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Genetic Algorithm Enhancement to Solve Multi Source Multi Product Flexible Multistage Logistics Network

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Abstract

To be successful in today's active business competition, enterprises need to design and build a productive and flexible logistics network. The flexible multistage logistic network (fMLN) problem is NP-hard. The previous papers were considering the problem as a single source logistic network problem while in real world we face a multi source logistic network problem. In this paper, we shall find the minimum cost of fMLN using proposed Route Based Genetic Algorithm (RB-GA) with considering a multi source multi product flexible multistage logistics network and the comparison based on numerical result between RB-GA and standard gentic algorithm is presented. We applied the penalty method in GA and new representation of GA to satisfy all existing constraints when. Additionally, we investigate all products amounts shipped from plants to customer. The best every product delivery route for each customer considering the constraints fulfilled will be found.

Keywords: *Multi Source Multi Product Flexible Multistage Logistics Network, Genetic Algorithms, Penalty Methods*

1. Introduction

The normal delivery in traditional logistics network is from one stage to another adjoining one. Another delivery method is called direct delivery or direct shipment, where goods move from plant to retailer directly and not via distribution centers, or sometimes the customer provides the goods from plant or from distribution center directly and not via retailer. The logistics network with the later delivery method is called flexible Multistage Logistics Network (fMLN) (Gen *et al.*, 2008). Figure 1 shows the structure of flexible multi stage logistic network.

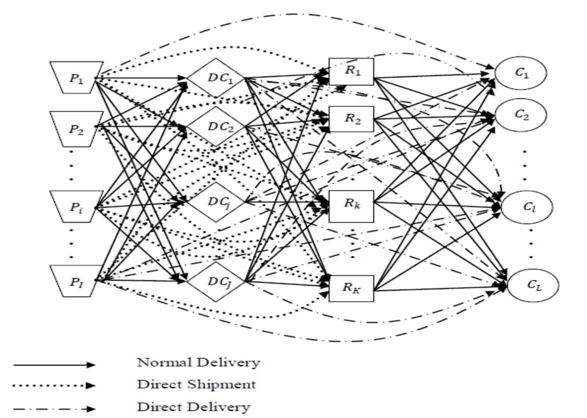


Figure 1: The structure of flexible multistage logistics network (fMLN) models *(*Gen *et al.*, 2008*).*

Currently, flexible multistage logistics network is under single product assumption and single source network is in the last layer which is between retailers and customers by Gen *et al.*, (2008). Since every customer can order several type of product in real world, it is important to consider the multi product problem. Additionally, every customer can fulfill his/her order using multiple sources simultaneously. In previous researches, multi product traditional multistage logistics network had been considered by Burcu and Keskin , (2007) where the model is only for two stage network. Altiparmak, *et al*, (2006) also considered to the single-source multi-product traditional multi-stage logistics design problem.

Recently, GAs has been successfully applied to logistics network models. Viagnaux and Michalewicz (1991) are among the first who discussed the use of GA for solving linear and nonlinear transportation problems. In their study, while matrix representation was used to construct a chromosome, the matrix-based crossover and mutation had been developed. Another (GA) approach for solving solid TP was given by Li *et al*. (1998). They used the three dimensional matrix to represent the candidate solution to the problem. Syarif and Gen *et al.* (2003) considered production/distribution problem modeled using tsTP and proposed a hybrid genetic algorithm. Gen *et al.* (2006) developed a priority-based Genetic Algorithm (priGA) with new decoding and encoding procedures considering the characteristic of tsTP. Altiparmak *et al*. (2006) extended priGA to solve a single-product multi-stage logistics design problem. The objectives are minimization of the total cost of supply chain, maximization of customer services that can be rendered to customers in terms of acceptable delivery time (coverage), and maximization of capacity utilization balance for DCs (*i.e*. equity on utilization ratios). Furthermore, Lin *et al.* (2007) proposed a hybrid genetic algorithm to solve the location-allocation model's problem of logistic network, and Altiparmak *et al.* (2006) also apply the priGA to solve a single-source, multi-product multi-stage logistics design problem. As an extended multi-stage logistics network model, Lee *et al.* (2007) apply the priGA to solve a multi-stage reverse logistics network problem (mrLNP), minimizing the total costs to reverse logistics shipping cost and fixed cost of opening the disassembly centers and processing centers. Gen and Gen and Syarif (2005) proposed a new approach called spanning tree-based hybrid genetic algorithm (hst- GA) to solve the multi-time period production/distribution and inventory problem (mt-PDI). Costa *et al*. (2010) presented an innovative encoding–decoding procedure embedded within a genetic algorithm (GA) to minimize the total logistic cost resulting from the transportation of goods and the location and opening of the facilities in a single product three-stage supply chain network.

