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Genetic Algorithm for A Generic Model of Reverse Logistics Network

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Abstract – **Firms incorporate products reverse flow to their systems for such reasons as ecological and economic factors, government regulations and social responsibilities. This work provides a mixed integer linear programming model for the reverse logistics network design problem which involves product returns and solves it using a genetic algorithm (GA) to give a minimum-cost solution. In proposed model, we have considered some characteristics of the real problem, such as multi capacity level, multi - product, multi - stage, some attach condition for recycle centers, recovery centers and the repairing, remanufacturing, second market options being taken into account simultaneously. To solve this problem, we proposed a genetic algorithm with "modified priority - based" encoding method. Different large - scale problems are solved within an experimental design scheme in order to validate the performance of the model.**

Keywords – **Genetic Algorithm (GA), Priority-Based Encoding Method, Reverse Logistics Network Design, Generic Model, Large-Scale MILP Model.**

I. Introduction

Due to the environmental concerns between the nations, using up the landfill capacities in numerous countries and enacted obligations by governments to deal with the end-of-life products, reverse logistics turns to receive a growing attention, recently. Generic networks described in this papers including gathering of the used products from customer centers, recovery, recycle, disposal of used products to make them reusable and then distributing them between the customers, are completely different from traditional networks. The strategic issue of reverse logistic system design may affect both a company's profitability and the customer service level, which is one of these issues can be defined as a process that includes all logistics activities and starts from the point of consumer to transform the used products to products which are reusable in the market [1, 2]. Reverse logistics activities can improve customer service level, the competence of enterprises, and reduce the production costs [3]. If a reverse logistics system is designed and managed properly, it can be a cost-driving area for improving profitability and customer satisfaction level. The ability to quickly and efficiently handle the return of products for necessary repair can be critical to customer service/ satisfaction [4]. There are a number of situations for products to be placed in a reverse flow. Normally, return flows are classified into, warranty returns, end-of-use, commercial returns, returns reusable container returns and others. Product recovery options can be classified as repairing, recycling, refurbishing, remanufacturing, and cannibalization. The right option may be selected by taking the condition and age of the returned product and economics into consideration [5]. Before determining that the product is a complete loss, and sending it to be recycled, many firms will attempt to remanufacture. There is an extensive literature review on reverse logistics [6, 7] but only a few researchers have focused on the development of a general framework and mathematical model about generic system. When, for some reason, the firm is prevented from selling the product to the secondary market, and the product cannot be given away, the final option is disposal. As always, the firm's objective is to receive the highest value for the item, or dispose of the item at the lowest cost, other items may be composed of materials that are of some value to scrap dealers, like steel and iron [8-10].

Recently, Genetic Algorithms have received a significant attention because of their potential as a new approach in solving the optimization problems [11-15]. It is noted that these entire problem can be formulated as some sort of a combinatorial optimization problem.

In the reverse logistic network research area almost all of the work just study a single capacity level for facilities and do not consider how capacity levels can be set [16-19]. Whereas, capacity levels are one of the most important factors in the real life applications because of their direct effect on the performance of the logistic networks. To cover the mentioned considerations, this work deal with the multi-stage, multi-product, closed loop reverse logistics network design (i.e. production, collection/ inspection, recovery, remanufacturing, repair, disposal and secondary market facilities with multiple capacity levels) which is environmentally friendly and profitable for return product is discussed.

II. Methodology

A. Proposed Reverse Logistics Network Problem

In the proposed model, the returned products in the collection/ inspection centers are tested and classified in two groups; the recoverable products are sent to recovery facilities, and scrapped products are assigned to the recycle/ disposal centers. Before developing the mathematical model for reverse logistics network design, we make the following underlying assumptions and simplifications:

A1: If the quantity of provided parts from processing center is not enough for requirement of manufacturer, then manufacturer must buy parts from supplier.
A2: If the quantity of provided parts from recycle/ Disposal center exceeds the capacity of recycle, then exceeded capacities distribute in order of disposal.
A3: Not considering the inventories.
A4: The parts demand of manufacturer is known in advance.
A5: Collection/ inspection centers, recovery centers and recycle centers maximum capacities are also known.

