 12 Table 13 shows the raw material cost per unit of material requirement from suppliers, manufacturing cost per unit of production process at plants and holding cost per unit of holding products at DCs. Table 14 shows fixed cost for operating at plants and DCs. This problem was solved in experiment 2 by LP and GA. For this experiment used only the equation (2).

Table 11 Capacity constraints and customer demand of medium problem.

Source	Capacity			Customer Demand
	Supplier	Plant	DC	
1	1000	1000	1000	1000
2	1000	1000	1000	600
3	1000	1000	1000	500
4	1000	1000	1000	1000
5	1000	1000	1000	700
6	1000	1000	1000	1000
7	1000	1000	1000	700
8	1000	1000	1000	500
9		1000	1000	
10		1000	1000	

Table 12 Transportation cost per unit for each stage of medium problem.

Suppliers	Plants									
	1	2	3	4	5	6	7	8	9	10
1	3	2	3	2	3	2	3	2	3	2
2	4	3	4	3	4	3	4	3	4	3
3	4	4	3	2	1	3	2	1	2	3
4	2	3	4	3	2	3	2	4	2	3
5	4	3	2	3	3	4	2	3	4	5
6	1	2	3	4	5	6	7	8	9	10
7	2	1	4	3	2	1	5	4	3	5
8	3	8	2	4	1	5	6	5	4	2
Plants	**DCs**									
	1	2	3	4	5	6	7	8	9	10
1	3	4	5	4	3	5	4	5	3	4
2	2	3	4	5	2	3	4	5	2	3
3	1	2	3	4	5	6	5	4	3	2
4	2	4	5	3	2	3	4	2	3	4
5	4	2	1	1	3	2	1	2	3	3
6	1	2	3	2	1	5	6	7	4	2
7	2	3	2	4	2	1	2	3	5	4
8	2	2	2	2	2	2	2	2	2	2
9	3	3	3	3	3	3	3	3	3	3
10	4	4	4	4	4	4	4	4	4	4

Table 12 Transportation cost per unit for each stage of medium problem (CONT).

DCs	Customers							
	1	2	3	4	5	6	7	8
1	2	3	4	5	6	7	8	9
2	1	2	3	4	5	6	7	8
3	3	4	5	6	7	8	9	10
4	8	7	6	5	4	3	2	1
5	2	3	2	3	2	3	2	3
6	4	5	4	5	4	5	4	5
7	5	6	4	5	6	4	5	6
8	6	7	8	7	6	7	8	6
9	5	6	5	6	5	6	5	6
10	5	5	5	5	4	4	4	4

Table 13 The raw material cost per, manufacturing cost and holding cost per unit of medium problem

Source	Raw material Cost at suppliers	Manufacturing Cost at plants	Holding Cost at DCs
1	5	15	3
2	6	14	4
3	4	16	5
4	7	13	6
5	6	12	3
6	5	17	4
7	4	16	5
8	8	15	6
9		14	4
10		13	5

Table 14 The fixed cost for operating at plants and Distribution Centres of medium problem.

Source	Plants	DCs
1	500	500
2	1000	1000
3	500	500
4	1000	1000
5	600	600
6	700	700
7	800	800
8	900	900
9	600	600
10	700	700

3. Large problem

For the large problem consists eight suppliers, sixteen plants, sixteen DCs and eight customers was considered as a testing problem, where the capacity constraints, customer demand and transportation cost per unit between stages are given in Table 15 and 16 Table 17 shows the raw material cost per unit of material requirement from suppliers, manufacturing cost per unit of production process at plants and holding cost per unit of holding products at DCs. Table 18 shows fixed cost for operating at plants and DCs. This problem was solved in experiment 2 for testing only GA model with used only the equation (2).

Table 15 Capacity constraints and customer demand of large problem.

Source	Capacity			Customer Demand
	Supplier	Plant	DC	
1	2000	1000	1000	3000
2	2000	1000	1000	1000
3	2000	1000	1000	1900
4	2000	1000	1000	800
5	2000	1000	1000	1500
6	2000	1000	1000	1300
7	2000	1000	1000	500
8	2000	1000	1000	2000
9		1000	1000	
10		1000	1000	
11		1000	1000	
12		1000	1000	
13		1000	1000	
14		1000	1000	
15		1000	1000	
16		1000	1000	

Table 16 Transportation cost per unit for each stage of large problem.

Suppliers	Plants															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
2	16	15	14	13	12	11	10	17	18	19	20	21	22	23	24	25
3	10	10	10	15	15	15	20	20	20	25	25	25	15	15	15	15
4	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
5	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14
6	11	13	15	17	19	21	23	25	27	29	27	25	23	21	19	17
7	30	25	20	15	10	15	20	25	30	25	20	15	10	15	20	25
8	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10

Table 16 Transportation cost per unit for each stage of large problem (CONT.).

Plants	DCs															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	3	4	5	4	3	5	4	5	3	4	2	3	4	5	2	3
2	4	5	2	3	1	2	3	4	5	6	5	4	3	2	2	4
3	5	3	2	3	4	2	3	4	4	2	1	1	3	2	1	2
4	3	3	1	2	3	2	1	5	6	7	4	2	2	3	2	4
5	2	1	2	3	5	4	2	2	2	2	2	2	2	2	2	2
6	3	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4
7	4	4	4	4	4	4	4	4	5	5	5	5	5	5	5	5
8	6	6	6	6	6	6	6	6	7	7	7	7	7	7	7	7
9	8	8	8	8	8	8	8	8	2	2	2	2	2	2	2	2
10	9	8	7	8	9	8	7	8	9	8	7	8	9	8	7	8
11	3	3	3	3	3	3	3	3	9	9	9	9	9	9	9	9
12	1	2	3	4	5	6	7	8	9	8	7	6	5	4	3	2
13	5	5	6	6	7	7	8	8	9	9	4	4	3	3	2	2
14	5	5	5	6	6	6	7	7	7	8	8	8	9	9	9	4
15	4	4	3	3	3	2	2	2	1	1	1	5	5	5	6	6
16	6	7	7	7	8	8	8	9	9	9	1	1	1	2	2	2

DCs	Customers							
	1	2	3	4	5	6	7	8
1	5	5	5	5	5	5	5	5
2	6	6	6	6	6	6	6	6
3	7	7	7	7	7	7	7	7
4	4	4	4	4	4	4	4	4
5	3	3	3	3	3	3	3	3
6	2	2	2	2	2	2	2	2
7	1	1	1	1	1	1	1	1
8	8	8	8	8	8	8	8	8
9	9	9	9	9	9	9	9	9
10	5	5	5	5	6	6	6	6
11	7	7	7	7	8	8	8	8
12	4	4	4	4	3	3	3	3
13	1	2	1	2	1	2	1	2
14	3	4	3	4	3	4	3	4
15	5	6	5	6	5	6	5	6
16	7	8	7	8	7	8	7	8

Table 17 The raw material cost per, manufacturing cost and holding cost per unit of large problem.

Source	Raw material Cost at suppliers	Manufacturing Cost at plants	Holding Cost at DCs
1	5	15	3
2	6	14	4
3	7	13	5
4	8	16	6
5	9	17	3
6	3	18	4
7	2	19	5
8	4	20	6
9		12	4
10		14	5
11		16	7
12		13	8
13		15	9
14		18	8
15		16	7
16		10	9

Table 18 The fixed cost for operating at plants and Distribution Centres per 1000 units of large problem.

Source	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Plants	2	1	3	4	6	5	2	3	4	5	6	8	7	5	4	3
DCs	2	1	3	4	6	5	2	3	4	5	6	8	7	5	4	3