For any optimization problem, there is an optimization criterion (i.e. evaluation function) to be minimized or maximized. The evaluation function represents a measure of the quality of the developed solution. Searching the space of all possible solution is a challenging task. An additional constraint on the domain of search for the parameters makes the problem quite difficult. The constraints might affect the performance of the evolutionary process since some of the produced solutions (i.e individuals) may be unfeasible. Unfeasible solution represents a waste of computation effort. In fact, it was reported that no general methodology to handle constraints exist although several methods were introduced. Rejecting unfeasible individuals, penalizing unfeasible individuals or moving these individuals to the feasible domain are among the many methods proposed (Sheta and Turabie, 2006).

There are some approaches to handle the constraints optimization problems such as death penalty, static penalties, dynamic penalties, GENOCOP system, Behavioral memory and etceteras (Yeniay, 2005). For some similar problems to fMLN with high constraints some researchers tried to add some heuristic rules to GA to satisfy the problem constraints and obtain a good solution. Yaohua and Chi (2007) proposed a random search based on heuristic rules and a dynamic rule selection method based on GA to solve large size single-stage batch scheduling problem and Alim and Ivanov (2005) proposed some heuristic rules embedded GA to solve In-Core Fuel Management Optimization Problem. Craenen *et al.* (2002) compared three different heuristics based Evolutionary Algorithm (EA) on the same problems and suggested the best one to solve the constraints optimization problems.

Although, a multi product network had been considered in supply chain and logistics network by previous researches but there is no model and solution for multi product multi source fMLN. The general objective of this paper is to discuss the algorithms that have been developed to solve the multi-source multi product flexible Multistage Logistics Network (fMLN) problem.

2. Mathematical Model of Multi Source Multi Product Flexible Multistage Logistics Network

In general, a multi source multi product flexible multistage network (fMLN) problem is to determine the optimum products quantity shipped from plants to the customers and the best delivery routes of every product to fulfill the customer's order that minimize the total logistics network costs. Here the developed model is presented below with the following assumptions:

1. Multi-product single time period case of a logistics network optimization problem is considered.
2. There are a maximum number of three stages: plants to DCs, DCs to retailers and retailers to customers.
3. There are normal delivery which it begins from plants to the customers consequently, direct shipment which the retailers can be supplied by the plants directly and direct delivery that every customer can be served by plants or DCs directly.

4. Every customer, retailer and distribution center (DC) can be served by multiple sources.
5. Customer demands are known in advance for every product.
6. Customers will get the products at the same price, no matter where he/she gets them; it means that the customers have no special preferences.

Notation:

Indices:

i index of plant $(i = 1,2,\cdots,I)$
j index of DC $(j = 1,2\cdots,J)$
k index of retailer $(k = 1,2.\cdots,K)$
l index of customer $(l = 1,2,\cdots,K)$
z index of product $(z = 1,2,\cdots,Z)$

Parameters:

