

A GA Model Development for Decision Making Under Reverse Logistics

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KEYWORDS

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Genetic Algorithm,
allocation problem,
integration

ABSTRACT

Managing products' end-of-life and recovery of used products is gaining significant importance during last years. Therefore, managing the reverse flow of products can be an important potential for winning consumers in future competitive markets. In this context, establishing reverse logistics networks is becoming a main problem in reverse supply chains. Genetic Algorithm (GA) is utilized to solve the proposed NP-hard problem and find the best possible design for different facilities. In order to test the applicability of proposed GA, we suppose a tire reverse logistic case and solve the problem. The results show that the least cost will be achieved by using the free space of distribution centers and integrating collection and inspection centers within them. In addition, we suggest using hybrid algorithm in future allocation problems to obtain best solutions.

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1. Introduction

One of the main parts of industrial firms with huge impacts on environment is their supply chain. This large impact and the growing need of societies have lead companies to green supply chains. Green supply chain management (GrSCM) tries to achieve profit and market share, while reducing environmental impacts and improving ecological efficiency of the organization (Srivastava, 2008). Managing a company's reverse flow is regarded as one of the most popular adopted practices in GrSCM, to respond its social responsibility towards environment (Bai, 2009). Its potential for value recovery, energy saving and cost saving is a strong motivator for managers to adopt reverse supply chain (RSC) and reverse logistics (RL) practices (Lee & Chan, 2009; Pokharel & Mutha, 2009)¹.

Typically RL is categorized to closed-loop and open-loop logistics. In closed-loop logistics (CLL) the used

products return back to the original producer while in open-loop logistics used products will be recovered by other parties (Prahinski & Kocabasoglu, 2006). A CLL is consisted of forward and reverse flows. Reverse flow, as its name shows, is started from customers, processing back to the manufacturer, recycler or dismantler (Wang & Hsu, 2010).

If a firm does not properly organize its access to used products, it cannot benefit from remanufacturing and recycling (Guide & Wassenhove, 2009). This is why deciding about facility locations and network design becomes an important aspect of RL. This decision involves the determination of facilities' location, type and capacities. The facilities include centers such as warehouses, collection, inspection, consolidation and repair centers in reverse flows (Ko & Evans, 2007). Another concern in RL network design is about whether to locate collection centers in distribution centers or use centralized return centers (CRC). Different studies identified advantages and disadvantages of each approach. Usually CRCs are preferred for their separability from forward flow and the degree of focus on reverse flow, that helps firms to be a RL professional (Guo et al., 2008).

The purpose of this paper is to provide a model for determining facilities location while deciding about their integration or separation. Our main focus is on

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¹ There is some disagreement between researchers about RSC and RL and they are used interchangeably in literature. We consider that the main focus of RL is on transportation, warehousing and inventory management and it is part of RSC activities.

deciding about integrating or separating different facilities in a RL. To achieve this goal, a mathematical model is presented to minimize the total costs of reverse logistics in a CLL framework. In the next section, a brief literature on reverse supply chain management (RSCM), RL and optimization in these fields is given. The used methodology is expanded in section 3. Then the problem is defined and a mathematical model is developed in two next sections. The solution approach is described in section 6 and appendix A. finally to test the mathematical model and solution approach a test problem in a tire and rubber recovery plant is demonstrated in seventh section. Finally we present a conclusion of the used model and results.

2. Literature Review

Although wide investigations has been done in supply chain management, the reverse flow in these chains is less studied in literature. This part is classified into two parts; first the literature about RL and next the optimization models in this subject will be described.

2-1. Reverse Logistics

Rogers & Tibben-Lembke (1998) in studying RL trends and practices, provided some insights on how to manage RL and examples of its large bottom-line impacts. It is anticipated that while the efficient handling and disposition of returned product is unlikely to be the primary reason upon which a firm competes, it can create a competitive advantage (Rogers & Tibben-Lembke, 1998). While all companies can provide features such as quality and customer services,

an effective RL management will differentiate a firm in the competitive market (Stock et al., 2002 as quoted by Guo et al., 2008). Prahinski & Kocabasoglu (2006) studying the literature about RSC observed that most research in this field, has relied on case studies and optimization models. They introduced ten research opportunities to use survey-based techniques for explaining the current position of RSC. It shows the lack of research in this field, that needs to be addressed especially by researchers in business and management.

