

Reverse Logistics Network Optimization Design under Fuzzy-stochastic Environment

Jing Ye, Xifu Wang and Zhaoyun Li

Abstract Considering the uncertainty of reverse logistics of waste products, combine enterprise decision-making of periodic reverse logistics networks, this paper builds the forward and reverse integrated logistics network optimization chance constrained model to minimize the construction and operation cost, within the warehouse capacity limits under random consumer and fuzzy recycling demand environment. Then we transform the model to certainty, puts forward multi-state ideas and designs GA, eventually solving the dynamic optimization analysis of network model by an example test and verifies its validity and rationality.

Keywords Reverse logistics · Fuzzy and random environment · Network optimization · Chance constrained

1 Introduction

In this paper, we present the model to solve the two-period facility location problem and flow distribution problem. The facility location problem includes: independent distribution centers, independent recycling centers, integrated logistics warehouses, paid recycling sites and free recycling sites. The flow distribution problem includes the forward logistics and the reverse logistics distribution.

J. Ye (✉) · X. Wang · Z. Li
School of Traffic and Transportation, Beijing Jiaotong University, 100044 Beijing, China
e-mail: yezhaoyan.work@gmail.com

X. Wang
e-mail: xfwang1@bjtu.edu.cn

Z. Li
e-mail: 13120815@bjtu.edu.cn

© Springer-Verlag Berlin Heidelberg 2015
Z. Zhang et al. (eds.), *LISS 2014*, DOI 10.1007/978-3-662-43871-8_195

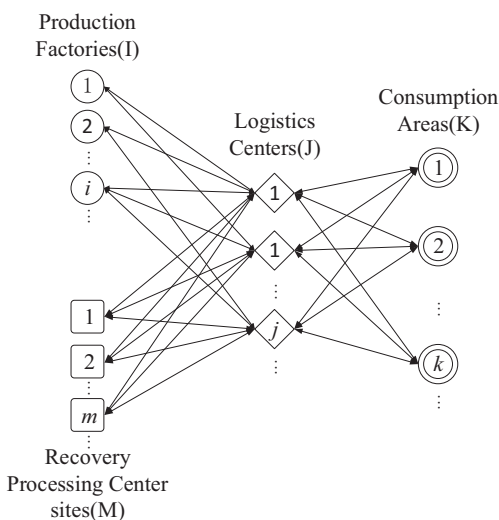
2 Model Formulation

The optimization design model of forward logistics and reverse logistics integrated network (as Fig. 1), mainly consider the following subjects: production factories, logistics centers, recovery processing center, and consumption areas. Logistics centers include three different types: independent distribution centers, independent recycling centers, and integrated logistics warehouses which are used for storing products as well as waste products (Bettac et al 1999). Products of production factories through independent distribution centers or integrated logistics warehouses to consumption areas, this is the main process of forward logistics. Waste products from recycling sites divided into paid recycling sites and free recycling sites built in consumption areas, are sent to independent recycling centers or integrated logistics warehouses. Then the waste products can be returned to their respective production factories or a recovery processing center of centralized processing (Ginter and Starling 1978).

The assumptions of the model are as follows.

1. The demands of consumption areas of each production factory are known.
2. Fixed investment of each alternative recovery processing sites are known.
3. All the waste products are sent to be processed, and ignore the compensation costs of recycling and processing.
4. The unit freight of transportation between logistics nodes are known; regardless of the time cost and the transportation in the area.
5. There is no time limit on recycling waste products; vehicles of forward logistics can be used to transport waste products, but only through the integrated logistics warehouses.

Fig. 1 The forward logistics and reverse logistics integrated network



2.1 The Model Notation

The model notation including:

1. Subscript: i denote the production factory ($i = 1, 2, \dots, I$); j denote the logistics center ($j = 1, 2, \dots, J$); k denote the consumption area ($k = 1, 2, \dots, K$); m denote the recovery processing center site ($m = 1, 2, \dots, M$).
2. Decision variable: x_{ij}^+ represent the flow from factory i to logistics center j ; x_{ijk}^+ represent the flow from factory i through logistics center j to consumption area k ; x_{ji}^- represent the reverse flow from logistics center j to factory i ; x_{kji}^- represent the reverse flow from consumption area k through logistics center j to factory i ; x_{jmi}^- represent the reverse flow from logistics center j to recovery processing center m . Y_m , value 1 if a recovery processing center m is built, otherwise 0; Y_j , value 1 if an independent distribution center j is built, otherwise 0; Z_j , value 1 if an independent recycling center j is built, otherwise 0. n_k^1 represent the construction quantity of paid recycling sites in consumption area k ; n_k^2 represent the construction quantity of free recycling sites in consumption area k .
3. Model parameter: d_{ki} represent the demand of products from factory i for consumption area k ; r_{ki}^1 represent the paid recycling quantity of factory i in consumption area k ; r_{ki}^2 represent the free recycling quantity of factory i in consumption area k .