I number of plants
J number of DCs
K number of retailers
L number of customers
Z number of products
p_i Plant i
DC_j DC_j
R_k Retailer k
C_l Customer l
b_{iz} Output of plant i for product z
d_{lz} Demand of customer l for product z
C_{1ijz} Unit shipping cost of product z from P_i to DC_j
C_{2jkz} Unit shipping cost of product z from DC_j to R_k
C_{3klz} Unit shipping cost of product z from R_k to C_l
C_{4ilz} Unit shipping cost of product z from P_i to C_l
C_{5jlz} Unit shipping cost of product z from DC_j to C_l
C_{6ikz} Unit shipping cost of product z from P_i to R_k
u^D_{jz} Upper bound of the capacity of DC_j for product z
u^R_{kz} Upper bound of the capacity of R_k for product z
f^F_j Fixed part of the open cost of DC_j
c^{1v}_{jz} Variant part of the open cost (lease cost) of DC_j for product z
q^1_{jz} Throughput of DC_j for product z
$q^1_{jz} = \sum_{i=1}^{I} X_{1ijz}$, $\forall j, z$
f_j Open cost of DC_j
$f_j = f^F_j + \sum_{z=1}^{Z} c^{1v}_{jz}\, q^1_{jz}$, $\forall j$
g^F_k Fixed part of the open cost of R_k
c^{2v}_{kz} Variant part of the open cost (lease cost) of R_k for product z
q^2_{kz} Throughput of R_k for product z
$q^2_{kz} = \sum_{l=1}^{L} X_{3klz}$, $\forall k, z$
g_k Open cost of R_k
$g_k = g^F_k + c^{2v}_{kz} q^2_{kz}$, $\forall k, z$

Decision Variables:

X_{1ijz} Transportation amount of product z shipped from P_i to DC_j
X_{2jkz} Transportation amount of product z shipped from DC_j to R_k
X_{3klz} Transportation amount of product z shipped from R_k to C_l
X_{4ikz} Transportation amount of product z shipped from P_i to C_l
X_{5jlz} Transportation amount of product z shipped from DC_j to C_l
X_{6ikz} Transportation amount of product z shipped from P_i to R_k

$$y^1_j = \begin{cases} 1, & if\ DC_j\ is\ open \\ 0, & otherwise \end{cases}$$

$$y^2_k = \begin{cases} 1, & if\ R_k\ is\ open \\ 0, & otherwise \end{cases}$$

The objective function is to minimize the total logistics cost:

$$\text{Min } Z = \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{z=1}^{Z} C_{1ijz}X_{1ijz} + \sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{z=1}^{Z} C_{2jkz}X_{2jkz} + \sum_{k=1}^{K}\sum_{l=1}^{L}\sum_{z=1}^{Z} C_{3klz}X_{3klz} + \sum_{i=1}^{I}\sum_{l=1}^{L}\sum_{z=1}^{Z} C_{4ilz}X_{4ilz} + \sum_{j=1}^{J}\sum_{l=1}^{L}\sum_{z=1}^{Z} C_{5jlz}X_{5jlz} + \sum_{i=1}^{I}\sum_{k=1}^{K}\sum_{z=1}^{Z} C_{6ikz}X_{6ikz} + \sum_{j=1}^{J} f_j y^1_j + \sum_{k=1}^{K} g_k y^2_k \quad (1)$$

Subject to:

$$\sum_{j=1}^{J} X_{1ijz} + \sum_{l=1}^{L} X_{4ilz} + \sum_{k=1}^{K} X_{6ikz} \le b_{iz} , \quad \forall i, z \quad (2)$$

$$\sum_{i=1}^{I} X_{1ijz} = \sum_{k=1}^{K} X_{2jkz} + \sum_{l=1}^{L} X_{5jlz} , \quad \forall j, z \quad (3)$$

$$\sum_{j=1}^{J} X_{2jkz} + \sum_{i=1}^{I} X_{6ikz} = \sum_{l=1}^{L} X_{3klz} , \quad \forall k, z \quad (4)$$

$$\sum_{i=1}^{I} X_{4ilz} + \sum_{j=1}^{J} X_{5jlz} + \sum_{k=1}^{K} X_{3klz} \ge d_{lz} , \quad \forall l, z \quad (5)$$

$$\sum_{i=1}^{I} X_{1ijz} \leq u_{jz}^{D}\, y_j^1 \quad , \quad \forall j, z \qquad \textbf{(6)}$$

$$\sum_{l=1}^{L} X_{3klz} \leq u_{kz}^{R}\, y_k^2 \quad , \quad \forall k, z \qquad \textbf{(7)}$$

$$X_{1ijz}, X_{2jkz}, X_{3klz}, X_{4ilz}, X_{5jlz}, X_{6ikz} \in N_0, \forall i, j, k, l, z$$

where;

$$N_0 = \{0, 1, 2, 3, \cdots\} \qquad \textbf{(8)}$$

$$y_j^1 \quad , \quad y_k^2 \quad \in \{0,1\} \qquad \forall j, k \qquad \textbf{(9)}$$