RSCM and RL deal with two kinds of products: (1) products that have reached their end-of-life (EOL) and (2) products that have been returned by the end-users. It aims at extracting the remaining value of these two groups to reduce negative environmental impacts, resource extraction and production costs (Bai, 2009). There are four main groups of disposition alternatives, for returned products, as shown in Fig. . (Prahinski & Kocabasoglu, 2006). As stated before, we consider RL as a part of RSCM processes. It is “the process of retrieving the product from the end consumer for the purposes of capturing value or proper disposal” (Bayles, 2001). RSCM is defined as the whole process; “effective and efficient management of the series of activities required to retrieve a product from a customer and either dispose it or recover value” (Prahinski & Kocabasoglu, 2006). Five principle processes in the flow of RL are defined as collection, storage, transportation, inspection and reduction. These steps are depicted in Figure 1. In this figure reduction process is containing the final decisions about returned products.

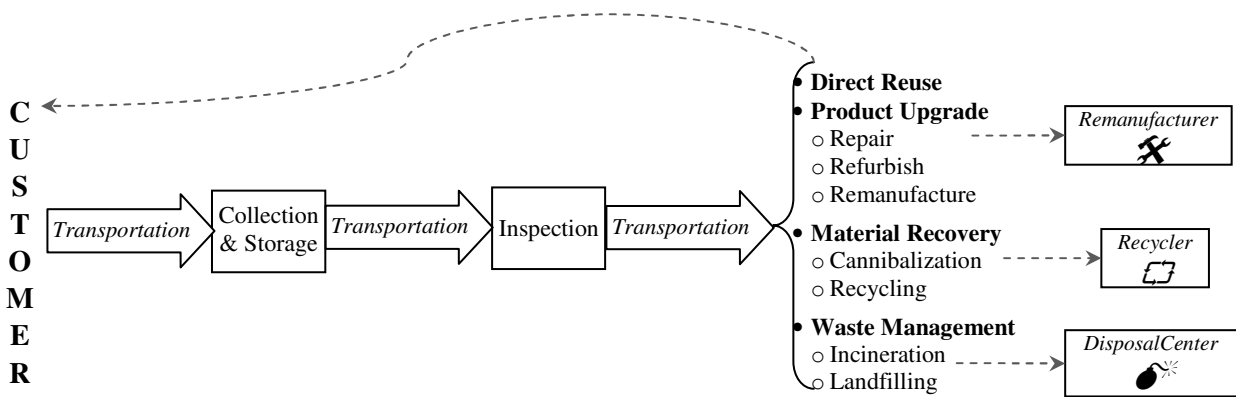


Fig. 1. Reverse logistic process

2-2. Optimization in RSCM

As stated by Prahinski & Kocabasoglu (2006), most studies on RSCM have relied on normative research methods, case studies, theoretical frameworks and optimization models. However yet there is small works done on this field in comparison with the forward flow. The growing need for RL leads firms to plan optimal routes, design RL networks and allocate facilities to gain more competitiveness. Thus, the 3R of reduce, recover and reuse can be achieved by the efforts of RL

managers. The problems in RSCM are modeled and optimized by various methods that a summary of them is presented in Table 1. Some of these literature are briefly described below:

Dehghanian & Mansoor (2009) using a multi-objective Genetic Algorithm (MOGA) designed a sustainable recovery network. Their model maximized economic and social benefits and minimized negative environmental impacts (Dehghanian & Mansour, 2009).

Lee and Chan (2009) using GA determined collection point locations in a RL network to maximize the coverage of customers. Considering the uncertainty of RL, they suggested using RFID to facilitate vehicle scheduling for transferring collected items to the return center and counting the quantities of items collected in different points during the reverse chain (Lee & Chan, 2009).

Srivastava (2008) using a conceptual model and a mixed integer linear programming, determined the location and capacity of facilities and disposition decisions for different grades of products in a RL network (Srivastava, 2008). Wang & Hsu (2010) investigated the integration of forward & reverse logistics and proposed a general method for closed-loop logistics (CLL). In order to minimize total costs, places of manufactories, distribution centers and dismantlers were selected using an integer linear programming. In their proposed network, used

products flow from customers back to distribution centers and then to dismantlers. dismantlers sort or disassemble products for recovery, reuse or disposal.

To design a model for integrated logistics network, Pishvae et al. (2010) developed a mixed integer programming formulation by two objectives for minimizing the total cost and maximizing the responsiveness of the network. In their model, collection and inspection centers are integrated and from these points, products are shipped to recyclers or disposal centers. Using a memetic algorithm and comparing the results with a previously studied GA, the preference of the proposed memetic algorithm is proven (Pishvae et al., 2010).

Guo et al., (2008) developed a stochastic inventory model for a single-CRC and multi-LCPs reverse supply chain. They used a cost minimization objective to determine the LCPs economic inventory level and the CRC economic batch size.