The following Parameters are assumed to be known: f_m represent the construction cost of recovery processing center m ; f_j^+ represent the construction cost of independent distribution center j ; f_j^- represent the construction cost of independent recycling center j ; f_j represent the construction cost of integrated logistics warehouse j ; f_k^1 represent the construction cost of paid recycling site in consumption area k ; f_k^2 represent the construction cost of free recycling site in consumption area k ; c_{ij}^+ represent the unit cost of transportation from factory i to logistics center j ; c_{jk}^+ represent the unit cost of transportation from logistics center j to consumption area k ; c_{kj}^- represent the unit cost of reverse transportation from consumption area k to logistics center j ; c_{ji}^- represent the unit cost of reverse transportation from logistics center j to factory i ; c_{jm}^- represent the unit cost of reverse transportation from logistics center j to recovery processing center m ; c_t represent the unit transportation cost savings by using the vehicles of forward logistics for reverse logistics; w_j represent the unit cost of storage fee in logistics center j ; g_j represent the warehouse capacity of logistics center j ; g_k^1 represent the capacity of paid recycling site in consumption area k , namely when the paid recycling quantity exceed the capacity, a new paid recycling site is needed; similarly g_k^2 represent the capacity of free recycling site.

2.2 The Optimization Model Design

This part based on the theory of uncertainty, stochastic theory, fuzzy theory and dynamic programming theory, transform the model into dynamic optimization chance constrained model under fuzzy-stochastic environment based on decision period, and solve the model by genetic algorithm. For stochastic constraints and fuzzy constraints, we use the probability measure, for a given confidence level, considering the period of programming, introduce the decision period, to make the probability measure is greater than or equal to the confidence level:

$$\begin{aligned} \min TC = & \left\{ \sum_{j \in J} [f_j^+ Y_j (1 - Z_j) + f_j^- Z_j (1 - Y_j) + f_j Y_j Z_j] + \sum_{k \in K} (n_k^1 f_k^1 + n_k^2 f_k^2) + \sum_{m \in M} f_m Y_m \right\} \\ & + \left[\sum_{i \in I} \sum_{j \in J} x_{ij}^+ c_{ij}^+ + \sum_{i \in I} \sum_{j \in J} \sum_{k \in K} x_{ijk}^+ c_{jk}^+ \right. \\ & + \left(\sum_{k \in K} \sum_{k \in K} \sum_{i \in I} x_{kji}^- c_{ji}^- - \sum_{k \in K} \sum_{j \in J} \sum_{i \in I} x_{kji}^- c_{iY_j Z_j} \right) \\ & + \left. \left(\sum_{j \in J} \sum_{i \in I} x_{ji}^- c_{ji}^- - \sum_{j \in J} \sum_{i \in I} x_{ji}^- c_{iY_j Z_j} \right) + \left(\sum_{j \in J} \sum_{m \in M} x_{jm}^- c_{jm}^- \right) \right] \\ & + \left[\sum_{i \in I} \sum_{j \in J} \sum_{k \in K} w_j (x_{ijk}^+ + x_{kji}^+) \right] \end{aligned} \tag{1}$$

$$\sum_{j \in J} x_{ijkt}^+ \geq \inf \{ K | K = \phi^{-1}(\alpha) \} \quad \forall k \in K, i \in I, t \in T \tag{2}$$

$$\sum_{j \in J} x_{kji}^- = (r_{ki}^1 + r_{ki}^2) \quad \forall k \in K, i \in I \tag{3}$$

$$\sum_{j \in J} x_{kjit}^- \geq (1 - \beta_1)(r_{kit1}^1 + r_{kit1}^2) + \beta_1(r_{kit2}^1 + r_{kit2}^2) \tag{4}$$

$$\sum_{j \in J} x_{kjit}^- \leq (1 - \beta_1)(r_{kit3}^1 + r_{kit3}^2) + \beta_1(r_{kit2}^1 + r_{kit2}^2) \tag{5}$$

