

The Dynamic Design of Reverse Logistics Network with Fuzzy Incentive-Dependent Return

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Abstract

Reverse logistics (RLs) network design issues have been popularly discussed in recent years. However, few papers in past literature have been dedicated to the use of incentive effect on return quantity of used products. This study formulates an optimization model of RLs network design based on fuzzy mathematical programming with the aim of management in allocating used product by coordinating collection centers and recovery facilities to ensure minimum cost as well as maximum profit. In this model, fuzzy approach has been applied to interpret the relation between rate of product return and the incentives for each product return. This work assumes collection centers as having multi-capacity levels and the model is multi-period on which budget limit is considered. Finally, although this problem is known as NP-hard, for the sake of simplicity, a small numerical example is presented and solved in Lingo software to show the applicability of this model.

Keywords

Reverse logistics, Fuzzy logic, Mixed integer nonlinear programming, incentive-dependent return

1. Introduction

With the growing importance of environmental issues, various industrial sectors have been affected with respect to used products collecting policies and regulations. The most important effect is that the manufacturers are forced to take back and recover their products at the end of their life in order to pass the obligatory regulations. (e.g. Ilgin and Gupta (2010)). Planning for the collection of used products is related to the Reverse Logistics (RLs) in supply chain management. Reverse logistics network design almost includes the selection of appropriate paths and vehicles for transporting goods and determining the optimal location and capacity for the opening the collection and recovery centers. Such decisions will be more challenging when we are facing with different products with varying levels of quality. Facing with different situations in reverse logistics network design, a wide variety of mathematical optimization model have been published. In these designs, different stages for network have been considered. Because the most of the used products do not have any value in terms of functionality (Schultmann et al., 2006), just collection and recycling some of them will have reasonable profit. Put the penalty cost for not collected products after use, is a sample of new approaches to ecological remedy that has been actively pursuing in the past decade. Customers typically have no motivation to return products after use (Guide et al., 2003). Unfortunately, there are few papers which have examined the effect of incentive price on the amount of returned products. The rate of product return by the customers is related to the incentive price provided by the collectors. This relation depends on the various factors such as distance from the collection or recycling centers, scraps quality and etc. So, determining the best price for gathering the largest amount of used products is the question that should be solved. In doing so, in this paper the relation between the rate of product return and its incentive price has modeled by the concept of fuzzy logic. In this manner, the rate of product return has been considered as a triangular fuzzy number with respect to provided incentive prices. The remainder of this paper is organized as follows. After review the relevant literatures in Section 2, in section 3 the problem and its objective function is defined in details. Next, the mathematical formulation for the model is developed. In Section 4, an illustrative example is provided to show the applicability of the model. Finally, the paper concludes with some final remarks.

2. Literature Review

Logistics literature is remarkably rich in papers that deal with the collection operations in the context of product recovery and recycling. Fleischmann et al. (2000) reviewed some case studies on logistics network design for product recovery in different industries, and then identified general characteristics for such logistics networks. They

denote five groups of activities that appear to be recurrent in product EOL recovery networks: collection, inspection/separation, re-processing, disposal and redistribution. Most of the papers that considered reverse flows formulate discrete facility location-allocation models. For example Jayaraman et al. (2003) have modeled the RLs of hazardous products with a multi-level warehouse location model. The objective of the model is to find the optimal number and location of collection and refurbishing facilities with the corresponding flow of the hazardous products. In their mixed integer linear programming model the number of hazardous products to be returned at each originating site is assumed to be given. Pishvae et al. (2009) have classified the literature about the logistics network into three sections: forward logistics, reverse logistics and integrated forward and reverse logistics. Then they developed a stochastic programming model for an integrated forward/reverse logistics network design under uncertainty. Bases on their classified literature, there are a few numbers of papers which considered the logistics network design in multi-periods (dynamic) environment. In dynamic environment, Min et al. (2006) have proposed a dynamic nonlinear mixed-integer programming model for the deterministic logistics network involving both spatial and temporal consolidation of returned products. Ko and Evans (2007) consider a network operated by a 3PL service provider and they present a multi-period mixed integer non-linear programming model for the simultaneous design of the forward and return network.