Tab. 1. a Summary of methods to solve reverse logistic problems

Reference	Reverse flow stages					Modeling					Solution			Objectives					Goal												
	U	C	I	D	R	S	CI	CD	CID	MO	IP	MIP	LP	MP	NP	MA	GA	H	S	C	R	E	S	V	N	L	M	D	S	I	
Ko & Evans (2007)	*								*						*	*	*	*	*										*		
Srivastava (2008)	*							*			*	*							*	*										*	
Guo, Liang, Huang and Xu (2008)	*	*																	*											*	
Lee and Dong (2008)	*				*				*				*					*	*										*		
Lee, Gen and Rhee (2009)				*	*	*							*				*	*	*										*		
Dehghanian and Mansour (2009)	*			*	*				*				*				*	*	*		*	*							*		
Lee and Chan (2009)	*	*		*	*	*							*				*									*			*	*	
Pishvae, Zanjirani and Dullaert (2010)	*			*	*	*	*			*		*				*			*	*		*	*							*	
Wang and Hsu (2010)	*				*				*		*	*				*		*	*								*	*	*	*	

KEY:

Reverse flow stages:	Modeling:	Solution methods:	Objective functions:	Goal:
U Customer	MO Multi-objective	MA Memetic	C Cost / profit	N Design network
C Collector	MIP Mixed integer programming	Algorithm	R Responsiveness	L Locating collection points
I Inspector	IP Integer programming	GA Genetic Algorithm	E Environmental impacts	M Locating manufacturer point
D Distributor	R Recycler /remanufacturer disposal center	H Heuristic Algorithm	S Social impacts	D Locating distributor point
R Recycler /remanufacturer disposal center	LP Linear programming	S Simulation /Scenario check	V Coverage of Customers	S Locating disposal point
CI Collector / inspector	MP Mathematical programming			I Inventory management
CD Collector / distributor	NP Non-linear programming			
CID Collector /inspector /distributor				

3. Methodology

This paper initially conducted a literature review of issues related to RL, optimization models and techniques in this subject. After this review, the problem is defined and the conceptual framework for this problem is depicted. The previous mathematical models are expanded and a new mixed integer model is presented. The model is solved by GA coded via

MATLAB 7. For applying the proposed GA, we consider a tire and rubber manufacturer and recycler plant. Some data for the case are derived from formal statistics. The unknown data are generated randomly.

4. Problem Definition

The reverse logistic is determined as a simple process: (1) Returned products are transferred and collected in

collection centers; (2) Collected items are tested and inspected at inspection centers; (3) The inspection center divides items to remanufacturable, recyclable and waste; and (4) The items transfer to remanufacturer, recycler or disposal according to categories assigned in previous step. To simplify the model, we assume just one manufacturer that has recycling and remanufacturing within itself. A disposal center is allocated somewhere else in another city. In the presented conceptual model (Fig), the forward flow from manufacturer to customer is assumed predetermined and the places are fixed. Therefore the forward flow is not mapped in this model to prevent the complexity.

The main objective of this paper is to design a decision model to help managers of RL in locating their

facilities and deciding about integrating some of them. As discussed before, some studies integrate collection, inspection and distribution centers, while others separate them.

We expect to determine which integrations will be most profitable and helps in collecting the maximum potential used products. The different potential models are shown by R1 to R4 in Figure 2. In R1 all the facilities are integrated in an available distribution center. By this decision the fixed cost of opening facility is decreased. In R2, just a collection center is integrated within distribution center. Two other models require installing new facilities, in R3 the facilities are separate and in R4 are integrated.

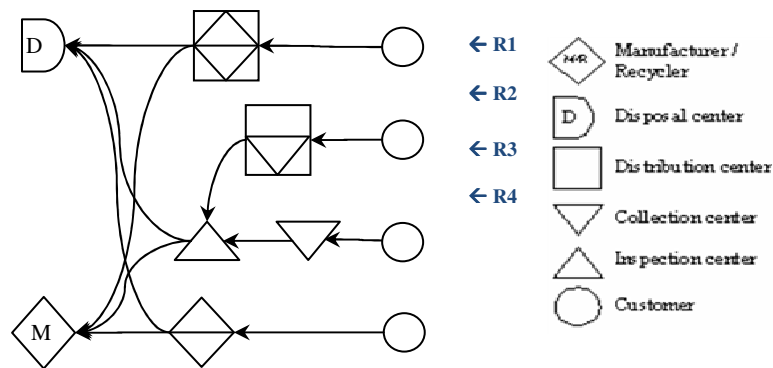


Fig. 2. The conceptual model for our problem model formulation

Prior to formulating the problem, some assumptions are made to simplify the model. When a collection or inspection center or both are established within a distribution center, distributor cannot use a fraction of its capacity. This will cause more costs for distributor to do its usual distribution tasks. To consider the increase in model, we assume that (1) every distribution, collection or inspection center has a capacity equal to C.