$$n_{kt}^1 \geq (1 - \beta_2) \left(\left[\sum_{i \in I} r_{kit1}^1 / g_k^1 \right] + 1 \right) + \beta_2 \left(\left[\sum_{i \in I} r_{kit2}^1 / g_k^1 \right] + 1 \right) \tag{6}$$

$$n_{kt}^1 \leq (1 - \beta_2) \left(\left[\sum_{i \in I} r_{kit3}^1 / g_k^1 \right] + 1 \right) + \beta_2 \left(\left[\sum_{i \in I} r_{kit2}^1 / g_k^1 \right] + 1 \right) \tag{7}$$

$$n_{kt}^2 \geq (1 - \beta_3) \left(\left[\sum_{i \in I} r_{kit1}^2 / g_k^2 \right] + 1 \right) + \beta_3 \left(\left[\sum_{i \in I} r_{kit2}^2 / g_k^2 \right] + 1 \right) \tag{8}$$

$$n_{kt}^2 \leq (1 - \beta_3) \left(\left[\sum_{i \in I} r_{kit3}^2 / g_k^2 \right] + 1 \right) + \beta_3 \left(\left[\sum_{i \in I} r_{kit2}^2 / g_k^2 \right] + 1 \right) \tag{9}$$

$$n_k^1 = \left[\sum_{i \in I} r_{ki}^1 / g_k^1 \right] + 1 \quad \forall k \in K \quad (10)$$

$$n_k^2 = \left[\sum_{i \in I} r_{ki}^2 / g_k^2 \right] + 1 \quad \forall k \in K \quad (11)$$

$$\sum_{i \in I} \sum_{k \in K} x_{ijk}^+ \leq g_j Y_j \quad \forall j \in J \quad (12)$$

$$\sum_{i \in I} \sum_{k \in K} x_{kji}^- \leq g_j Z_j \quad \forall j \in J \quad (13)$$

$$\sum_{i \in I} \sum_{k \in K} (x_{ijk}^+ + x_{kji}^-) \leq g_j \quad \forall j \in J \quad (14)$$

$$\sum_{i \in I} \sum_{k \in K} x_{ijk}^+ \sum_{i \in I} x_{ij}^+ \quad \forall j \in J \quad (15)$$

$$\sum_{i \in I} x_{ji}^- = \left(1 - \sum_{m \in M} Y_m \right) \sum_{i \in I} \sum_{k \in K} x_{kji}^- = \forall j \in J \quad (16)$$

$$\sum_{m \in M} x_{jm}^- = Y_m \sum_{i \in I} \sum_{k \in K} x_{kji}^- \quad \forall j \in J, m \in M \quad (17)$$

$$x_{ij}^+, x_{ijk}^+, x_{kji}^-, x_{ji}^-, x_{jm}^- \geq 0 \quad (18)$$

$$Y_j, Y_m, Z_j, \sum_{m \in M} Y_m \in \{0, 1\} \quad (19)$$

The objective function (1) is to minimize the costs of reverse logistics, including: the construction costs of independent distribution centers, independent recycling centers, integrated logistics warehouses, paid recycling sites, free recycling sites; transportation costs of forward logistics and reverse logistics, including the cost savings by using the vehicles of forward logistics for reverse transportation; storage costs of products and waste products (Guiltingan and Nwokoye 1975).

Constrain conditions including: the forward flow meet the demand of consumption area (2); all the flow of waste products through the reverse logistics network(2)–(9); the construction of paid recycling sites meet the demand of paid recycled quantity (10); the construction of free recycling sites meet the demand of free recycled quantity (11); the storage of independent distribution center is no more than the capacity (12); the storage of independent recycling center is no more than the capacity (13); the storage of integrated logistics warehouse is no more than the capacity (14);

the flow of forward logistics through logistics warehouse meet the flow conservation (15); the flow of reverse logistics through logistics warehouse meet the flow conservation (16) (17); non-zero constraints (18); 0–1 constraints (19).

The model solve two main questions: one is the location problem, the other is the flow distribution problem. The decision variable of location problem is 0–1 variables, and the decision variable of flow distribution problem is real variables.