Where the objective function of Eq. (1) means to minimize the total logistic cost, only the shipping cost will be considered. The constraint at Eq. (2) means the production limit of plants for each product. The constraint at Eqs.3 and Eqs.4 are the flow conservation principle. The constraint at Eq. (5) ensures that the customers' demands should be satisfied for every product. The constraints Eq. (6) and Eq. (7) make sure that the upper bound of the capacity of DCs and retailers for every product cannot be surpassed.

3. Proposed Solution

A tree-based representation is known to be one way for representing network problems (Altiparmak *et al*, 2009). There are three ways of encoding tree:

(1) Vertex-based encoding
(2) Edge-based encoding
(3) Edge-and-vertex encoding

Gen *et al.* (2008) used vertex-based encoding to solve single product fMLN problem. Using this chromosome representation, if the total demand to the plant exceeds its supply capacity, the customer is assigned to another plant with sufficient products supply and the lowest transportation price between the plant and the customer. According to the above representation, solution is based on finding the best route for delivering the product to each customer when the network is single source in the last layer. Based on above mentioned solution the customer is not allowed to split the order to be fulfilled from different sources simultaneously. The length of every chromosome here is equal to: $3 \times L$. The use of vertex based chromosome representation as in Gen *et al*, (2008) could alternative the algorithm. Here most of the constraints would be embedded to the chromosome representation. It was argued that the solution proposed by Gen *et al*, (2008) is not useful to solve multi source fMLN problem. Here, Edge-and-vertex encoding is used to solve multi source fMLN problem and the new algorithm namely Route Based GA (RB-GA) is developed. Figure 2 represents the chromosome with edge- and vertex encoding. In a normal shipment which the number of plants, DCs, and retailers are I, J and K , representing the number of possible routes for product delivery from plant to each customer, using permutation theory is given by: $I \times J \times K$.
The total number of possible routes in fMLN = the number of routes for normal delivery + the number of routes for direct shipment + the number of routes for direct delivery = $I \times J \times K$ + $I \times K$ + I + $I \times J = I \times (J+1) \times (K+1)$
Therefore, the total number of possible routes for each customer named NOR and is given by:
$NOR = I \times (J+1) \times (K+1)$

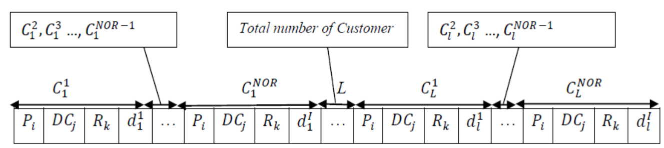
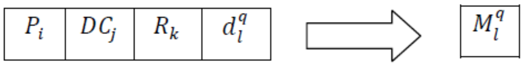


Figure 2: Edge-and-vertex encoding

Referring to Figure 2, it is obvious that the demand of customer l (d_l) is distributed to the possible routes which are pertinent to customer l with random amount between 0 and d_l. Therefore;
$d_l = d_l^1 + d_l^2 + d_l^3 + \cdots + d_l^I$
where $d_l^1, d_l^2, d_l^3, \cdots and\ d_l^I$ are generating as follows:
$d_l^1 = randomize\ (d_l)\ , \forall l$
$d_l^2 = randomize\ (d_l - d_l^1)\ , \forall l$
$d_l^3 = randomize\ (d_l - (d_l^1 + d_l^2)\ , \forall l$
$\vdots$
$d_l^{NOR-1} = randomize\ (d_l - \sum_{q=1}^{NOR-2} d_l^q)\ , \forall l$
$d_l^{NOR} = d_l - \sum_{q=1}^{NOR-1} d_l^q\ , \forall l$

There are several units of the chromosome for every customer (the number of NOR) which every unit indicates one possible product delivery route to a customer. Here, to simplify and decrease the number of gene especially for large size problem case, every unit is changed to be one gene of the chromosome. Therefore, every gene shows a possible route for customer l with the amount of customer l's demand as follows:



where

M_l^q indicates the q [th] possible route to fulfill the l [th] customer order, that is, the amount product shipped to customer l through the q [th] route, where $q = 0, 1, 2, \cdots, NOR$.