Integrating two or three of these centers, decreases the capacity to 1/2 or 1/3 for each one. To calculate the increase in cost, we assume that (2) every distribution center uses $B_m \geq 0.5$ of its capacity in the forward flow.

Therefore, the increase in distribution costs by integrating one and centers within distributor is calculated by $(B_m - 0.5)d_m$ and $(B_m - 0.33)d_m$.

The notations in the formula of our model are as follows:

- Q_i Return quantity of used products from customers in location i
- QC_i Quantity of collected products in collection center i
- e Average re-manufacturable or recyclable fraction in every inspection center

- C_i^p Fixed cost of opening collection center in location i with capacity level p
- I_i^p Fixed cost of opening inspection center in location i with capacity level p
- dc Fixed saving cost of integrating a collection and distribution center in location i
- ic Fixed saving cost of integrating inspection and collection center in location i
- di Fixed saving cost of integrating inspection and distribution center in location i
- cid Fixed saving cost of integrating collection, inspection and distribution centers in location i
- CC Transfer cost per unit of products per kilometer from customer to collection center
- CI Transfer cost per unit of products per kilometer from collection center to inspection center
- IR Transfer cost per unit of products per kilometer from inspection center to remanufacturer / recycler
- ID Transfer cost per unit of products per kilometer from inspection center to disposal
- B_i Percent of used capacity in distribution center i in forward logistics flow
- D_i Average distribution cost in distribution center i in forward logistics flow
- M The number of planned centers (collection and inspection) to implement in different locations

Variables:

- $y_i = \begin{cases} 1 & \text{if a single collection center is installed in location } i \\ 0 & \text{otherwise} \end{cases}$
- $z_i = \begin{cases} 1 & \text{if a single inspection center is installed in location } i \\ 0 & \text{otherwise} \end{cases}$
- $x_{ik} = \begin{cases} 1 & \text{if a collection center in location } i \text{ serves customers of location } k \\ 0 & \text{otherwise} \end{cases}$
- $m_{ik} = \begin{cases} 1 & \text{if an inspection center in location } i \text{ serves collection center of location } k \\ 0 & \text{otherwise} \end{cases}$
- $yd_i = \begin{cases} 1 & \text{if collection center is integrated to distribution center in location } i \\ 0 & \text{otherwise} \end{cases}$
- $yz_i = \begin{cases} 1 & \text{if collection center is integrated to inspection center in location } i \\ 0 & \text{otherwise} \end{cases}$
- $zd_i = \begin{cases} 1 & \text{if inspection center is integrated to distribution center in location } i \\ 0 & \text{otherwise} \end{cases}$
- $yzd_i = \begin{cases} 1 & \text{if collection and inspection centers integrate to distribution center } i \\ 0 & \text{otherwise} \end{cases}$

5. Mathematical Model

The problem for designing RL is formulated as follows. The objective function is in accordance with Pishvae et al. (2010), while some modifications are performed. The increase in distribution costs that will be occurred by integrating facilities is not considered in literature that is added to the objective function. The savings from integrating different facilities is more precisely expanded in current formula. In addition, the

distance between centers is added to the current model for transportation costs. Given the above information, the objective function is composed of following components:

Total cost = Fixed opening costs - Savings from integrating facilities + Increase in distribution costs (for limiting distributors capacity) + Transportation costs (between collection-inspection and inspection-recycling and inspection-disposal).

$$\begin{aligned}
 \text{Min } Z = & \sum_{i \in I} (y_i + yd_i + yz_i + yzd_i)C_i^p + \sum_{i \in I} (z_i + yz_i + zd_i + yzd_i)I_i^p - \sum_{i \in I} ic.yz_i \\
 & - \sum_{i \in I} dc.yd_i - \sum_{i \in I} di.zd_i - \sum_{i \in I} cid.yzd_i + \sum_{i \in I} (yd_i + zd_i).(B_i - 0.5).D_i \\
 & + \sum_{i \in I} yzd_i.(B_i - 0.33).D_i + \sum_{i \in I} (\sum_{j \in I} QC_j.y_j.m_{ij}).CI \\
 & + [\sum_{i \in I} (\sum_{j \in I} QC_j.y_j.m_{ij}).e.dsr_i].IR \\
 & + [\sum_{i \in I} (\sum_{j \in I} QC_j.y_j.m_{ij}).(1 - e).dsd_i].ID
 \end{aligned} \tag{1}$$

Subject to:

