A Bi-Level Programming For Reverse Logistics Network Design

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Abstract

In this paper a nonlinear mixed integer bi-level programming model for designing a reverse logistics network is presented. The main goal for designing this network is to collect the End-of-Life (EOL) products and sending them for recycling in the supervision of the government. So the government purchased the EOLs from the customer zones and collects them in collection centers and then sells them to private sector for recycling. Government is the leader in this model and minimizes the total costs of purchasing and transportation of EOLs and defines the optimal price for purchasing and selling of EOLs. Private sector is considered as the follower and seeks to maximize its profit via recycling. Since the bi-level programming models are NP-hard, a heuristic approach based on the genetic algorithm has been applied to solve the presented bi-level model. Finally in this paper, results are given for an illustrative example.

Keywords: Bi-level programming, reverse logistics, End-Of-Life(EOL) product, Genetic algorithm

1. Introduction

With increasing concern over environmental degradation, the collection of used or recyclable products for reprocessing and recycling has grown increasingly in past recent decades. As a result, waste management and also reverse logistics have become of major challenges faced with policymakers and researchers. As a part of worldwide efforts to rationalize waste management, governments have put in place various types of policy mechanisms to stimulate recycling and reprocessing. One class of such policy initiatives has been the establishment of regulatory incentives for product recycling, whether these products will be reused after processing (recycling a used item) or they will be completely reprocessed for subsequent use as a raw material for a new product(recycling an unrecoverable item) (Aksen et al. 2009). Fleischmann et al. (2000) denote five groups of activities that appear to be recurrent in reverse logistics networks: collection, inspection/separation, re-processing, disposal and redistribution. Many researchers have attempted optimization techniques in reverse logistics network design in order to pollution abatement (e.g., Amouzegar and Moshirvaziri (1999); Aksen, et al. (2009) ; Dehghanian and Mansour (2009)). In most of them, it is assumed that there is only one decision maker who decides about the whole network activities. In real world, this assumption is not true for many situations. For example, government can collect the EOL products and private sector independently decides about investing in recycling activities.

In fact, collection of EOL products is one of the major concerns for private sector to invest in recycling projects. So facilitating the collection can be the potential area for the government to stimulate private sector to incorporate in recycling. In this paper government takes the responsibility of collecting the EOLs by providing the incentives (purchase price) to the EOL product holders. In this manner, government collects the EOLs into the potential collection centers and then sells them to private investors in such a price to guarantee the profitability of the recycling projects. Private investors will be responsible for recycling the EOLs. In doing so, they purchase the collected EOLs from the collection centers and then transport the EOLs to the potential recycling centers. It is assumed that recycling centers obtain revenue from recycled materials in market without limitation. So in this problem the important duty for government is to define optimal prices for buying and selling the scrap tires to stimulate the recycling activities. This problem constitutes a leader-follower game that is known as bi-level programming. Accordingly, government and private investors play the leader and follower role respectively. Bi-level programming problem, BLPP, is a mathematical model of a two-stage, non-cooperative game in which the first decision maker (leader) can influence but not control the actions of the second (follower) so the cooperation is not allowed. A typical bilevel programming model can be shown as follows:

$$
\begin{aligned}
&\min_{x \in X} F(x, y) \\
&\quad s.t. \\
&\qquad G(x, y) \le 0 \\
&\qquad \min_{y \in Y} f(x, y) \\
&\qquad\quad s.t. \\
&\qquad\qquad g(x, y) \le 0 \\
&\qquad\qquad x, y \ge 0
\end{aligned}
$$

Each of the decision makers optimizes his/her objective function. The leader starts first by choosing a vector $x \in X$ in an attempt to optimize his/her objective function $F(x, y)$. The leader's choice of strategies affects both the follower's objective and decision space. The follower observes the leader's decision and reacts by selecting a vector $y \in Y$ that optimizes his/her objective function $f(x, y)$. In doing so, the follower affects the leader's outcome. The hierarchical decision-making problem may involve decisions in both discrete and continuous variables. Bi-level programming problems involving both continuous discrete and decision variables are called mixed-integer BLPPs. If there are nonlinear relations in the model the bilevel model will be nonlinear. In this paper, a nonlinear mixed integer bilevel programming problem (NBLPP) is presented to design the reverse logistic network.