B. Mathematical Model

The notations are defined as follows:

cq_{kl}	The distance between the k[th] customer center and the l[th] Collection/inspection center
cq_{li}	The distance between the l[th] Collection/inspection Center and the i[th] recovery center
cq_{lm}	The distance between the l[th] Collection/inspection Center and the m[th] recycle/disposal center
cq_{mmf}	The distance between recycle/disposal center m and production center mf
cq_{smf}	The distance between supplier center m and production center mf
cq_{mdc}	The distance between recycle/disposal center m and disposal center dc
cq_{mr}	The distance between recycle/disposal center m and recycle material market center r
cq_{ig}	The distance recovery center I and second Market center g

Indices

J	Index of product.
Z	Index of part.
I	Index of potential recovery center.
K	Index of fixed customer center.
L	Index of potential collection/inspection center.
M	Index of potential recycle/disposal center.
DC	Index of disposal center.
G	Index of second market center.
R	Index of recycle material market center.
Mf	Index of potential production center.
S	Index of supplier center.
N	Index of capacity levels accessible to facilities.

Parameters

D_{jk}	Demand of customer center k.
RD_{jk}	Return rate of used jth product from Customer center k.
S1	The average of disposal fraction.
RA	Average repair of product fraction.
1−RA	Average recovery of product fraction.
AD_{jz}	Amount of component that can be obtained from a single unit of the jth product.
TD_z	Overall demand received for part z.

Cost Parameters

C_j	Transportation cost per unit for the j[th] product.
CC_z	Transportation cost per unit for the z[th] part.
CR_z	Recycle cost per unit for the z[th] part.
CD_z	Disposal cost per unit for the z[th] part.
SM_j	Revenue per unit sale for the z[th] part to the second Market.
CM_j	Remanufacture cost per unit for the z[th] part.
CRE_j	Repair cost per unit for the z[th] part.
CRP_z	Purchase cost per unit for the z[th] part.
SRR_z	Revenue per unit sale of part z to material.
FR_i^n	Fixed cost of stablishing the i[th] recovery center with Capacity level n.
H_l^n Hln	Fixed cost of stablishing the l[th] collection/inspection Center with capacity level n.
BD_m^n BD mn	Fixed cost of stablishing the m[th] recycle/disposal Center with capacity level n.

III. Distance Parameters

Decision variables

X_{jkl}	Amount of the j[th] products shipped from the k[th] customer center to the l[th] collection /inspection center
X_{jli}	Amount of the j[th] products shipped from the l[th] collection /inspection center to the i[th] recovery center
X_{jlm}	Amount of the j[th] products shipped from the l[th] collection /inspection center to the m[th] recycle/disposal center
X_{zmdc}	Amount of part z shipped from recycle /disposal center m to disposal center dc
X_{zmr}	Amount of part z shipped from recycle/disposal Center m to recycle material market center
X_{Zsmf}	Amount of part z shipped from of supplier Center s to production center mf
X_{Zmmf}	Amount of part z shipped from recycle /disposal center m to production center mf
X_{jig}	Amount of products j shipped from recovery Center i to second market center g

$$W_i^n \begin{cases} 1 & \text{If a recovery center with capacity level n is Opened at location i} \\ 0 & \textit{Otherwise} \end{cases}$$

$$Z_l^n \begin{cases} 1 & \text{If a collection/inspection center with capacity level n is Opened at location l} \\ 0 & \textit{Otherwise} \end{cases}$$

$$V_m^n \begin{cases} 1 & \text{if a recycle/disposal center with capacity level n is opened at location m} \\ 0 & \textit{Otherwise} \end{cases}$$