- $QC_i = \sum_{j \in I} Q_{ij}.x_{ji} \quad \forall i \in (1, \dots, I) \tag{2}$
- $\sum_i (z_i + yz_i + zd_i + yzd_i) \geq 1 \tag{4}$
- $\sum_i x_{ik} (y_i + yd_i + yz_i + yzd_i) \geq 1 \quad \forall k \in (1, \dots, K) \tag{5}$
- $\sum_i (y_i + z_i + yd_i + yz_i + yzd_i + zd_i) \leq M \tag{3}$
- $\sum_i Q_{i, x_{ki}} \leq P(y_k + yd_k + yz_k + yzd_k) \quad \forall k \in (1, \dots, K) \tag{6}$

$$m_{ik} \leq z_i + zd_i + yz_i + ydz_i \quad \forall i,k \quad (7)$$

$$m_{ik} \leq y_k + yd_i + yz_k + ydz_k \quad \forall i,k \quad (8)$$

$$x_{ik} \leq y_i + yd_i + yz_i + ydz_k \quad \forall i,k \quad (9)$$

Equation (2) calculates the quantity of collected products in collection center i . It is equal to the quantity of used products in the places that send their products to the collection center. Constraint (3) limits the number of installed facilities in the different zones. Constraint (4) obligates the model to install at least one inspection center. Constraint (5) shows that customers at each location should be serviced at least by one collection point. Constraint (6) is the limit of collection centers' capacity. (7), (8) and (9) are constraints for m_{ik} and x_{ik} . These constraints show that if a collection / inspection center is considered for serving another point, the center must be installed at the place.

6. Solution Approach

The closed loop logistic model is known as an NP-hard problem in most researches (Wang & Hsu, 2010; Ko & Evans, 2007; Min & Ko, 2008; Lee & Dong, 2008). Furthermore, the proposed mathematical model includes a large number of constraints and nonlinear components in the objective function and constraints. That is why we propose GA to obtain good solutions. The effectiveness of GA for allocation and supply chain networks problems is proved in previous researches. In reverse supply chain and reverse logistic also, this approach is used and optimized, that are discussed in previous parts.

In the current paper, GA is coded via MATLAB 7. To define initial population and reproduce chromosomes, the constraints of our mathematical model are applied in the code. The steps of proposed GA and the results of running the model are described in appendix A.

7. Model Application and Results

By the increasing use of vehicles in transportation and material handling, mountains of used tires has grown during last decade and this leads to considering tires as assets of a society (Dehghanian & Mansour, 2009). By estimating population, car usage and tire recycling trend in Iran, it is anticipated that more than 1,400,000 tons of used rubber will be produced in Iran until 2025 that can be hazardous for environment (News: Automobile Industry Database, 2010), while country will lose its potential economical and social benefits (Dehghanian & Mansour, 2009).

The added value in car and truck tire remanufacturing, will reduce the manufacturing costs of new tire and rubber while improving the sustainability of tire industry (Lebreton & Tuma, 2006). These are some reasons that we test our proposed model in a tire and rubber recovery case.

Usually five different options are defined for tires end-of-life decisions:

- Reusing scrap tires, that regularly used in agriculture and civil engineering applications.
- Recycling of scrap tires that can be reclaiming of the rubber content of scrap tires and grinding scrap tires into crumb rubber.
- Retreading tires that means replacing tire tread by a new one.
- Discarded tires that are utilized for their energy value in power plants, tire-manufacturing facilities, cement kilns, and pulp and paper production.
- Disposing in landfill is the last EOL option that is the least favorable because of its negative impact on environment (Dehghanian & Mansour, 2009).

In this paper, we consider two main categories of EOL options as:

- 1) Recycling / Remanufacturing – includes reusing, recycling and retreading.
- 2) Disposal – includes discarding and disposal.

A six-echelon network consisting of one manufacturer, one recycler, one disposal site, four distribution centers and some collection and inspection centers, that will be decided on the number and type, is considered in this paper. To simplify the estimations about distances and quantity of used rubber, we assume four central provinces of Iran: Yazd, Isfahan, Kerman and Fars. A manufacturing site is located in Yazd province that has the recycling site within itself. In Isfahan, a disposal plant is located that uses the energy value of tires. To calculate return quantity of used products from these cities, we consider 111.6 automobile per 1000 person as presented by Iran transportation energy data book (2006). Distances between these cities are shown in Table 2.

