A Decentralized Reverse Logistics Network for End of Life Vehicles from Third Party Provider Perspective

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Abstract— With increasing concerns over environmental issues in End of Life vehicles, researches on life cycle management and reverse logistics are being expanded in automotive industry. Also, automotive producers have been involved in reverse logistics activities as a result of legislations for management of End of Life vehicles such as Directive 2000/EC/53. On the other hand, it has been proved that reverse logistics has the aspects of uncertainty on quantity, quality, time and place of returns and it is barely possible to reach economies of scale for any individual manufacturer. Therefore, third party reverse logistics is regarded as another alternative by automotive manufacturers. In this paper, designing a reverse logistics network for end of life vehicles, that contains third party provider, is studied. The proposed network is modeled from the third party provider perspective with aim at the minimization of total costs of the network. The mathematical model is a capacitated facility location allocation problem formulated as MILP. A numerical example from Iran’s current situation is considered and is solved by Cplex 6.3 for testing and validation of the proposed model.

Keywords- third party provider; reverse logistics; location allocation; dismantling; end of life vehicles

I. INTRODUCTION

In theory, reverse logistics is opposite to the forward logistics, it is actually very involved and can be extremely complex [1]. Reverse logistics generally includes events necessary to retrieve, transport, recycle and dispose of EOL (End-of-Life) goods. Recently, an exhaustion of resources and growing concern for environmental problems has led to policies that influence on reverse logistics in various industrial sectors [2]. One of these industries is the automotive manufacturing that is currently subject to accomplish the requirements of Directive 2000/53/EC in the European Union. Some important elements of this Directive are the prevention of waste from vehicles, the improvement of vehicle dismantling and recycling to make them more environmentally. This Directive aims at producer responsibility and obliges manufacturers to take-back, collect and recycling the ELVs (End-of-Life Vehicles) [3].

In some complex products, such as vehicles, it is very difficult to predict when returns happen, what quality goods are and how many they are, there is great uncertainty for reverse logistics. On the other hand, most reverse logistics needs investments on facilities e.g. retrieve centers and dismantling equipments. Furthermore, the payback period is long and goods in reverse flow are relatively low value and the volumes of them are less than in forward flow. In order to reach economies of scale and enhance value added in collected items, a new reverse logistics mode i.e. third party reverse logistics can be implemented [1].

In this paper, a two level collecting network is proposed for design of RL network through third party sectors. The rest of the paper is organized as follows: section 2 defines the problem and briefly reviews the relevant literature; in section 3, the mathematical model is introduced; in section 4, a numerical example is presented to demonstrate the efficiency of the proposed model; and finally in section 5, conclusions are outlined.

Problem Definition and Literature Review

Limited capacity and resources of companies cannot cover everything. For example, Xerox must replace and upgrade hundreds of office printers monthly. By means of outsourcing RL and on-site dismantling, it can improve customer service quality, increases customer satisfaction and international competitiveness [4].

The intrinsic uncertainties in RL caused enterprises do not have adequate capacity to build core RL system [5]. 3PRL automotive enterprise concentrates on core operations and improving the core processes. Professional 3PRL providers, usually have complete RL network, advanced equipments of substantial operation experience and advanced management system. Then they are capable to provide professional RL services, improve service levels and diminish the risks and uncertainties. For instance, they can provide warehousing services to the returned process. They can also provide logistics tracking service, etc. From professional view, 3PRL automotive enterprises could help manufacturers to improve their product design by appear feed backing to them [5].

The building of RL collection and dismantling centers, establishment of recycling disposal facilities and setting up information systems, all of these require extensive funds with long capital revival cycle. On the other hand, creation of RL network is extremely complicated as well, it must include high transportation and logistics technology, information technology and personnel quality. In fact, these are not core capabilities of the manufacturer. It is difficult to obtain profit from self RL operation.

Due to professional services, 3PRLs can serving most customers to collect, transport and dispose of their goods that improve the economies of scale. Just as GENCO, the well-known RL company of the United States, that provides RL services for K-mart, Wal-Mart and other retailers [2].
automotive industry, through gathering various brands of vehicles, 3PRLs can increase number of collected ELVs and achieve much better economies of scale.