Therefore, Figure 2 can be changed to Figure 3 as below:

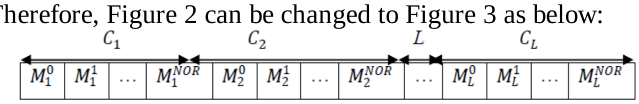


Figure 3: Proposed RB-GA chromosome representation

d_l is the l [th] customer demand and $M_l^0, M_l^1, \cdots, M_l^{NOR-1}$ and M_l^{NOR} could be generated as follows:

$M_l^0 = randomize\ (d_l)$, $\forall l$

$M_l^1 = randomize\ (d_l - M_l^0)$

$M_l^{NOR-1} = randomize\ (d_l - \sum_{q=0}^{NOR-2} M_l^q)$, $\forall l$

$M_l^{NOR} = d_l - \sum_{q=0}^{NOR-1} M_l^q$, $\forall l$

therefore

$d_l = M_l^0 + M_l^1 + M_l^2 + \cdots + M_l^{NOR}$

In fMLN with J number of DCs and K number of retailers are, the q [th] route for the l [th] customer is defined by the following procedures:

i) Let $\boldsymbol{w}$ be the quotient of $q \div (K+1)$ and $\boldsymbol{s}$ is the remainder of $(q \div (K+1))$.

ii) Let $\boldsymbol{q}$ be the quotient of $\boldsymbol{w} \div (J+1)$ and $\boldsymbol{r}$ is the remainder of $(\boldsymbol{w} \div (J+1))$.

The ID of plant involved q [th] route is: $\boldsymbol{q+1}$, which indicates the first node of the route.

The ID of DC involved q [th] route is: $\boldsymbol{r}$, which indicates the second node of the route.

The ID of retailer involved q [th] route is: $\boldsymbol{s}$, which indicates the third node of the route.

For further illustration suppose that I=2 which is the number of plants, J=2 which is the number of DCs and K=3 which is the number of retailers. Here, the total number of possible routes for each customer is calculated as:

$I \times (J + I) \times (K + 1) = 2 \times (2 + 1) \times (3 + 1) = 24$

Suppose that the 17 [th] route is required, therefore, according to above procedures this route is defining as follows:

$17 \div (3 + 1) \Longrightarrow$ $\boldsymbol{w} = 4$ and $\boldsymbol{s} = 1$

$4 \div (2 + 1) \Longrightarrow$ $\boldsymbol{q} = 1$ and $\boldsymbol{r} = 1$

Therefore;

The ID of plant involved 17 [th] route is $\boldsymbol{q+1} = 2$, the ID of DC involved this route is $\boldsymbol{r} = 1$ and the ID of retailer involved this route is $\boldsymbol{s} = 1$, that is:

Plant 2 → DC 1 → Retailer 1 → Customer l

Subsequently the following decision variables could be defined as well:

X_{121} which is product amount shipped from Plant 2 to DC 1.

X_{211} which is product amount shipped from DC 1 to Retailer 1.

X_{31l} which is product amount shipped from Retailer 1 to Customer l

Based on above explanation, all types of decision variables ($X_{1ijz}, X_{2jkz}, X_{3klz}, X_{4ilz}, X_{5jlz}, X_{6ikz}$) and their values can be obtained using the following procedures (Figure 5):

In multi product fMLN problem every customer can order more than one product. Therefore it is possible to obtain the optimum amount of every product for every customer as long as the total cost must be at minimum. As Figure 4 shows, the length of chromosome is longer than the length of chromosome for single product which is a multiply of the number of product (Z).