The rest of the paper has been organized as follows. The next section is dedicated to literature review of designing reverse logistic network and application of bi-level programming in reverse logistics. In Section 3, problem definition and the bi-level mathematical model are introduced. In section 4 a new heuristic algorithm based on genetic algorithm to solve is proposed to solve the bi-level model. Finally, a numerical example is given to illustrate the applicability of the model and its solution approach.

2. Literature review

Reverse logistics is gaining increasing levels of consideration because of environmental factors as well as economic reasons (Erkut and Alp 2007). Responding to this fact, reverse logistics network design is rich in the literature. Pishvaee et. al., (2010) have reviewed the recent literature in logistics network design. This paper concentrates only on the application of bilevel programming in logistics network design. Amouzegar and Moshirvaziri (1999) may be the first authors who applied the bilevel in logistics. They developed optimization model for hazardous waste capacity planning and treatment facility locations that models the behavior of private firms in the presence of central planning decisions (leader) and price signals. In that model the government is assumed to control all location/allocation decisions for installing incineration and disposal firms. Government as a leader applies a tax system for inducing the polluters as followers to reduce their discharges. Kara and Verter (2004) and Erkut and Gzara (2008) provide a bi-level integer programming for hazardous material transportation. The government as a leader tries to minimize risk while the carriers are followers who seek to minimize cost at the same time. Sun et al. (2008) have presented a bi-level programming model to seek the optimal location for logistics distribution centers. The upper-level model is to determine the optimal location by minimizing the planners' cost, and the lower gives an equilibrium demand distribution by minimizing the customers' cost. Another interesting paper is Aksen et al. (2009) who provided two models that describe the subsidize agreement between the government and a company engaged in collection and recovery operations. The government's regulation will be satisfied once the overall cumulative collection rate reaches or exceeds the target value. So the only variable in the leader problem is subsidies and the follower is responsible for just collection of used products where the product return is incentive-dependent. The work of this paper is an extension of the work done by Aksen et al. (2009). The designed network is three-level and both leader and follower faced with location/allocation problem and government have a central rule for controlling the reduction of pollution in the environment by recycling the EOL products.

3. Problem Definition

The reverse logistics network under consideration is illustrated in Fig. 1. In this model, the government is introduced as the leader of bi-level model, who is responsible for collections of EOLs from product holders (P.hs) into the collection centers. So the government should find the optimal location of the collection centers in order to minimization of his total costs. For this reason government buys the EOLs from the Product holders with a price which is defined by the government. Price offered for purchasing of EOL should be as large as that the P.hs will be agree to sell their EOLs, therefore the rate of EOL return is price-dependent. We model the relation between the EOL product acquisition and the offered price with respect to the right triangular distribution as similar to the work of Aksen et al. (2009).

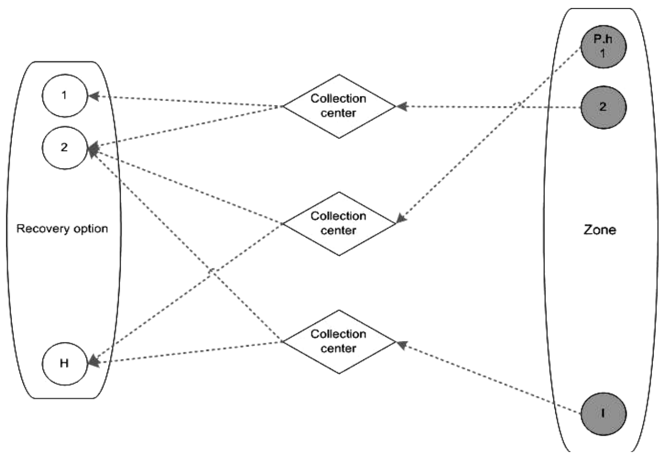

Figure1: Reverse logistic network

The product holder *i* which have the used product type *k* will make a return if the government offer a unit incentive pu_k that is at least as large as a reservation price pu_{0k}. It is assumed that all P.hs in different locations have the same mental model in responding the similar offered price. We assume that pu_{0k} follows the right triangular distribution (RTD) of which density function is given in (1) and Fig. 2. The proportion P_k of product holders of type *k* who are willing to return their EOLs when the collectors offer incentive pu_k per product is calculated from equation 2.