In short, judged to the traditional model of RL (reverse logistics), 3PRL (third party reverse logistics) model of automotive enterprises could not only decrease the investment on reverse logistics facilities, but also improve the competitiveness of companies.

With increasing concerns over environmental issues in ELVs, research on life cycle management and reverse logistics has expanded in automotive industry. Designing of RL network is an important part of the reverse logistics management. There are some papers that focus on this problem (designing RL network for ELVs). For example, Schultmann et al. (2006) [3] designed reverse logistic tasks within closed-loop supply chains for ELVs. Reynaldo et al. (2009) [2] formulated ELV collecting network as an uncapacitated facility location model in Mexico. There exist also case studies in the literature which address ELVs reverse logistics problems. For example, Chen et al. (2009) [6] studied managing reverse logistics in the Chinese automobile industry. After good experiences due to implementing of third party logistics, researches on third party reverse logistics began in initiate of last century. Krumwiede et al. (2002) [1] is the most famous paper in this subject that studied conceptual issues of 3PRL. Recently, third party reverse logistics have been more seen in paper titles, for example, Wang et al. (2009) [4] or Bo et al. (2009) [5] that first paper presented a benchmarking model for third party reverse logistics.

II. THE MATHEMATICAL MODEL

A. Conceptual Model

Reverse logistics is the process of moving EOL products from downstream to upstream to satisfy customers’ demands and to protect environment. In general, the practice of automobile reverse logistics includes several distinct operations; collecting, transporting, dismantling, refurbishing, remanufacturing, recycling, and disposal.

a) Collection and Transportation

Collection can be described as the process of collecting and removing ELVs from a customer. ELVs are collected from the ultimate consumer. The 3PRL provider is responsible for collecting all of ELVs from consumer regions to collection centers. This step includes collection, transportation and warehousing. Despite that ultimate owners may ship ELVs to collection center by themselves, but since ELVs are collected from scattered customers, logistics cost is high. Transportation in RL network is considered to be the actual movement of goods from one location back to another location and is one of the key factors because it is extensively involved in all aspects of reverse logistics.

b) Dismantling and refurbishing

In practice, 3PRL providers do not want to process the ELVs remanufacturing and recycling themselves, they mainly participate in take-back operations by collecting the ELVs from final users and selling them after dismantling and refurbishing processes.

After dismantling and refurbishing operations, the resalable parts are sold in reuse markets, remanufacturable parts are sent to manufacturers, hazardous materials are carried to landfills and remains, that can be recycled, are delivered to recyclers (hulks and metal parts are carried to metal recycler after crushing in shredders).

c) Decentralized Network

In traditional reverse logistics networks, one type of facility is considered as base of the network, that is, a number of collecting centers are located in regard to locations of the exits facilities and customer regions. This kind of RL networks is very common in simple goods, such as computers and electronic products, in which the processing activities are performed in collection centers. In case of End of Life vehicles, because of complex and heavy operations required for vehicles, this is seemed better to consider another facility for processing activities that is called dismantling center.

There are some differences between locating of collection centers and dismantlers. Whereas collection centers are simpler than dismantling centers, they are more flexible in locating as there are more candidate locations for opening them. On the other hand, because collection centers have fewer costs of opening and operations, the number of founded collection centers would be more than dismantling ones, that is, collection centers are founded in small capacities but large numbers and dismantlers are founded in large capacities but few numbers.

Fig. 1 illustrates the proposed network of third party reverse logistics for ELVs. The 3PRL provider collects ELVs from customer by opening collection centers in customer regions. Collection center is a place for gathering, holding, and some initial processes in order to preparation for dismantling in dismantling centers. After moving ELVs to dismantling centers and dismantling them, the 3PRL provider transfers the separated parts and materials according to the matter explained above. It is necessary to say that 3PRL sales that parts and materials (except hazardous materials), then flows such as recyclers to suppliers and suppliers to producers are not included in 3PRL provider function.

The main focus of the model is on establishing the collecting and dismantling centers in optimal locations and determining the optimal capacities of these centers. The other purpose is to optimize the quantity of materials flow between various engaged facilities.