A class of the papers in the product recovery literature discusses analytical models for the relation between financial incentives and used product acquisition. The most recent work in this area relates to the work done by Aras et al., (2008). They formulate a mixed-integer nonlinear facility location-allocation model to find both the optimal locations of a predetermined number of collection centers and the optimal incentive values for different return types. Clearly, the amount of the incentive offered by the company influences the quality level and amount of the returned products. So they assume that reservation price follows the right triangular distribution (RTD). They believe use of RTD represents characteristic of customer wisdom in such a way that the change in the number of potential returns per unit growth in a unit incentive occur at an increasing rate. This paper extends the current literature by considering the fuzzy relation between the incentive and product acquisition. It also considers the multi-product and multi-period in reverse logistics network design with limited budget in each period. Furthermore in this research penalty cost has been considered for non-collected used products.

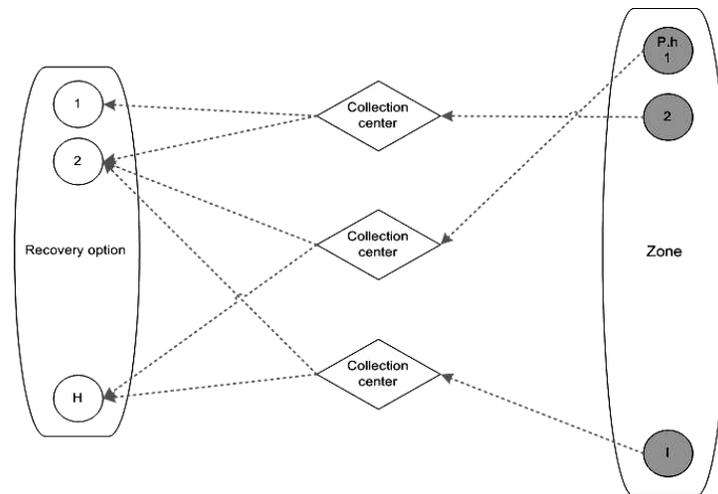


Figure 1: Reverse logistic network

3. Problem definition

The network stages that are considered in this research have been illustrated in Fig. 1. Based on this figure, the products are collected from product holders (P.h.) into the collection/inspection centers. Then they are moved to different recovery centers for recycling. The following are the assumptions considered in design of such network:

- The model is a multi-period.
- The model considers multiple products of which have a different but known quality level.
- Customers' locations are known and fixed with deterministic quantity of used products.

Table 1: Nomenclature

Index	Description
Sets	
P	set of used product types
T	set of time periods
I	set of fixed customer locations
J	set of potential collection/inspection centers (CICs)
H	set of potential recovery locations
L	set of transportation mode
M	set of recovery facilities (RFs) outputs
N	set of capacity levels available for facilities
Q	set of used products quality levels referred to as types
Parameters	
oc_{jt}^n	setup cost for installation of CIC j with capacity level n in period t
fc_{jt}	operating fixed cost for CIC j in period t
vc_{pqjt}	variable operating cost of product p with quality level q for CIC j in period t
w_{jt}^n	inventory capacity of collected products at CIC j with capacity level n in period t
hc_{jt}	inventory holding cost at CIC j in period t
bc_t	maximum budget to install CICs in period t
or_{ht}^n	setup cost for opening RF h with capacity level n in period t
fr_{ht}	operating fixed cost for RF h in period t
vr_{pqht}	variable operating cost of product p with quality level q for RF h in period t
pc_{ht}	penalty cost per unit of non-utilized capacity at RF h in period t
car_{ht}^n	capacity with level n for RF h in period t
S_{mht}	unit sale price of product m at RF h in period t
α_{mpqht}	product m fraction generated of used product p with quality level q at RF h in period t
br_t	maximum budget for installation of RFs in period t
$d1_{ij}$	distance between customer location i and CIC j
$d2_{jh}$	distance between CIC j and RF h
ct_{lt}	cost per unit distance traveled by transportation mode l in period t
c_{plt}	transportation and handling cost per unit of product p using transportation mode l in period t
$ca1_{ijlt}$	maximum capacity of products flow from customer location i to CIC j using transportation mode l in period t
$ca2_{jhl}$	the maximum capacity of products flow from CIC j to RF h using transportation mode l in period t
r_{pait}	Deterministic quantity of used product p with quality level q in customer zone ia in period t
uc_{pt}	unit penalty cost for non-collected returns of type p in period t
B_{pqit}^0	price range that customers contemplate for used product p sales which follow right triangular distribution
Decision variables	
$Q1_{pqijlt}$	quantity of returned product p with quality level q shipped from customer location i to CIC j using transportation mode l in period t
$Q2_{pqjhlt}$	quantity of returned product p of type q shipped from CIC j to RF h using transportation mode l in period t
B_{pat}	unit incentive offered for used product p with quality level q in period t
X_{jt}^n	Binary variable, it takes 1 if CIC j with capacity level n is installed in period t and 0 otherwise
Y_{ht}^n	Binary variable, it takes 1 if RF h with capacity level n is installed in period t and 0 otherwise
Dependent variable	
I_{pjt}	inventory level of used product p at CIC j in period t
U_{pit}	quantity of uncollected returns of type p of customer ia in period t
Sc_t	remaining budget for installation of CICs in period t
Str_t	remaining budget for installation of RFs in period t
P_{pqit}	proportion of potential returns of type p and with quality level q sell by customer in period t
φ_{jt}^n	Binary variable, it takes 1 if CIC j with capacity level n has installed in the period before of t and 0 otherwise
ξ_{ht}^n	Binary variable, it take 1 if RF h with capacity level n has installed in the period before of t and 0 otherwise