Tab. 2. Distance between studied cities – in kilometer

	Isfahan	Yazd	Fars	Kerman
Isfahan		300	485	661
Yazd	300		425	361
Fars	485	425		571
Kerman	661	361	571	

Since little information is publicly available about RSCM in Iran, we can hardly access the non-biased data. For example about the percent of disposal and recycling, as stated by head of Iran environmental protection agency, only 7% of tires are recycled in Iran. On the other hand, Dehghanian & Mansour (2009) claimed that about 70% of scrap tires are disposed in stockpiles and only 30% are processed in retreading. By this high difference between information, we decide to rely on randomly generated parameters using uniform distribution for not-available

data. The numbers are shown in Table 3 and Table 4. To simplify the model, we consider that the capacity of each collection or inspection center is about 2,000,000 tires.

Tab. 3. Simplify the model

	Isfahan	Yazd	Fars	Kerman
Q_i	502,125	106,949	471,032	288,467
C_i^p - (million rails)	1,080	3,660	1,010	1,840
I_i^p - (million rails)	4,680	6,580	4,470	5,220
B_i	0.50	0.60	0.50	0.90
D_i	2,330	1,380	3,900	4,330

Tab. 4. Simplify the model

dc	470 million
ic	600 million
di	790 million
cid	1,670 million
CI	178
IR	221
ID	107
e	0.3

The model is tested for installing maximum four facilities in the studied cities. The results of solving the problem by two different settings of GA are demonstrated in appendix A. In the recommended solution by setting 2, that has less cost, a collection center is installed in Yazd, a collection /inspection center in Fars, a collection /inspection / distribution center in Kerman and an inspection center in distribution center of Isfahan. Isfahan gets collection services from Yazd. Considering this result, it is observable that by integrating collection / inspection centers in the distribution center of Fars, the total cost will decrease 7 units. This occurs because of the nature of meta-heuristic algorithm, that leads us to recommend using hybrid algorithms for solving similar problems.

8. Conclusion

Due to the global concern about environmental protection and the problem of used products, companies will be obligated to design their RL networks and decrease their product wastes. In this paper, we address RL facility allocation and integration problem. A mathematical model is formulated and GA is applied to solve the model. To test the applicability of model, it is used in a case of tire recovery problem. The results show that usually best solutions are achieved when the free space of distribution centers is used for collecting / inspecting used products, especially in cities without recycling / disposal center. However, it must be considered that this decision depends on the free space of distribution centers as

well as the costs for installing new facilities and transporting used products. The model also can be developed to contain benefits of RL such as material, energy and labor cost saving and become more precise. In this study GA has shown good performance in allocation problem, but as its nature is, sometimes the final solution is not the best one. To overcome the local optimum problem, it is recommended to use hybrid algorithms in future researches. Moreover, by real-data from other industries the performance of mathematical model can be approved and enhanced to use in future problems.

References

- [1] Bai, H., *Reverse Supply Chain Coordination and Design for Profitable Returns*. Massachusetts: Worcester Polytechnic Institute, 2009.
- [2] Bayles, D., *E-Commerce Logistics and Fulfillment*. Upper Saddle River, NJ: Prentice-Hall, 2001.
- [3] de la Fuente, M.V., Ros, L., Cardos, M., Integrating Forward and Reverse Supply Chains: Applications to a Metal-Mechanic Company. *International Journal of Production Economics*, 111, 2008, pp. 782-792.
- [4] Dehghanian, F., Mansour, S., *Designing Sustainable Recovery Network of End-of-life Products Using Resources, Conservation and Recycling*, 53, 2009, pp. 559-570.
- [5] Guide, V.D., Wassenhove, L.N., *The Evolution of Closed-Loop Supply Chain Research*. *Operations Research*, 57 (1), 2009, pp. 10-18.
- [6] Guo, Q., Liang, L., Huang, Z., Xu, C., *A Joint Inventory Model for an Open-loop Reverse Supply Chain*. *International Journal of Production Economics*, 116, 2008, pp. 28-42.
- [7] Ko, H.J., Evans, G.W., *A Genetic Algorithm-Based Heuristic for the Dynamic Integrated Forward/Reverse Logistics Network for 3PLs*. *Computers & Operations Research*, 34, 2007, pp. 346-366.
- [8] Lee, C., Chan, T., *Development of RFID-Based Reverse Logistics System*. *Expert Systems with Applications*, 36, 2009, pp. 9299-9307.
- [9] Lee, D.H., Dong, M., *A Heuristic Approach to Logistics Network Design for End-of-Lease Computer Products Recovery*. *Transportation Research Part E*, 44, 2008, pp. 455-474.
- [10] Lee, J.E., Gen, M., Rhee, K.G., *Network Model and Optimization of Reverse Logistics by Hybrid Genetic Algorithm*. *Computers & Industrial Engineering*, 56, 2009, pp. 951-964.
- [11] Min, H., Ko, H.J., *The Dynamic Design of a Reverse Logistics Network from the Perspective of Third-Party*

Logistics Service Providers. International Journal of Production Economics , 113, 2008, pp. 176–192.