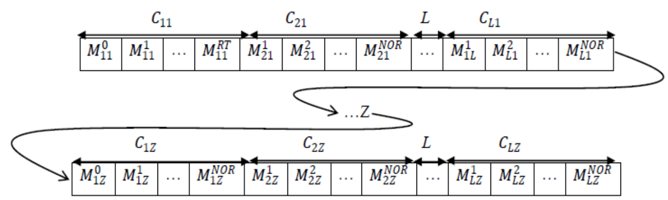


Figure 4: Proposed RB-GA chromosome representation for multi source multi product fMLN

It is obvious that to serve every customer at least one plant is needed. Considering the multi source assumption where each customer can be served by multi facilities the ID of plants must be non zero while the ID of DCs and retailers could be zero since for the flexible logistics model, there is direct shipment or direct delivery. Therefore, the customer would be able to split his/her order to be fulfilled from different facilities. Based on the above mentioned chromosome representation (Figure 4.14), the total number of genes for every customer is equal to:

$I \times (J + 1) \times (K + 1)$

(I is the total number of plants, J is the total number of DC and K is the total number of retailer).

Procedure: *Define the product amount shipped at every arc of fMLN.*
Input: *Number of Plants (I), number of DCs (J), number of Retailers (K) ,the number of Customer* ***(L)*** *and number of products* ***(Z)***
Output: *Decision variables and their values*
for *z = 1 to* ***Z***

for *l = 1 to L*
for *i =1 to I*
for *j= 0 to J*
for *k = 0 to K*

if *j ≠0*
we have: X_{1ijz}
if *k≠0*
we have: X_{2jkz} *and* X_{3klz}
else
we have: X_{5jlz}
end

else
if k≠0
we have: X_{6ikz} *and* X_{3klz}
else
we have: X_{4ilz}
end
end
end
end
end
end
end
Output: *Decision variables and their values*

Figure 5: Pseudo-code to derive decision variables from possible routes

Subsequently the total number of genes for every chromosome is calculated as follows:
Z × { $[I \times (J+1) \times (K+1)] \times L$ } *(L is the total number of Customers and Z is the total number of product).*

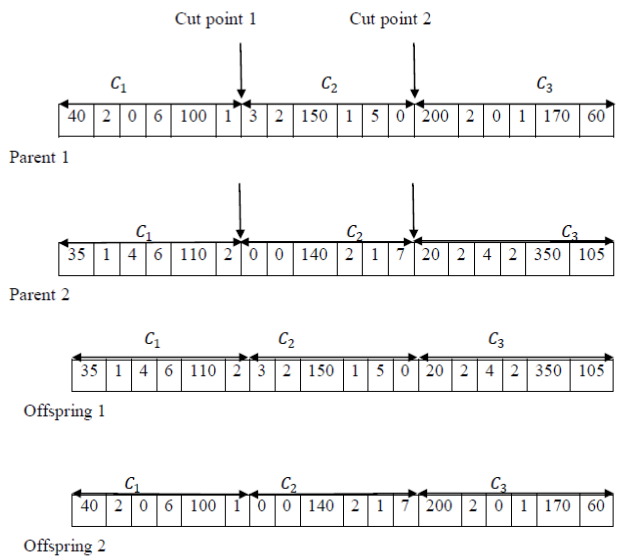
Every gene is one set of ID of a plant, ID of DC and ID of retailers with the part of amount of customer demand. The *NOR* number of gene constitutes one unit for every customer where each unit represents all possible delivery routes to a customer with amount of customer demand for each route from the plant via DC and retailer.

3.1 Crossover for Edge-and-Vertex Encoding (RB-GA):

It randomly selects two cutting points and then exchanges the substrings between the two parents.

Cutting point 1 = Randomize (L)
Cutting point 2 = Randomize (L)

where; L = total number of customers.



The cross points located at the beginning of every unit, therefore, after crossover, an infeasible solution may not be generated and repairing procedure is not needed. the above mentioned crossover can be developed when there are some kind of products also.