- The returned quantities depend on offered incentive for used product.
- The potential locations of collection/inspection and recovery facilities are known.

- Costs parameters (setup, fixed, variable, non-utilized capacity, non-collected returns, transportation and holding costs) are known for each location, products and time period.
- Capacity of each location is known for each time period.
- The holding cost depends on the residual inventory at the end of each period.
- Critical parameters such as budget, sale price and distance between locations are known and deterministic.
- Recovery options operate independently.
- Non-collected used products by the collector are excreted by own customers
- The budget is only intended for the construction of facilities, it should be noted that this amount is limited and the remainder at the end of each period can be used in other periods.

Nomenclature that is used in this paper is presented in Table 1.

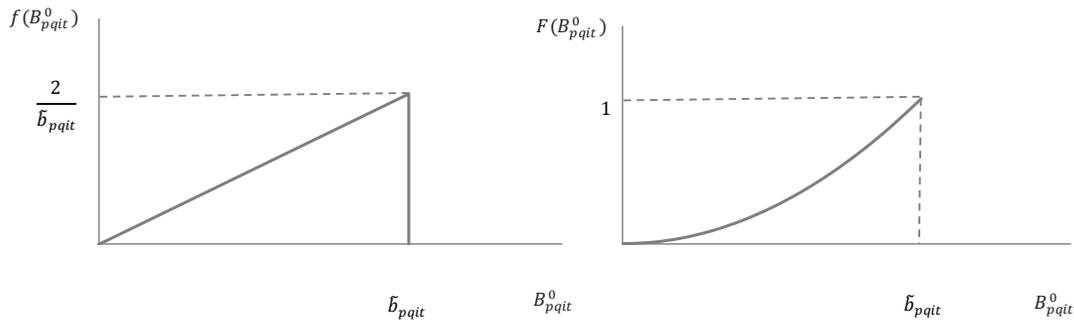


Figure 2: The triangular distribution of purchase incentive

Based on Aras et al., (2008) the product holders return decisions could be modeled by using the notion of consumer surplus. The product holder i which have the used product type p with quality level q at time t will make a return if the collection centers offer a unit incentive B_{pqt} that is at least as large as a reservation price B_{pqt}^0 . It is assumed that all customers in different locations have the same mental model in responding the similar offered price. We assume that B_{pqt}^0 follows the right triangular distribution (RTD) of which density function is given in (1) and Fig. 2. The proportion P_{pqt} of product holders of type p with quality level of q at time t in zone i who are willing to return their cores when the collectors offer incentive B_{pqt} per product is calculated from equation 2.

$$f(B_{pqt}^0) = 2B_{pqt}^0/b_{pqt}^2 \quad (1)$$

$$P_{pqt} = \Pr(B_{pqt}^0 \leq B_{pqt}) = F(B_{pqt}^0) = B_{pqt}^2/b_{pqt}^2 \quad (2)$$

Note that B_{pqt}^0 takes on values in the interval $[0, b_{pqt}]$ where b_{pqt} represents the maximum incentive level of product type p at quality q . Considering the end of this interval to be deterministic does not seem logical, while each customer doesn't consider the exact price for the sale of their products. Thus in this model to reach the best results the number b_{pqt} is considered to be a triangular fuzzy number and it is shown by \tilde{b}_{pqt} .