$$f(pu_{0k}) = 2pu_{0k}/a_k{}^2 \tag{1}$$

$$P_{\mathrm{k}} = \Pr(pu_{0k} \le pu_k) = F(pu_k) = pu_k^2/a_k{}^2 \tag{2}$$

Note that pu_{0k} takes on values in the interval $[0,a_k]$ where a_k represents the maximum incentive level of product type p.

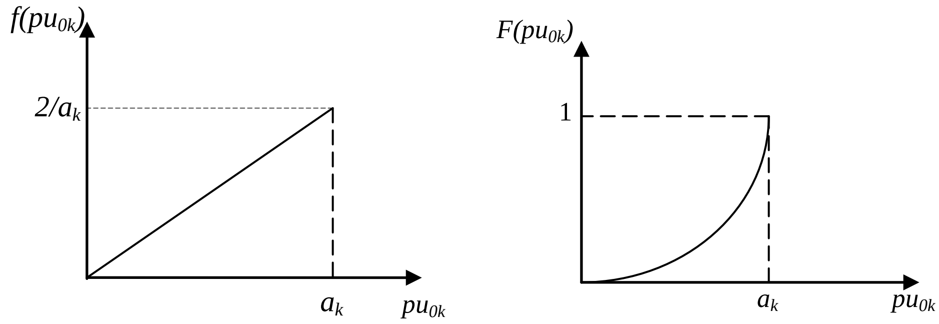

Figure 2. RTD distribution of incentive price

The objective of government as a leader is to minimize the total costs of acquiring EOLs, transportation of EOLs into the collection centers and opening and operating cost of collection centers in such a way that minimum total collection and recycling rate of EOLs from all P.hs is fulfilled and also recycling centers' (as followers) minimum profit is guaranteed. Government could also earn revenue from sales of collected EOLs to the follower who recycled the EOLs in recycling centers.

In other side the follower buy the EOLs from collection centers and earn revenue by recycling them in recycling centers. Sales price of EOLs is determined by the leader in such a way that followers have been encouraged to purchase the EOLs and the government has the lowest losses for transferring them. Other assumptions for model development are as follows:

- This model is designed for a single period.
- Locations of product holders' zones are known to be fixed.
- The quantity of EOL products and their quality are fixed and known in the customer zones.
- Potential locations for installing the collection and recycling centers are known.
- Collection and recycling centers are capacitated with known capacity.
- Recycling method for each type of EOL product can be different; therefore the revenue of recycling is different from each other with respect to various outputs of recycling methods.
- Transportation vehicles from Product holders to the collection centers are the same and transportation vehicles from collection centers to recycling centers are also the same, however, these two groups are different from each other.

The model indices, parameters and variable definitions are as follows:

Model indices:

i	index of locations of customer zones i=1,…,I
j	index of candidate locations for collection centers j=1,…,J
z	index of candidate locations for recycling centers z=1,…,Z
k	index of types of EOL products k=1,…,K
r	index of types of recycling centers r=1,…,R
o	index of types of outputs from recycling o=1,…,O

Parameters:

s_{ik}	quantity of returned products type k at customer zone i
cu_{ij}	transportation cost per unit of EOL product from customer zone i to collection center j
co_{jz}	transportation cost per unit of EOL product from collection center j to recycling center z
du_{ij}	road distance from customer zone i to collection center j
do_{jz}	road distance from collection center j to recycling center z
C1	fixed unit vehicle operating cost for the trucks that travel from customer zones to collection centers
C2	fixed unit vehicle operating cost for the trucks that travel from collection centers to recycling centers
fu_j	fixed cost of opening and operating collection center j
fo_{zr}	fixed cost of opening and operating recycling center type r located at zone z
$capu_j$	maximum capacity of collection center j
$capo_{zr}$	maximum capacity of recycling center z type r
w_{ik}	minimum percentage of EOL product type k at customer zone i that must be shipped to recycling centers
P	minimum profitability ratio desired by the recycling centers
g_{zkro}	unit profit from EOL product type k for recycling center type r located at zone z for output type o
v_{ij}	capacity of the trucks that travel form customer zone i to collection center j
e_{jz}	volume of the tracks that travel form collection center j to recycling center z
γ_{kro}	fraction of output type o generation from recycling EOL product type k in recycling type r
a_k	maximum reservation incentive level for EOL product type k for customer zones