[12] Mutha, A., Pokharel, S., *Strategic Network Design for Reverse Logistics and Remanufacturing using New and old Product Modules*. Computers & Industrial Engineering , 56, 2009, pp. 334–346.

[13] Pokharel, S., Mutha, A., *Perspectives in Reverse Logistics: A Review. Resources, Conservation and Recycling* , 53, 2009, pp. 175-182.

[14] Prahinski, C., Kocabasoglu, C., Empirical research opportunities in reverse supply chains. *Omega* , 34, 2006, pp. 519 – 532.

[15] Rogers, D.S., Tibben-Lembke, R.S., *Going Backwards: Reverse Logistics Trends and Practices*. Reno: University of Nevada, Center for Logistics Management, 1998.

[16] Srivastava, S.K., Network design for reverse logistics. *Omega* , 36, 2008, pp. 535 – 548.

[17] Stock, J., Speh, T., Shear, H., Many happy (product) returns. *Harvard Business Review* , 80 (7), 2002, pp. 16–17.

[18] Wang, H.F., Hsu, H.W., *A Closed-loop Logistic Model with a Spanning-tree Based Genetic Algorithm*.

Computers & Operations Research , 37, 2010, pp. 376-389.

[19] Yikai, H., *Analysis of the Supply Chain Design and Planning Issues: Models and Algorithms*. Phd Thesis, National University of Singapore, Department of Civil Engineering, 2007.

Appendix

Appendix A. The proposed Genetic Algorithm (GA) Steps in GA

The steps in proposed GA are in accordance with the process defined by Lee & Chan (2009), by some modifications for our special problem. The pseudo code for our proposed algorithm to solve by MATLAB 7 is shown in Figure 7. The proposed GA is as follows:

- a- **Initializing** - The designed chromosome for the CLL problem is presented as consisting of *i* major segments, where *i* is the number of potential points for installing facilities. Six first gens of every segment are related to facilities installation. These binary variables show that what facilities are installed in potential point *i*. The last gen in every segment show that where the potential point *i* is served for collecting items. An illustration of the chromosome is depicted in Figure 3.

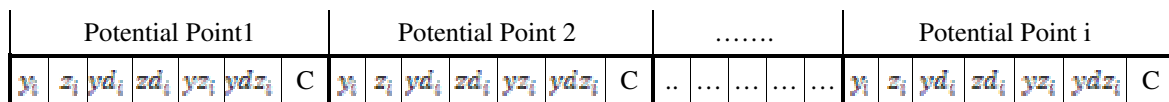


Fig. 3. An illustration of the model chromosome

For example the representation of a chromosome in Figure 4 shows that in potential point 2 a collection center is installed ($y_2 = 1$) and in potential point 4 an inspection center is integrated to the collection and distribution center ($ydz_4 = 1$).

The collection center in point 4 serves points 3 and 4 for collecting and inspecting and collection center in point 2 serves points 1 and 2 for collecting items. ($C_1 = 2, C_2 = 2, C_3 = 4, C_3 = 4$).

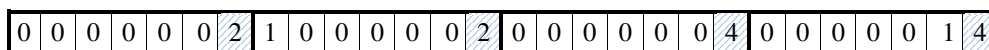


Fig. 4. A genetic representation of a solution

- b. **Fitness evaluation**–Fitness function evaluates the performance of each solution that usually improves in successive populations. In this paper, the objective function of mathematical model is considered as the fitness function.
- c. **Selection** - Selection gives a higher chance to parents and children with higher fitness values to be chosen for producing next generation. In

this study, roulette wheel selection method is used to increase the likelihood of creating superior offspring (Lee & Chan, 2009).

- d. **Crossover** - After selecting pairs of chromosomes, crossover helps to exchange information between them to create children. The two-point crossover shown in Fig. is applied in this paper.

e. **Mutation**- Mutation diversifies solutions by changing some genes of chromosomes to avoid similar gene swap in crossover. In this

paper, as some kind of mutation is applied for infeasible solutions, mutation operators are just applied for infeasible chromosomes.