Base on the aforementioned parameters and indices the fuzzy mixed integer nonlinear programming (FMINLP) model is developed as follows:

(F) Minimize

$$\begin{aligned} & \sum_n \sum_j \sum_t oc_{jt}^n X_{jt}^n + \sum_j \sum_t fc_{jt} \left(\sum_n \varphi_{jt}^n \right) + \sum_p \sum_q \sum_i \sum_j \sum_l \sum_t vc_{pqt} \cdot Q1_{pqijlt} + \sum_n \sum_h \sum_t or_{ht}^n \cdot Y_{ht}^n + \\ & \sum_h \sum_t fr_{ht} \left(\sum_n \xi_{ht}^n \right) + \sum_p \sum_q \sum_j \sum_h \sum_l \sum_t vr_{pqlt} Q2_{pqjhlt} + \sum_n \sum_p \sum_q \sum_i \sum_j \sum_l \sum_t Q1_{pijlt} \cdot B_{pqt} + \\ & \sum_p \sum_j \sum_t I_{pjt} \cdot hc_{jt} + \sum_p \sum_i \sum_t U_{pit} \cdot uc_{pt} + \sum_p \sum_q \sum_i \sum_j \sum_l \sum_t Q1_{pqijlt} (c_{plt} + ct_{lt} \cdot d1_{ij}) \end{aligned} \quad (3)$$

$$\begin{aligned}
& + \sum_p \sum_q \sum_j \sum_h \sum_l \sum_t Q2_{pqjhlt} (c_{plt} + ct_{lt} \cdot d2_{jh}) + \sum_h \sum_t p_{cht} \cdot \left(\sum_n \xi_{ht}^n \cdot car_{ht}^n - \sum_p \sum_q \sum_j \sum_l Q2_{pqjhlt} \right) \\
& - \sum_n \sum_m \sum_p \sum_q \sum_j \sum_h \sum_l \sum_t Q2_{pqjhlt} \cdot \alpha_{mpqht} \cdot S_{mht},
\end{aligned}$$

Subject to

$$\sum_t \sum_j X_{jt}^n \leq 1, \quad \forall j \in J, \quad (4)$$

$$\sum_t \sum_h Y_{ht}^n \leq 1, \quad \forall h \in H, \quad (5)$$

$$\sum_p \sum_q Q1_{pqijlt} \leq \sum_n \varphi_{jt}^n \cdot ca1_{ijlt}, \quad \forall i \in I, j \in J, \forall l \in L, t \in T, \quad (6)$$

$$\sum_p \sum_q Q2_{pqjhlt} \leq \sum_n \xi_{ht}^n \cdot ca2_{jhlt}, \quad \forall j \in J, h \in H, \forall l \in L, t \in T, \quad (7)$$

$$\sum_p \sum_q \sum_j \sum_l Q2_{pqjhlt} \leq \sum_n car_{ht}^n \cdot \xi_{ht}^n, \quad \forall h \in H, t \in T, \quad (8)$$

$$I_{pj(t-1)} + \sum_q \sum_i \sum_l Q1_{pqijlt} = I_{pj t} + \sum_q \sum_h \sum_l Q2_{pqjhlt}, \quad \forall p \in P, \forall j \in J, t \in T, \quad (9)$$

$$I_{pj0} = 0, \quad \forall p \in P, \forall j \in J, \quad (10)$$

$$\sum_t I_{pj t} \leq w_{jt}^n \cdot \varphi_{jt}^n, \quad \forall j \in J, t \in T, \quad (11)$$

$$\sum_q \sum_j \sum_l Q1_{pqijlt} + U_{pit} = \sum_q r_{pqit}, \quad \forall p \in P, i \in I, t \in T, \quad (12)$$

$$\sum_j \sum_l Q1_{pqijlt} \leq P_{pqit} \cdot r_{pqit}, \quad \forall p \in P, \forall q \in Q, i \in I, t \in T, \quad (13)$$