$$\begin{aligned} Min\ f = & \sum_{i\in I}\sum_{n\in N} FR_i^n W_i^n + \sum_{l\in L}\sum_{n\in N} H_l^n Z_l^n + \sum_{m\in M}\sum_{n\in N} BD_m^n V_m^n \\ & + \sum_{j\in J}\sum_{k\in K}\sum_{l\in L} c_j cq_{kl} X_{jkl} + \sum_{j\in J}\sum_{l\in L}\sum_{d\in D} c_j cq_{ld} X_{jld} + \\ & \sum_{j\in J}\sum_{l\in L}\sum_{d\in D} CD_j X_{jld} + \\ & \sum_{j\in J}\sum_{l\in L}\sum_{i\in I} c_j cq_{li} X_{jli} \sum_{j\in J}\sum_{l\in L}\sum_{m\in M} X_{jlm} CR_j \\ & + \sum_{z\in Z}\sum_{m\in M}\sum_{f\in F} c_z cq_{Sf} X_{Zsf} + \sum_{z\in Z}\sum_{l\in L}\sum_{i\in I} CRP_z X_{Zsf} \\ & + \sum_{z\in Z}\sum_{m\in M}\sum_{f\in F} c_z cq_{mf} X_{Zmf} + \sum_{j\in J}\sum_{l\in L}\sum_{i\in I} CRE_j RA X_{jli} \\ & + \sum_{z\in Z}\sum_{m\in M}\sum_{r\in R} c_z cq_{mr} X_{zmr} + \sum_{z\in Z}\sum_{m\in M}\sum_{r\in R} SRR_z X_{zmr} \\ & - \sum_{j\in J}\sum_{i\in I}\sum_{g\in G} (\mathrm{SM}_j - \mathrm{CM}_j)\mathrm{X}_{jig} \end{aligned} \quad (1)$$

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$$\sum_{k\in K}\sum_{l\in L} X_{jkl} = \sum_{k\in K} D_{jk} RD_{jk} \qquad \forall j\in J \qquad (2)$$

$$\sum_{l\in L}\sum_{m\in M} X_{jlm} = sl \sum_{k\in K}\sum_{l\in L} X_{jkl} \qquad \forall j\in J \qquad (3)$$

$$\sum_{l\in L}\sum_{i\in I} X_{jli} = (1-sl)\sum_{k\in K}\sum_{l\in L} X_{jkl} \qquad \forall j\in J \qquad (4)$$

$$\sum_{g\in G}\sum_{i\in I} X_{jig} = (1-RA)\sum_{i\in I}\sum_{l\in L} X_{jli} \qquad \forall j\in J \qquad (5)$$

$$\sum_{mf\in MF} X_{zmmf} + \sum_{r\in R} X_{zmr} + \sum_{dc\in DC} X_{zmdc} = \sum_{j\in J}\sum_{l\in L} X_{jlm} AD_{jz} \qquad (6)$$

$$\forall z\in Z, m\in M$$

$$\sum_{mf\in MF} X_{zmmf} + \sum_{r\in R} X_{zmr} \le \sum_{n\in N} V^{n}_{m} \sum_{j\in J} ca_{mj} AD_{jz} \qquad (7)$$

$$\forall z\in Z, m\in M$$

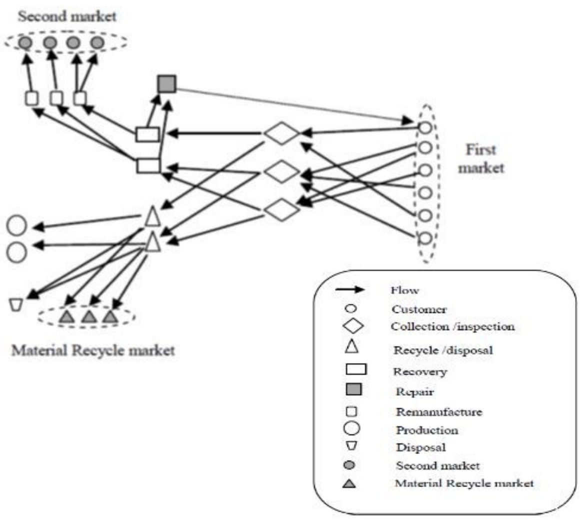

Fig. 1. Reverse logistics process in the studied network

$$\sum_{k\in K} X_{jkl} \le \sum_{n\in N} Z^{n}_{l} caz^{n}_{jl} \qquad \forall j\in J, l\in L \qquad (8)$$

$$\sum_{l\in L} X_{jlm} \le \sum_{n\in N} V^{n}_{m} cav^{n}_{jm} \qquad \forall j\in J, l\in L \qquad (9)$$

$$\sum_{l\in L} X_{jli} \le \sum_{n\in N} W^{n}_{i} car^{n}_{ji} \qquad \forall j\in J, l\in L \qquad (10)$$