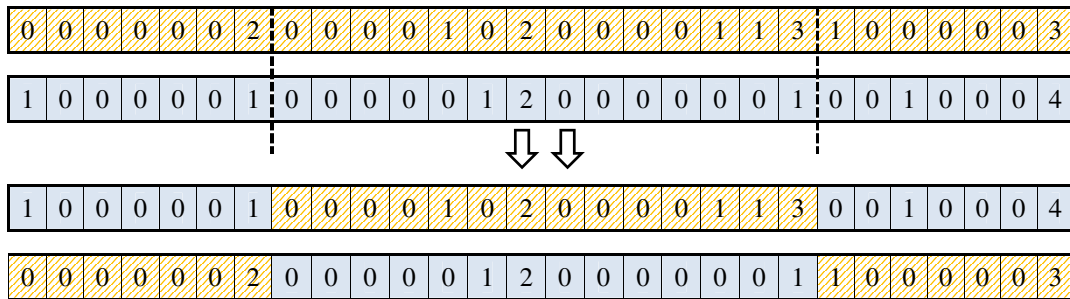


Fig. 5. An illustration of crossover operator

f. **Repair** - Performing genetic operations may lead to infeasible solutions that must be replaced by feasible ones. The repair process is to test different alternatives for changing collection and inspection centers in every segment. At last, the one with best fitness function will replace the infeasible solution. For example, the infeasible solution presented in Figure 6 has four collection centers, with no

inspection center. To repair the chromosome, different alternatives for installing inspection center in potential points 1 to 4 are tested and fitness function for these alternatives is calculated. As shown in Figure 6, the best gene for replace has a fitness function equal to 95. The genes with “N” symbol cannot be changed, because the outcome contravenes the restrictions.

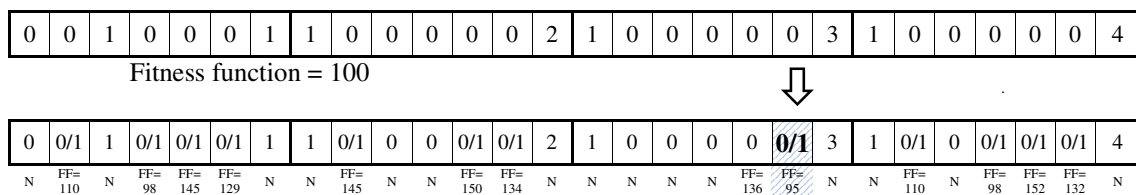


Fig. 6. An illustration of repair process

g. **Replacement**– from three main types of replacement strategies, we adopt elitist strategy. To apply this strategy, four best parents according to their fitness values, will replace worst four children. Then these parents and other offsprings will survive in next generation (Lee & Chan, 2009).

- Initial population = 20 , number of iterations = 50
- Initial population = 30 , number of iterations = 100

h. **Termination**– we defined stopping criteria for evolutionary process when the best chromosomes were not improved in the last 10 generations. In addition, if the number of generations exceeds 100, the algorithm will stop.

Despite 50 and 100 iterations for termination, another stopping criterion is not improving for 10 generations. Since then, as the results show, the average number of iterations that lead us to final solution is 38 and maximum number of iterations is 49. This is concluded that 50 iterations usually lead us to the best solution. Comparing 20 and 30 for population size also shows better results for larger populations.

Two final solutions for the two settings of GA are shown in Tab..

Considering the second setting in this paper, it is observable that by integrating collection / inspection center in distribution center of Fars, the total cost will decrease 7 units. This occurs because of the nature of meta-heuristic algorithms.

Computational Results

The proposed GA model is tested for installing maximum four facilities in the studied cities by two different settings:

Tab. 5. The final solutions for the two different settings of GA

Setting	number of generations	Pop. size	final solution				Final Fitness	Chart
			Isfahan	Yazd	Fars	Kerman		
1	100	20	-- C→ Fars	C	CID	CID	14,120	
2	50	30	DI C→ Yazd	C	CI	CID	10,950	

```

WHILE h < 31
  Create chromosome (h) randomly and check the constraints for it
  WHILE at least one constraint is not met
    Revise the chromosome (h)
  ENDWHILE
  Fitness (h) = Fitness (chromosome (h)) , h=h+1
ENDWHILE
WHILE generation < 50
  IF fitness is not improved in last 10 generations or generation = 50 THEN
    Select the best chromosome and best fitness as the response
  ENDIF
  FOR m = 1 to 4
    Elite (m) = chromosome with best fitness
  ENDFOR
  FOR t=1 to 30 step 2
    Parent 1 = Roulette Wheel Selection
    Parent 2 = Roulette Wheel Selection
    Crossover parents in two points and name them chromosome (t) , chromosome (t+1)
  ENDFOR
  FOR t = 1 to 30
    Check the constraints for chromosome (t)
    IF at least one constraint is not met
      Repair the chromosome
    ENDIF
    Fitness (t) = Fitness (chromosome (t))
  ENDFOR
  FOR m = 1 to 4
    Replace the worst fitness (m) with elite (m)
  ENDFOR
  generation = generation + 1
ENDWHILE

```

Fig.7. GA pseudo code