$$P_{pqit} = \frac{B_{pqt}^2}{\bar{b}_{pqit}^2}, \quad \forall p \in P, \forall q \in Q, i \in I, t \in T, \quad (14)$$

$$\sum_n \sum_j oc_{jt}^n \cdot X_{jt}^n + SC_t = bc_t + SC_{t-1}, \quad t \in T, \quad (15)$$

$$SC_0 = 0, \quad (16)$$

$$\sum_n \sum_h or_{ht}^n \cdot Y_{ht}^n + Sr_t = br_t + Sr_{t-1}, \quad t \in T, \quad (17)$$

$$Sr_0 = 0, \quad (18)$$

$$B_{pqt} \leq \bar{b}_{pqit}, \quad \forall p \in P, \forall q \in Q, \forall i \in I, t \in T, \quad (19)$$

$$\sum_{t'=1}^t X_{jt'}^n = \varphi_{jt}^n, \quad \forall j \in J, n \in N, t \in T, \quad (20)$$

$$\sum_{t'=1}^t Y_{ht'}^n = \xi_{ht}^n, \quad \forall h \in H, n \in N, t \in T, \quad (21)$$

$$B_{pqt}, P_{pqit}, U_{pit}, I_{pj t}, Q1_{pqijlt}, Q2_{pqjhlt}, SC_t, Sr_t \geq 0, \quad \forall p \in P, \forall q \in Q, \forall i \in I, \forall j \in J, \forall h \in H, \forall l \in L, t \in T, \quad (22)$$

$$X_{jt}^n, Y_{ht}^n \in \{0,1\} \forall j \in J, \forall h \in H, n \in N, t \in T, \quad (23)$$

In the model, Eq. (3) is the objective function, Eq. (3) namely minimizes setup, total fix and variable costs both for collection/inspection and recovery centers, total cost of used products purchase, inventory holding costs at collection/inspection centers, non-collected returns penalty cost, transportation costs and unutilized capacity penalty at recovery facilities respectively and at the end of this equation we subtract total income of new products sale. Constraints (4) and (5) ensure that a facility can be installed in each location at most at one capacity level. Eq. (6) and (7) express capacity limitation of products transportation between different nodes. Constraints in (8) represent the capacity restrictions of the recovery facilities in terms of total products entry to them. Eq. (9) assures the inventory balance of used products at collection/inspection centers between time periods. Eq. (10) determines the initial inventory of products collected at collection/inspection centers. Constraint (11) expresses inventory capacity limitation at collection/inspection centers. Eq. (12) relates the quantity of returned products to its potential quantity in customer zones. On the other hand, this equation bounds the amount of returned products. Constraint (13)

represents possible uttermost quantity of various products that can be collected from customers. Eq. (14) relates the proportion of potential returns to incentive offered for used product. Eqs. (15) to (18) assure budget balance for installation of collection/inspection and recovery centers respectively across time periods. Fuzzy Eq. (19) ensures that offered incentives do not exceed of distribution upper bound. Eqs. (20) and (21) show the facilities which has been opened in previous periods. Finally, constraints in set (22) enforce the non-negativity restrictions on the corresponding decision variables and constraints in set (23) enforce the integrality restrictions on the binary variables.

Model is a nonlinear programming. For solving, at first we apply a linear ranking function for convert fuzzy numbers in this model into deterministic number, with the first index of Yager (1978) and Yager (1981), although the approach could be easily adapted to the use of any other index. Thus by applying the first index of Yager and by considering triangular fuzzy numbers, aforementioned FMINLP problem is transformed into the crisp equivalent mix-integer non-linear programming problem by changing fuzzy constraints (14) and (19) with equations (24) and (25).

$$P_{pqt} = \frac{B_{pqt}^2}{\left[m_{pqt}^c + \frac{d_{pqt}^R - d_{pqt}^L}{3} \right]^2}, \quad \forall p \in P, \forall q \in Q, i \in I, t \in T, \quad (24)$$

$$B_{pqt} \lesssim m_{pqt}^c + \frac{d_{pqt}^R - d_{pqt}^L}{3}, \quad \forall p \in P, \forall q \in Q, \forall i \in I, t \in T, \quad (25)$$

Where, for instance, d_{pqt}^R and d_{pqt}^L are the lateral margins (right and left, respectively) of the triangular fuzzy number with central point of m_{pqt}^c (Fig. 3).