$$TD_{z} \le \sum_{m\in M}\sum_{mf\in MF} X_{zmmf} + \sum_{s\in S}\sum_{mf\in MF} X_{zsmf} \qquad (11)$$

$$\forall z\in Z$$

$$\sum_{s\in S}\sum_{mf\in MF} X_{zsmf} \le \sum_{s\in S} c_{szl} \qquad \forall z\in Z \qquad (12)$$

$$\sum_{m\in M} X_{zmmf} + \sum_{s\in S} X_{zsmf} \le cas_{zmf} \qquad (13)$$

$$\forall z\in Z, mf\in MF$$

$$\sum_{m\in M} W^{n}_{i} \le 1 \qquad \forall i\in I \qquad (14)$$

$$\sum_{n\in N} Z^{n}_{l} \le 1 \qquad \forall l\in L \qquad (15)$$

$$\sum_{n\in N} V^{n}_{m} \le 1 \qquad \forall m\in M \qquad (16)$$

$$V^{n}_{m}, Z^{n}_{l}, W^{n}_{i} \in \{0,1\} \qquad (17)$$

$$\forall i\in I, \forall l\in L, \forall m\in M, \forall n\in N$$

$$X_{jkl}, X_{jli}, X_{zmdc}, X_{jlm}, \qquad (18)$$

$$X_{zmr}, X_{Zmmf}, X_{Zsmf}, X_{jig}, yy(j,k,l,i) \ge 0$$

Objective function (1) minimizes the overall costs including the fixed establishing costs of facilities and the transportation costs. Equation (2) guarantees that the all customers' demands are met and the returned products from all customer zones will be collected. Equations (3)–(7) addresses the flow at customer centers, collection/ Inspection, recovery, recycle /disposal and makes sure that they are balanced. Equations (8)–(10) are dealing with the capacity of facilities. These equations prevent the transferring the products (units of products, returned products, recoverable and scrapped products) into the facilities that are not established. Equation (11) guarantees that the all customers' demands are met. Equations (14)–(16) enforces a specific facility to be assigned to at most one capacity level. Finally, Equation (17) and (18) show the binary and non- negativity restrictions on the associated decision variables.

A. Solution Procedure Involving Genetic Algorithm Representation

Representation is the first step in designing the Genetic Algorithms and is one of the most important issues that affects the performance of Gas in converging to the optimal solution. Tree-based representation is known to be one way for representing network problems. Basically, there are three ways of encoding tree: (1) edge-based encoding, (2) vertex-based encoding, and (3) edge-and-vertex encoding [20].

The first application of encoding structure to a single product transportation problem was carried out by [21]. As it is known, the chromosome is structured by genes which have two characteristics locus and allele [22]. The locus presents the position of a specific gene in the chromosome and allele shows the value that has been assigned to it. For instance, in priority-based encoding method, the locus is used to represent a node and the allele shows the preference of associated node for establishing a tree within the given candidates [23].

Algorithm: Modified priority-based representation

Inputs :

	K	Set of sources.
	L	Set of warehouses.
	TD_{jk}	Demand for the j^{th} product from the k^{th} source.
	caz^{n}_{jl}	Accessible capacities in the l^{th} depot.
	$cost_{jkl}$	Transportation cost per unit of the j^{th} product from the k^{th} source to the l^{th} depot.
	$\upsilon(k+1)$	Chromosome ∀k ∈K, ∀l ∈L.
Outputs:	X_{jkl}	Amount of the j^{th} product shipped from the k^{th} source to the l^{th} depot.
	Z^{n}_{l}	Binary variable shows the opened Facilities.