3 Numerical Example

Choosing two ($i = 1, 2$) product factories, it is known that the products of the both factories have the same five ($k = 1, 2, \dots, 5$) consumption areas. The two factories jointly build logistics network, and the logistics warehouse can be built at three alternative address in which forward/reverse logistics warehouse can be integrated to build (Joaquin and Jordi 2006). Waste products can be returned production enterprise for processing or centralized disposed in a processing center that built at one of the three alternative address. According to the scrap companies can establish multiple paid recycling site and free recycling site in the same consumption area. Planning period is divided into two decision cycle.

According to the prediction for positive/reverse logistics demand in consumption area, two product makers get positive/reverse logistics demand's uniform distribution in two decision cycle. Reverse logistics demand has less historical data and high degree of uncertainty. So reverse logistics can adopt two decision cycle triangular fuzzy distribution of demand.

This paper assume that deserve logistics product can use positive transport vehicle to save 2 RMB/ piece of freight and reverse logistics fee is 80% of positive logistics fee when positive logistics transportation route is the same to reverse logistics transportation route. In the meanwhile this article don't consider the problem of TSP in the same area and the change of charge along with time.

3.1 Simulation Results

According to the design of genetic algorithm, we use the toolbox function in Matlab2012 to do the simulation calculation. We set population size as 100, the number of iterations Maxgen as 100, crossover probability Pc values 0.85, mutation probability Pm as 0.01. We can obtain four different situations: $t = 1, \sum_{m \in M} Y_m = 0$

(Table 1.); $t = 1, \sum_{m \in M} Y_m = 1$; $t = 2, \sum_{m \in M} Y_m = 0$

(Table 2.); $t = 2, \sum_{m \in M} Y_m = 1$.

Above are optimal results, in the first period of logistics network planning, the integrated logistics warehouse need to be constructed at $j = 3$; the second period of network programming, an independent distribution center need to be built at $j = 1$.

Table 1 Results under situation $t = 1, \sum_{m \in M} Y_m = 0$ ($TC_{10} = 291631$)

Decision variable	Y_j			Z_j			Y_m			x_{jm}^-		
Location	1	2	3	1	2	3	1	2	3	x_{31}^-	x_{31}^-	x_{33}^-
	0	0	1	0	0	1	0	0	0	0	0	0
Decision variable	x_{ij}^+			x_{ijk}^+								
	x_{13}^+	x_{23}^+	x_{131}^+	x_{132}^+	x_{133}^+	x_{134}^+	x_{135}^+	x_{231}^+	x_{232}^+	x_{233}^+	x_{234}^+	x_{235}^+
Flow	1206	1113	326	254	214	261	154	181	256	227	224	226
Decision variable	x_{ji}^-			x_{kji}^-								
	x_{31}^-	x_{32}^-	x_{131}^-	x_{231}^-	x_{331}^-	x_{431}^-	x_{531}^-	x_{132}^-	x_{232}^-	x_{332}^-	x_{432}^-	x_{532}^-
Flow	302	253	88	82	44	54	34	30	59	53	54	58

Table 2 Results under situation $t = 2, \sum_{m \in M} Y_m = 0$ ($TC_{20} = 517576$)

Decision variable	Y_j			Z_j			Y_m							
	1	2	3	1	2	3	1	2	3					
Location	1	0	1	0	0	1	0	0	0					
Decision variable	x_{ij}^+			x_{ijk}^+										
	x_{11}^+	x_{21}^+	x_{13}^+	x_{23}^+	x_{111}^+	x_{112}^+	x_{113}^+	x_{114}^+	x_{115}^+	x_{231}^+	x_{232}^+	x_{233}^+	x_{234}^+	x_{235}^+
Flow	1436	0	0	1380	373	302	283	282	196	249	306	289	274	264
Decision variable	x_{ji}^-			x_{kji}^-										
	x_{31}^-	x_{32}^-	x_{131}^-	x_{231}^-	x_{331}^-	x_{431}^-	x_{531}^-	x_{132}^-	x_{232}^-	x_{332}^-	x_{432}^-	x_{532}^-		
Flow	662	694	168	138	128	126	102	104	158	161	114	158		

4 Conclusion

The fuzzy random environment is a form a variety of uncertain factors intertwine together. This article taking the minimality of network construction and operating costs in the reverse logistics network building as the objective, considering infrastructure cost, storage cost, transportation cost in the reverse network, establish a waste products positive/reverse logistics network integrated optimization model to solve the decision problem of facilities layout, traffic distribution and positive/integrated reverse logistics warehouse in different decision circle.

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