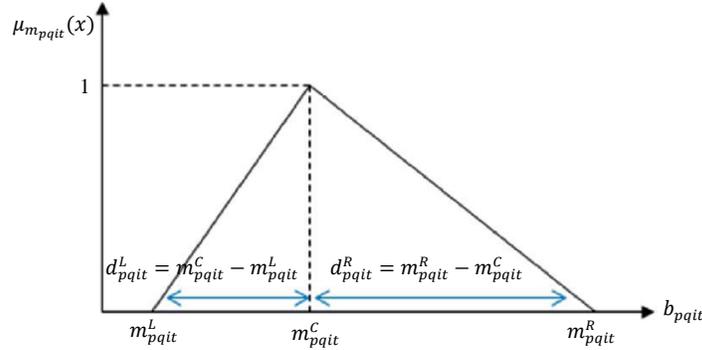


Figure 3: Triangular fuzzy number

According to Cadenas and Verdegay (1997), the membership function associated with fuzzy constraint (19), with \tilde{t}_{pqt} a fuzzy number giving the maximum violation of constraint is:

$$\mu_{pqt}(B_{pqt}, \tilde{b}_{pqt}) = \frac{g(\tilde{t}_{pqt}(-)B_{pqt}(+) \tilde{b}_{pqt})}{g(\tilde{t}_{pqt})}, \quad (26)$$

Where g is a linear ranking function and $(-)$ and $(+)$ are the usual operations among fuzzy numbers.

Given above equation, \lesssim with the membership function (26) and using the decomposition theorem (Negoita and Ralescu, 1975; Cadenas, 1993) for fuzzy sets, the following is obtained:

$$\begin{aligned} \mu_{pqt}(B_{pqt}, \tilde{b}_{pqt}) \geq \beta &\Leftrightarrow \frac{g(\tilde{t}_{pqt}(-)B_{pqt}(+) \tilde{b}_{pqt})}{g(\tilde{t}_{pqt})} \geq \beta \\ &\Leftrightarrow g(\tilde{t}_{pqt}) - g(B_{pqt}) + g(\tilde{b}_{pqt}) \geq g(\tilde{t}_{pqt}) \cdot \beta \\ &\Leftrightarrow g(B_{pqt}) \leq g(\tilde{b}_{pqt}(+) \tilde{t}_{pqt}(1 - \beta)) \\ &\Leftrightarrow B_{pqt} \leq_g \tilde{b}_{pqt} + \tilde{t}_{pqt}(1 - \beta), \end{aligned} \quad (27)$$

Where \leq_g is the relationship corresponding to g .

Therefore, an equivalent constraint for equation (24) is the following:

$$B_{pqt} \leq \left(m_{pqt}^c + \frac{d_{pqt}^R - d_{pqt}^L}{3} \right) + \left(mt_{pqt}^c + \frac{dt_{pqt}^R - dt_{pqt}^L}{3} \right) (1 - \beta), \quad \forall p \in P, \forall q \in Q, \forall i \in I, t \in T, \quad (28)$$

If we substitute deterministic equations (24) and (28) with fuzzy equations (14) and (19) respectively, we will convert fuzzy programming model to deterministic programming model that β is settled parametrically ($\beta \in [0, 1]$) to obtain the value of the objective function for the different levels of the fuzzy parameters considered in the model. The result is a fuzzy set and the decision maker has to decide which (β, F) is more adequate to obtain a crisp solution.

4. Evaluation of Model Performance with an Illustrative Example

A small illustrative example has been developed to evaluate the performance of the model. The size of the investigated example and its parameters value are given in Table 2 and Table 3 respectively. The model has been solved by the Lingo 13.0 solver. The experiments were run in an Intel(R) core(TM) i3 CPU, at 2.13GHz and with 4.00 GB of RAM memory. Here, we compare the behavior of the proposed fuzzy model with different β values. Table 4 shows the computational characteristics of the proposed fuzzy model. The data are related to the iterations, number of constraints, variables, integers, non-zero elements, calculation time.