$while \quad \upsilon(1,t) \neq 0 \quad t \in K$

$Step1: \forall k \in K, \forall l \in L \quad X_{jkl} = 0$

$Step2$: select a node based on

$a = \arg\max\{\upsilon(1,t) \;\; t \in k+L\}$

$Step3: if \;\; a \in k$ then a source is selected, $k^* = a$

$l^* = \arg\min\{cost_{jkl} \mid \upsilon(1,t) \neq 0, l \in L\}$

Select a depot with minimum cost, $n^* = \upsilon(2, l^*)$

$Else \quad l^* = a$, adepotisselected

$k^* = \arg\min\{cost_{jkl} \mid \upsilon(1,k) \neq 0, k \in K\}$

Select a source with minimum cost, $n^* = \upsilon(2, k^*)$

$Step4: \; X_{jk^*l^*} = \min(caz^{n^*}_{jl^*}, TD_{jk^*})$

Update demands and capacities

$caz^{n^*}_{jl^*} = caz^{n^*}_{jl^*} - X_{jk^*l^*}, TD_{jk^*} = TD_{jk^*} - X_{jk^*l^*}$

$Step5: if \;\; caz^{n^*}_{jl^*} = 0 \; then \;\; \upsilon(1,l^*) = 0$

if $TD_{jk^*} = 0 \; then \;\; \upsilon(1,k^*) = 0$

End of loop

Step6: for 1 to K

If $\sum_{k \in K} X_{jkl} > 0 \;\; then \;\; n = \upsilon(2,l), Z^n_l = 1$

End

For decoding other stages, decoding procedure stage 3rd in [10] was used.

➢ *Crossover*

In this paper segment-based crossover is utilized in which the corresponding segments of the parents will be selected with the same probability. Each time a crossover operator is applied, two offspring solutions are generated. Weight mapping crossover (WMX) operator is used to merge the parents and produce the two alternative solutions. WMX can be considered as an extension of simple one-cut point crossover operator for permutation representation.

➢ *Selection Operator*

For this experimentation, a binary tournament selection method is used that begins by constructing two group of chromosomes [16]. Each team is formed by two chromosomes that are randomly drawn from the current population set. The two best chromosomes that are taken from one of the two teams are selected for crossover operations to generate the offspring solutions.

➢ *Mutation*

A simple mutation operator is exploited in this study, in which a random chromosome is selected from the population set and based on its length two integer random numbers are generated to choose the genes that are supposed to exchange.

➢ *Elitism*

After computing the fitness of each chromosome, our algorithm directly passes chromosomes of highest fitness values to the next generation, so that the best solutions are never lost. The fitness function plotted by the algorithm is therefore always ascending.

IV. Numerical Experiment

To evaluate the performance of the proposed algorithm, different large-scale problems are solved by using both the proposed GA and GAMS (Table 1). These parameters are, population size=15 number of generations=300, selection rate = 0.2, crossover rate = 0.75, mutation rate =0.2 .Table. 2 shows the Summary of test results for Different large-scale problem. Here, the error value are calculated by equation 19.

$$\%error = \left(\frac{ans.GA - ans.GAMS}{ans.GAMS}\right) \times 100 \qquad (19)$$

Table 1. The size of test problems

Number Sample	Problem Size |J| ∗ |Z| ∗ |I| ∗ |K| ∗ |L| ∗ |M| ∗ |DC| ∗ |jG| ∗ |R| ∗ |MF| ∗ |S| ∗ |N|
1	3*4*3*3*3*2*3*2*2*3*3*2
2	5*4*6*6*6*4*4*4*4*6*6*3
3	6*4*10*15*10*15*6*6*6*6*2
4	10*4*15*20*20*20*10*10*10*10*10*3
5	10*10*30*30*30*30*20*20*20*20*20*20*5

Table 2. Computational results with GAMS and GA

Number sample	GA Average objective	GA t	GAMS Objective	GAMS t	% error
1	3.4798e+007	3.39	3.3894E+7	1	2.67
2	5.0069E+7	16.17	4.8932E+7	6.8	2.32
3	5.9233e+7	18.2	5.5976E+7	12.3	5.82
4	1.1465e+8	37.8	1.0978E+8	75.4	4.44
5	2.3042e+8	87	2.1431E+8	192.3	7.52

V. Conclusion

In this paper a generic reverse logistics network is designed which can satisfy different industries' requirements and to solve it a mixed integer programming model is developed for the remanufacturing – repair systems. It is important to note that since we encounter a large scale problem, the computational burden is much larger and the runtime is not very satisfactory. We used a genetic algorithm with modified priority-based encoding method to solve the model. Future research could be aimed models with uncertainty in demand return flows.

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