In order to attain the above objectives, the mathematical model must provide answers to the following questions:

- What are the optimal locations for opening the collection centers?
- What are the optimal locations for opening the dismantling centers?
- What are the optimal capacities of established centers?
- What is the best cost effective approach for material transportation between various facilities of the network?
B. Mathematical Formulation

Based on the candidate locations of the collection centers and dismantlers and on the corresponding capacities of these centers, the objective function minimizes the total cost of RL network for ELVs from the perspective of 3PRL provider. Fig. 2 indicates which part of the network is variable and must be minimized.

The formulated model is a capacitated location-allocation problem in a discrete space. Two kinds of facilities must be located simultaneously: collection centers and dismantling centers.

The coordinated indexes, parameters and variables are followed:

Indexes:
- \( i = \) ELV region \((i=1,\ldots,I)\)
- \( j = \) collection center \((j=1,\ldots,J)\)
- \( k = \) dismantler \((k=1,\ldots,K)\)
- \( q = \) ELV type \((q=1,\ldots,Q)\)
- \( s = \) recycler \((s=1\) recycler of plastic and tier; \(s=2\) recycler of glass; \(s=3\) recycler of liquids\)
- \( p = \) automotive producer \((p=1,\ldots,P)\)
- \( h = \) shredder \((h=1,\ldots,H)\)
- \( m = \) sales market \((m=1,\ldots,M)\)
- \( l = \) landfill \((l=1,\ldots,L)\)

Parameters:
- \( d_{ij} = \) distance between ELV region \(i\) and collection center \(j\)
- \( d_{1jk} = \) distance between collection center \(j\) and dismantler \(k\)
- \( d_{5ks} = \) distance between dismantler \(k\) and recycler \(s\)
- \( d_{2km} = \) distance between dismantler \(k\) and market \(m\)
- \( d_{3kp} = \) distance between dismantler \(k\) and manufacturer \(p\)
- \( d_{4kh} = \) distance between dismantler \(k\) and shredder \(h\)
- \( d_{6kl} = \) distance between dismantler \(k\) and landfill \(l\)
- \( c_1 = \) the transportation cost per ELV per unit distance
- \( c_2 = \) the transportation cost per unit weight per unit distance
- \( w_q = \) the average weight of an ELV type \(q\) per unit weight
- \( F_{C1} = \) the fixed opening cost of collection center \(j\)
- \( f_{C1} = \) the fixed operating cost per ELV in collection center \(j\)
- \( m_c = \) minimum capacity of collection centers
- \( M_c = \) maximum capacity of collection center \(j\)
- \( F_k = \) the fixed opening cost of dismantler \(k\)
- \( f_k = \) the fixed operating cost per ELV in dismantler \(k\)

Decision variables:
- \( b_{ijq} = \) number of ELVs type \(q\) received from region \(i\) to collection center \(j\)
- \( U_{Cj} = \) capacity of collection center \(j\)
- \( h_{1jkq} = \) number of ELVs type \(q\) received collection center

Figure 1. Conceptual model of 3PRL of ELVs.

Figure 2. Variable section of the 3PRL network that would be minimized in mathematical formulation.

- \( m = \) minimum capacity of dismantlers
- \( M_k = \) maximum capacity of dismantler \(k\)
- \( \beta_1q = \) weight percent of plastics and tiers in ELV type \(q\)
- \( \beta_2q = \) weight percent of glasses in ELV type \(q\)
- \( \beta_3q = \) weight percent of liquids in ELV type \(q\)
- \( \beta_4q = \) weight percent of hulk in ELV type \(q\)
- \( \beta_5q = \) weight percent of resalable parts in ELV type \(q\)
- \( \beta_6q = \) weight percent of remanufacturable parts in ELV type \(q\)
- \( \alpha_q = \) percent of ELVs that shipped to collection centers by RL network
- \( 1-\alpha_q = \) percent of ELVs that delivered to collection centers by ELV owner
- \( D_q = \) number of ELVs type \(q\) that must be collected from region \(i\)
To dismantle $k$

$U_k$ = capacity of dismantler $k$

$b_{2km}$ = total weight transported from dismantler $k$ to market $m$

$b_{3kp}$ = total weight transported from dismantler $k$ to manufacturer $p$

$b_{ahk}$ = total weight transported from dismantler $k$ to shredder $h$

$b_{sk}$ = total weight transported from dismantler $k$ to recycler $s$

$b_{lai}$ = total weight transported from dismantler $k$ to landfill $l$

$X_{cj} = \begin{cases} 
1 & \text{if collection center } j \text{ is opened} \\
0 & \text{otherwise} 
\end{cases}$