Table 2. Problem size

Product types	2
Time Periods	3
Customers	5
Collection/inspection centers	3
Recovery centers	2
Transportation mode	2
Quality levels	3

Table 3. The values of the parameters used in the test problems

Parameter	Symbol	Range
Setup cost	oc_{it}^n	~ uni[200,450]*
Operating fixed cost	fc_{it}	~ uni[50,100]
Operating variable cost	vc_{pait}	~ uni[0.1,1]
Inventory capacity	w_{it}	~ uni[500,2000]
Holding cost	hc_{it}	~ uni[0.2,0.6]
Budget	bc_t	~ uni[400,700]
Setup cost	or_{ht}^n	~ uni[400,700]
Operating fixed cost	fr_{ht}	~ uni[100,150]
Operating variable cost	vr_{pght}	~ uni[0.1,1.5]
Non-capacity penalty	pc_{ht}	~ uni[0.2,0.5]
Capacity	car_{ht}^n	~ uni[7000,9000]
Sole price	s_{mht}	~ uni[7,12]
Transmutation fraction	α_{mpght}	~ uni[0,1]
Distance	$d1_{ij}$	~ uni[100,250]
Distance	$d2_{jh}$	~ uni[40,150]
Transmit cost	ct_{it}	~ uni[0.001,0.01]
Transmit cost	c_{plt}	~ uni[1,3]
Flow capacity	$ca1_{ijlt}$	~ uni[4000,6500]
Flow capacity	$ca2_{jhlt}$	~ uni[7000,9000]
Potential return	r_{pait}	~ uni[300,800]
Upper bound price range	\tilde{b}_{pait}	~ uni[5,9]
Maximum violation	\tilde{t}_{pait}	~ uni[0,1.6]
Non-collected penalty	uc_{pt}	~ uni[4,7]

* Uniform distribution [lower bound, upper bound]

Table 4.Characteristics of the computational experiment

Iterations	110'833
Constraints	694
Total variables	1'306
Integers	80
Non zero elements	6'999
CPU time (s)	5'884

Table 5 summarizes the evaluation results with the different β values ($\beta \in [0, 1]$), according to a group of parameters defined in Table 3. In Table 5, non-collected returns are calculated as the sum of the total quantity of uncollected used products from all customers, remaining budgets is the remaining budget for installation of CICs and RFs at the end of the planning periods, total income that will be earned by new products sale, new products relates to the output of recycling, total costs are the sum of all the costs that are generated in every period of the considered planning horizon and objective value that will be earned based on difference between total cost and total income. Table 5 shows that in average fuzzy model reaches the better results with respect to objective values.

Table 5. Evaluation of results

	β	non-collected returns	Remaining budget (\$)	Total income (\$)	Total cost (\$)	Objective value (\$)
(1)	0.0	49,110	2,460	2,000.3	180,891.4	178,891.1
(2)	0.1	36,538	1,490	2,243.0	84,956.9	82,713.9
(3)	0.2	41,683	2,000	1,462.2	159,054.5	157,592.3
(4)	0.3	42,128	2,230	2,523.5	170,343.2	167,819.7
(5)	0.4	30,803	1,610	3,544.9	190,274.2	186,729.3
(6)	0.5	41,889	1,840	2,348.6	155,454.0	153,105.4
(7)	0.6	44,334	2,040	2,141.6	154,634.5	152,492.9
(8)	0.7	40,226	1,700	2,058.7	78,578.9	76,520.2
(9)	0.8	44,435	2,700	2,613.8	193,534.4	190,920.6
(10)	0.9	39,576	1,660	3,109.9	164,756.2	161,646.3
(11)	1.0	37,506	1,560	3,639.1	104,933.0	101,293.9
(12)	Deterministic model	38,090	2,570	3,454.6	123,522.3	120,067.7
	Best choice	(5)	(9)	(12)	(8)	(8)

5. Conclusion

In this paper, a fuzzy mixed integer non-linear programming model was presented to obtain optimum planning for a reverse logistics in multi time periods environment. In this model the relation between used product acquisition and price offers to purchase the used product was calculated with respect to right triangular distribution with triangular fuzzy parameter. The fuzzy parameters and inequalities are then de-fuzzified and the final model was solved with commercial optimization software Lingo for an illustrative example. Computational results show that consideration of fuzzy parameters can result in better performances with respect to deterministic modeling. Time complexity is not addressed in this paper, since the computational time increases significantly when the size of problem increase, therefore developing efficient exact or heuristic solution methods is a critical need in this area.

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