3.2 Mutation for Edge-and-Vertex Encoding (RB-GA)

Here, some offspring will be selected according to mutation rate and the mutation procedure is explained as below:

Step1: Generate randomize (*L*-*1*) +1 *// l ih customer will be found//*

Step2: Generate randomize (d_l) denoted as *m_n* .
Step 3: Generate randomize (*NOR*) denoted as *m_u*, and *NOR* is the total possible routes for product (z) delivery to each customer // *the number of specific gene of l ih customer for z th product that must be mutated will be found //*
Step 4: *m_u* ← *m_n*
Step 5: Generate randomly the number of route (randomize (*NOR*)) denoted as *A*, then set g_*m* = *NOR* – *A // the number of second specific gene of l ih customer for z th product that must be mutated will be found //*

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Step 6 : $g\_m \leftarrow m\_n$ – randomize (m_n)

It is noted that using the proposed crossover and mutation, the chromosomes still would be able to satisfy the equality constraints.

Using this encoding method, an infeasible solution may be generated, which violates the facility capacity constraints, where the penalty method could be useful. As it was mentioned earlier about difficulty for satisfying the two main constraints which are:

$$\sum_{i=1}^{I} X_{1ijz} = \sum_{k=1}^{K} X_{2jkz} + \sum_{l=1}^{L} X_{5jlz} \quad , \quad \forall j, z$$

$$\sum_{j=1}^{J} X_{2jkz} + \sum_{i=1}^{I} X_{6ikz} = \sum_{l=1}^{L} X_{3klz} \quad , \quad \forall k, z$$

Proposed RB-GA could satisfy them simply by embedding to the chromosome representation. The above mentioned constraints depict that the summation of incoming product amount to each facility (DC or Retailer) must be equal to summation of out coming product amount from the same facility.

Using proposed RB-GA; define the all possible routes for every product delivery to each customer which every route contains the constant amount of the every product at all stage of network. It is obvious that every route which passes each DC or retailer has the same amount of incoming and out coming in that DC or retailer. Therefore the summation of all incoming of all routes are equal to the summation of all out coming of all routes at every DC or retailer. In conclusion, it is true that the above equality constraints are satisfied simply.

4. Numerical Experiment

In this section the numerical results of using RB-GA are presented. The data used in this research was generated by the authors as the problem case. Diverse 3 problem cases have been created by this research to implement the proposed algorithm and compare the obtained solutions. Hardware platforms employed by the researcher were a 2 GHz processor intel core 2 duo with 1GB memory and running windows 7 professinal. It is noted that the scope of this research did not include establishing nessesary conditions to hardware requirements. The mathematical model of fMLN was translated into program written in Matlab version 7, 2009. The first problem case in Table 1 had been solved by LINDO software and the result was 8150. It is indicated that standard GA with penalty method and RB-GA could obtain the exact solution as long as it is the same with LINDO solution.

Table 1: Solution comparison between HR-GA and P-GA to solve multi source multi product fMLN problems

Problem #	***Number of plants***	***Number of DCs***	***Number of Retailers***	***Number of Customers***	***Number of Products***	***Number of Decision variables***	***Solution of Standard GA with penalty methods***	***Solution of using RB-GA***
1	2	2	2	2	2	52	8150	8150
2	2	4	7	25	2	782	30040	4896
3	4	7	10	30	3	2344	65813	15787

Table 1 show that with the same problem cases (case 2 and 3) the solution obtained using RB-GA is more acceptable than the solution obtained using standard GA with penalty method.

5. Conclusion

In this paper, a multi source multi product flexible multistage logistics network (fMLN) model was considered. It is proven that the problem became larger and more complex comparing with the single product fMLN problem. Since the genetic algorithm which is a strong search technique was used to solve NP-hard problems, the existing constraints of this problem are too many to be satisfied. Therefore the proposed Route Based GA (RB-GA) to solve this kind of problem to obtain an acceptable solution within a reasonable time. The solution obtained using proposed algorithm was extremely better than the result of using standard GA with penalty method in terms of minimum cost of the network. The result of standard GA with penalty method and RB-GA was proven and verified using LINDO software as well.

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