Variables:

pu_k	price offered for EOL product type k to customer zones
R_k	price offered by collection centers (leader) to recycling centers (followers) for EOL products type k
x_{ijk}	quantity of EOL products type k shipped from customer zone i to collection center j
y_{jzkr}	quantity of EOL products type k shipped from collection center j to recycling center z type r
N_{ij}	number of vehicles required to transport EOL products from customer zone i to collection center j
M_{jz}	number of vehicles required to transport EOL products from collection center j to recycling center z
yu_j	1 if a collection center is installed at location j, otherwise 0
yo_{zr}	1 if a recycling center located at zone z type r is installed, otherwise 0

Based on the above notations the nonlinear bilevel mixed integer programming model is presented through equations (3) to (20). In this bilevel model $pu_k, x_{ijk}, yu_j, R_k, N_{ij}$ are leader variables and y_{jzkr}, yo_{zr}, M_{jz} are the follower variables.

Leader:

$$\text{Min } \sum_i \sum_j \sum_k pu_k\, x_{ijk} + \sum_i \sum_j C1 N_{ij} + \sum_i \sum_j \sum_k 2cu_{ij}\, du_{ij} x_{ijk} + \sum_j fu_j\, yu_j - \sum_j \sum_z \sum_k \sum_r y_{jzkr} R_k \tag{3}$$

Subject to:

$$\pi_{net} \geq P\left(\sum_j \sum_z \sum_k \sum_r y_{jzkr}\ R_k + \sum_j \sum_z \mathrm{C2} M_{jz} + \sum_j \sum_z \sum_k \sum_r 2co_{jz} do_{jz}\ y_{jzkr} + \sum_z \sum_r fo_{zr} yo_{zr}\right) \tag{4}$$

$$\sum_j x_{ijk} \leq s_{ik}\ \frac{{pu_k}^2}{{a_k}^2} \qquad \forall i, k \tag{5}$$

$$\sum_i \sum_k x_{ijk} \leq yu_j\ capu_j \qquad \forall j \tag{6}$$

$$N_{ij} \geq \frac{\sum_k x_{ijk}}{v_{ij}} \qquad \forall i,j \tag{7}$$

$$pu_k \leq a_k \qquad \forall k \tag{8}$$

Follower:

$$\text{Max } \pi_{net} = \sum_j \sum_z \sum_k \sum_r \sum_o \gamma_{kro} y_{jzkr}\, g_{zkro} - \sum_j \sum_z \sum_k \sum_r y_{jzkr} R_k - \sum_j \sum_z (\mathrm{C2} + 2co_{jz} do_{jz}) M_{jz} - \sum_z \sum_r fo_{zr} yo_{zr} \tag{9}$$

Subject to:

$$\sum_j \sum_k y_{jzkr} \leq yo_{zr}\ capo_{zr} \qquad \forall z, r \tag{10}$$

$$\sum_i x_{ijk} \geq \sum_Z \sum_r y_{jzkr} \qquad \forall j,k \tag{11}$$

$$\sum_j \sum_z \sum_k \sum_r y_{jzkr} \geq \sum_i \sum_k w_{ik}\ s_{ik} \tag{12}$$

$$M_{jz} \geq \frac{\sum_k \sum_r y_{jzkr}}{e_{jz}} \qquad \forall j,z \tag{13}$$