$X_k = \begin{cases} 
1 & \text{if dismantler } k \text{ is opened} \\
0 & \text{otherwise} 
\end{cases}$

Objective function:

Minimize

$$\sum \left( Fc_j X_{cj} + f_c U_c \right) + \sum \left( F_k X_k + f_k U_k \right)$$

$$+ c_1 \sum \sum \sum \left( b_{ij} d_{ijk} + c_1 \sum \sum \sum \left( b_{ijk} d_{ijk} \right) \right)$$

$$+ c_2 \sum \sum \sum \left( b_{abk} d_{abk} + c_2 \sum \sum \sum \left( b_{ahk} d_{ahk} \right) \right)$$

$$+ c_3 \sum \sum \sum \left( b_{sk} d_{sk} + c_3 \sum \sum \sum \left( b_{lai} d_{lai} \right) \right)$$

$$+ c_2 \sum \sum \sum \left( b_{sk} d_{sk} + c_2 \sum \sum \sum \left( b_{lai} d_{lai} \right) \right)$$

subject to:

$$\sum b_{ij} = D_{ijq} \forall i,q$$

$$U_{cj} \leq Mc_j X_{cj} \forall j,$$

$$U_{cj} \geq me X_{cj} \forall j,$$

$$U_{cj} = \sum \sum b_{ij} \forall j,$$

$$\sum b_{1jkq} = \sum b_{jiq} \forall j,q,$$

$$U_k \leq M_k X_k \forall k,$$

$$U_k \geq m X_k \forall k,$$

$$U_k = \sum \sum b_{1jkq} \forall k,$$

$$\sum b_{lai} = \sum \sum w_{ik} \beta_{ikq} b_{1ikq} \forall k,$$

$$\sum b_{lai} = \sum \sum w_{ik} \beta_{ikq} b_{1ikq} \forall k,$$

$$b_{sk} = \sum \sum w_{ik} \beta_{ikq} b_{1ikq} \forall k,s,$$

$$\sum b_{2km} = \sum \sum w_{ik} \beta_{ikq} b_{1ikq} \forall k,$$

$$\sum b_{3kp} = \sum \sum \sum \sum w_{ik} \beta_{ikq} b_{1ikq} \forall k, \quad (14)$$

$X_{cj} = 0, 1 \forall j, X_k = 0, 1 \forall k,$ and all other variables are integer $\geq 0$.

The first two terms in objective function represent the allocated opening and operating costs of the collection centers and dismantlers. The second and third terms show the transportation costs of ELVs from customer regions to the collection centers and dismantlers. The other terms represent the transportation costs from dismantlers to landfills, shredders, recyclers, markets, and producers respectively. The constraint 2 ensures that the all ELVs are shipped or delivered to the collection centers. The constraints 3 and 4 are capacity constraints and don’t allow to open a collection center with exceeded capacity from minimum and maximum limits, the constraint 5 determine the capacity of each collection center. The constraints 6 to 9 are similar to the constraints 2 to 5 and play similar rules for dismantlers. The constraints 10 to 14 insure that all materials dismantled from ELVs are transported to landfills, shredders, recyclers, markets, and producers respectively, the constraint 11 states that the parts delivered to any producer should not exceed its demand.

### III. Numerical Example

The current situation performed in Iran for collection of ELVs is influenced by governmental rules, for example forbiddance of driving by ELVs. A governmental sector, cooperated with major automobile manufacturers, is established to replace the ELVs by new vehicles. But this strategy is not stable and effective. The core reason for this is the absence of consolidated RL networks adding value to ELVs. As there is a lack of legal motivations and disaggregation, most of the processes for ELVs management are not standardized. Without standardization, bad practices are raised in many cases in ELVs management operations, which lead to depressing effects on the recovery value from ELVs. The total number of ELVs generated in Iran remains unknown because of different criteria for counting ELVs. However, there is a direct relationship between vehicular productions and ELV generation. Indeed, the vehicular inputs now will generate ELV in the future. In the lack of detailed information, the number of ELV generated in Iran is guessed as a percentage of the total number of vehicles. Table I contains total number of vehicles in vehicular fleet of Iran and Table II shows the portion of it which is called ELV according to government decision and must be collected.