$$x_{ijk} \geq 0 \qquad \forall\ i,j,k \tag{14}$$

$$y_{jzkr} \geq 0 \qquad \forall\ j,z,k,r \tag{15}$$

$$R_k \geq 0 \qquad \forall\ k \tag{16}$$

$$pu_k \geq 0 \qquad \forall\ k \tag{17}$$

$$yu_j \in \{0,1\} \qquad \forall j \tag{18}$$

$$yo_{zr} \in \{0,1\} \qquad \forall z,r \tag{19}$$

$$N_{ij} \geq 0 \text{ and integer} \qquad \forall i,j \tag{20}$$

$$M_{jz} \geq 0 \text{ and integer} \qquad \forall j,z \tag{21}$$

The leader's objective function in (3) minimizes the total costs of purchasing of EOLs, opening and operating cost of collection centers and transportation cost minus the revenue from the selling EOLs to the recycling firms. The constraints which are related to the leader are presented through equations (4) to (8). Constraint (4) shows that the government tries to guarantee the minimum profit for private investors. Constraint (5) guarantees that the collected return products should not be more than the whole existing products in customer zones. Constraint (6) shows the capacity limitation of collection centers. Number of required vehicles to transport EOLs from customer zones to collection centers is determined through equation (7). Equation (8) ensures that the offered price for purchasing EOLs should not be greater than the defined maximum value. The follower's objective function is defined in equation (9). It considers the revenue from recycling and also cost of transportation and opening and operating of recycling centers. Constraint (10) is regarding to the capacity of the recycling centers. Constraint (11) is related to the flow of the materials in the network and guarantees that amount of the products that transmitted from collection centers to the recycling centers should not be more than the amount of the collected products in collection centers. Constraint (12) ensures the minimum collection and recycling rate of total EOL products of all product holders. Equation (13) determines the number of vehicle required for transportation of EOLs from collection centers to the recycling centers. Equations (14) to (21) define the integrality condition of variables.

4. Solution approach

For BLPPs, there exist several algorithms, such as branch-and bound algorithms (Shi et al. 2006), penalty function-based approaches (Farvaresh and Sepehri 2011), trust region methods (Colson et al. 2005) as well as some intelligent algorithms, such as genetic algorithm (Kuo and Han 2011) Amongst the algorithms, some involve the application of replacement the follower's problem with its K-K-T conditions. But all of the mentioned approaches are very time-consuming, especially when the follower's programming is a large scale problem, and some algorithms cannot solve the BLPPs with nondifferentiable functions, such as the trust region algorithm and penalty method. For nonlinear BLPP, the existing algorithms can be divided into two classes, one always begins from leader's variables, and for each selected leader's variable value, to solve follower's problem for follower's variable value, while the other uses some techniques to transform BLPP into a single level programming, such as K-KT conditions or penalty functions (Hecheng and Yuping 2009). We try to solve the problem from another point of-view. At first, we encode each individual by using the leader's variable values and the base of follower's programming model. Then a new fitness function is given, which consists of leader's objective and a penalty term. In doing so, based on the solution strategies of the follower 's sub problem and an exponential distribution used to design crossover operator (EDGA) (Hecheng and Yuping 2008), a genetic algorithm with real number encoding is proposed for solving the mixed-integer nonlinear bi-level programming.

For evaluating the performance of proposed algorithm a small illustrative example is introduced with considering three customer zones with two potential candidates for collection and recycling centers respectively. The parameters are given in Table 1.

For getting initial population we have used BARONS 7.5.3 (solver using AIMMS version 3.12 (Sahinidis, 2011) the parameters are chosen as follows: the population size N = 200, the crossover probability p_c = 0.8, the mutation probability p_m = 0.2, and penalty constant M =1,000,000, the algorithm stops when the best results are not improved in 10 successive generations or the maximum number of cycles 100 is reached. The algorithm is implemented in MATLAB 2011 and tested on a 64-bit 1.73GHz intelQ740 core i7 processor running widows 7. The MIPs are all solved globally with GLPK MEX version 7.8.1 (Giorgetti, 2011) through system calls. We execute EDGA in 100 independent runs and record the following data:

(1) Best solutions found in 200 runs.
(2) Best value (Fbest), worst value (Fworst), mean value (Fmean), and standard deviation (*Std*) of $F(x, y)$ in 200 runs for each test problem.

All results are presented in Tables 2.

Table 1. parameters value for illustrative example

parameter	value	parameter	value	parameter	value
s_{11}	100	C2	8	λ_{121}	0.5
s_{12}	120	fu_1	50000	λ_{211}	0.45
s_{21}	90	fu_2	40000	λ_{221}	0.35
s_{22}	110	fo_{11}	100	λ_{112}	0.4
s_{31}	80	fo_{12}	200	λ_{122}	0.5
s_{32}	70	fo_{21}	200	λ_{212}	0.55
cu_{11}	6	fo_{22}	100	λ_{222}	0.65
cu_{21}	6	$capu_1$	3000	g_{1111}	400
cu_{21}	6	$capu_2$	4000	g_{1112}	500
cu_{22}	6	$capo_{11}$	3000	g_{1121}	600
co_{11}	6	$capo_{12}$	5000	g_{1122}	600
co_{21}	6	$capo_{21}$	4000	g_{1211}	300
co_{21}	6	$capo_{22}$	6000	g_{1212}	700
co_{22}	6	w_{11}	0.7	g_{1221}	500
du_{11}	20	w_{21}	0.7	g_{1222}	500
du_{21}	10	w_{31}	0.75	g_{2111}	600
du_{31}	30	w_{12}	0.6	g_{2112}	700
du_{12}	40	w_{22}	0.8	g_{2121}	300
du_{22}	30	w_{32}	0.85	g_{2122}	300
du_{32}	10	p	0.8	g_{2211}	300
do_{11}	40	v_{ij}	10	g_{2212}	400
do_{12}	10	e_{jz}	200	g_{2221}	400
do_{21}	20	a_1	40	g_{2222}	100
do_{22}	30	a_2	50		
C1	8	λ_{111}	0.6		

Table 2. Results of solving illustrative example

variable	value	variable	value
x_{111}	61.24	y_{1111}	0
x_{112}	18.76	y_{1112}	0
x_{121}	6.14	y_{1121}	93.03
x_{122}	43.84	y_{1122}	0
x_{211}	36.03	y_{1211}	162.2
x_{212}	73.97	y_{1212}	0
x_{221}	24.09	y_{1221}	0
x_{222}	5.16	y_{1222}	0
x_{311}	64.93	y_{2111}	0
x_{312}	0.31	y_{2112}	0

x_{321}	9.11	$\mathbf{y_{2121}}$	117.93
x_{322}	68.9	$\mathbf{y_{2122}}$	0
r_1	105.88	$\mathbf{y_{2211}}$	39.33
r_2	256.27	$\mathbf{y_{2212}}$	0
pu_1	39.7	$\mathbf{y_{2221}}$	0
pu_2	49.72	$\mathbf{y_{2222}}$	0
n_{11}	8	$\mathbf{m_{11}}$	1
n_{12}	3	$\mathbf{m_{12}}$	1
n_{21}	5	$\mathbf{m_{21}}$	1
n_{22}	8	$\mathbf{m_{22}}$	1
n_{31}	11	$\mathbf{yo_{11}}$	1
n_{32}	10	$\mathbf{yo_{12}}$	0
yu_1	1	$\mathbf{yo_{21}}$	1
yu_2	1	$\mathbf{yo_{22}}$	0
Best solution		133222.296	
Worst		139407.375	
Mean		134198.631	
Std		0.6058	

5. Conclusion

In this paper, a nonlinear bilevel mixed integer programming model has been presented for optimal designing of the reverse logistics network. In this bilevel modeling, government is considered as the leader of the problem who seeks to collect the EOL products from product holders by giving them an incentive price. Private sector as the follower of the model buy the EOLs from the collection centers owned by the government and recycle them in recycling centers in order to gain profits. Since the bilevel programming models are NP hard, a heuristic approach based on the genetic algorithm has been introduced to solve the model. Performance of the algorithm is evaluated through an illustrative example. Future efforts should dedicate to solve bigger size problems and evaluating the performance of the proposed algorithm.

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