In this case we focus on designing RL network in Tehran since about %30 of produced vehicles are entered to Tehran vehicular fleet [7]. The 3PRL provider can serve collection and RL activities for number of automotive producers as much as he wants. Though, a principal criterion for this decision is the economies of scale that would be enhanced by increasing the collected number of ELVs. In this example, we suppose that the 3PRL provider cooperates with two major manufacturers, A and B, that produce 61.3, 22.8 percent of domestic passenger cars respectively [7]. Table III
indicates more details about these producers and ELVs in Tehran. Other assumptions are as follows:

- 22 customer regions are considered according to 22 municipal areas and distribution of ELVs in these regions is determined randomly.
- According to Table II, there are 20 ELV types.
- 20 candidate sites are considered for opening the collection centers and 10 candidate sites are considered for opening the dismantlers.
- There are 2 shredders, 2 markets, 2 landfills, and one recycler for each type of recycling.
- \( c_1 = 1; \ c_2 = 0.001; \ m_c = 300; \ m_r = 4000; \) for all candidate collection centers \( fc = 5; \) for all candidate dismantlers \( fc = 5; \) and for all ELV types \( \alpha = 20\%.
- Third party provider, based on contract with two producers, must collect all current ELVs in five years. Therefore, 3PRL deals with \( 20\% \) of total ELVs every year. At the end of fifth year, same amount must be collected annually.

The numerical example has been solved by Cplex 6.3 and optimal solution has been yield:

- Opening 8 collection centers in candidate sites 3, 11, 12, 14, 16, 17, 18, 20 with capacities 7300, 6800, 6000, 2711, 6700, 7100, 7500, 7500 respectively. Centers 3, 11, 16, 17, 18, 20 are in maximum capacity.
- Opening 5 dismantling centers in candidate sites 2, 3, 5, 9, 10, with capacities 7100, 6700, 20100, 7500, 10211 respectively. Only Center 5 is in maximum capacity.
- Total cost is 10456875.0324 units.

It is obvious that, with increasing parameter \( \alpha \), the total cost will be increased. Value of parameter \( \alpha \) is determined based on the experience of ELV collection in Iran and it would be better to determine \( \alpha \) for each type of ELVs individually.

Another crucial issue is the percentages of reselling, remanufacturing, recycling, and landfilling that may be changed (i.e. landfilling will limited to a small weight percentage of the ELVs) and affect the optimal solution. Hence, the numerical example was solved based on Directive 2000/53/EC percentages.

<table>
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<tr>
<th>Old (year)</th>
<th>Passenger car</th>
<th>Bus</th>
<th>Minibus</th>
<th>Light truck</th>
<th>Truck</th>
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<td>23167</td>
<td>11589</td>
<td>662277</td>
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<tr>
<td>5-10</td>
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<td>12053</td>
<td>6672</td>
<td>173533</td>
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<tr>
<td>11-15</td>
<td>409577</td>
<td>6938</td>
<td>15338</td>
<td>120887</td>
<td>34114</td>
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<tr>
<td>16-20</td>
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<td>3469</td>
<td>9511</td>
<td>59995</td>
<td>21476</td>
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<tr>
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<td>9061</td>
<td>15834</td>
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<td>1127630</td>
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<table>
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<th>Longevity (year)</th>
<th>ELV (unit)</th>
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<tr>
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<td>Truck</td>
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<td>255,466</td>
</tr>
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</table>

### IV. SUMMARY AND CONCLUSION

In order to efficiently manage the ELVs dismantling and recovery process, the automotive producers prefer outsourcing their reverse logistics operations. Actually the collecting, dismantling, and transportation are the better activities to outsource because of good experience of third party providers in this area. In this paper after introducing the 3PRL network for end-of-life vehicles, a mathematical model was formulated to minimize the total cost of network as the third party point of view. A numerical example, from Iran automotive industry, was used to test and validate the proposed model. After solving by Cplex6.3, results indicated the optimal locations for establishing the collection centers and determined their capacities in a reasonable manner.

### REFERENCES