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Research on reverse logistics location under uncertainty environment based on grey prediction

BAO Zhenqiang[a], ZHU Congwei[a], ZHAO Yuqin[a] ,PAN Quanke[b]

[a]*Information engineering college,Yangzhou University,Yangzhou City, Jiangsu Province, China*
[b] *College of computer ,Liaocheng University, Liaocheng City, Shandong Province, China*

Abstract

This article constructs reverse logistic network based on uncertain environment, integrates the reverse logistics network and distribution network, and forms a closed network. An optimization model based on cost is established to help intermediate center, manufacturing center and remanufacturing center make location decision. A gray model GM (1, 1) is used to predict the product holdings of the collection points, and then prediction results are carried into the cost optimization model and a solution is got. Finally, an example is given to verify the effectiveness and feasibility of the model.

Keywords:network design; facility location; optimization software; gray model

1.Introduction

In the re-manufacturing reverse logistic system, product recovery network designing, re-manufacturing and manufacturing hybrid inventory management, manufacturing production planning and scheduling are the three key issues[1]. And reverse logistic system is based on re-manufacturing reverse logistic network. We can re-construct re-manufacturing reverse logistic network[2-4], or we can construct it on the existing structures[5,6]. Therefore, this article presents a mixed-integer linear programming (MILP) model for remanufacturing logistics network optimization design based on the traditional production distribution networks, integrates recovery network with the traditional distribution network, and constructs mathematical model based on system total cost according to the building network.

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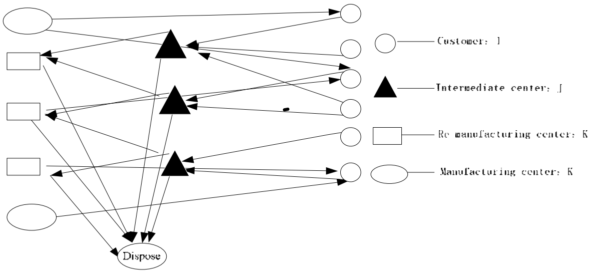

Figure 1. Diagram of re-manufacturing logistics network

2.Remanufacturing reverse logistics network design

We assume that there are four parts in the re-manufacturing system: the customer or recycling, intermediate centers, re-manufacturing center and the original manufacturing center (shown as Fig.1). At the part of customer, with product demand and recovery of waste products, we use gray prediction to predict the amount of product after a certain stage of the customer product demand and obsolescence, and the results will be applied to the closed reverse logistics network; intermediate centers are used for reverse channel, and take responsible for some important activities, such as cleaning, demolition, inspection and classification before the handover, and the goods are transported back to re-manufacturing center; re-manufacturing center for intermediary processing checks accepted return parts and recycled parts will be used for re-manufacturing products; in the forward network, recycled parts are used by the re-manufacturing center, and manufacturing center use traditional production model, the two products meet customer demand together.

3.Model of remanufacturing Network Location Based on cost

3.1.Model assumption

- There are *i* collection points, assuming the same rate for each point;
- All of the recalled products for various reasons (such as product quality, etc.) must first go through the intermediary center;
- Parts handled by the intermediary center will be delivered to the re-manufacturing or manufacturing center;
- Customer demand for products are provided by the re-manufacturing center, or by re-manufacturing factories and manufacturing together;
- The quality of products produced by re-manufacturing are same with that of traditional production, these two meet customer demand together;
- To simplify the model, we only consider the recovery of one branded product, regardless the other competitors in the network;
- Each intermediate center has the same cost of processing unit products, the same as re-manufacturing center.

3.2.Symbol Notations

- CT_j : The cost of intermediate center processing unit products;

- CP_k : The cost of Unit re-manufacturing processing unit products;
- P_k : Unit product cost of manufacturing factory;
- T_{ij} : Unit transportation cost from collection *i* to intermediate center *j*;
- T_{jk} : Unit transportation cost from intermediate center *j* to re-manufacturing *k*;
- T_{ki} : Unit transportation cost from manufacturing center or re-manufacturing center k to customer *i*;
- λ : Recovery ratio of intermediate center;
- D_i : The amount of product demand at Customer *i*;
- R_i : The amount of products to be recovered at Customer *i*;
- F_j : Facility location cost of intermediate center;
- F_k : Facility location cost of manufacturing center;
- FR_k : Facility location cost of re-manufacturing center;
- $Y_j = 1$ means set up intermediary centre at point *j*, and 0 means not;
- $Y_k = 1$ means set up manufacturing at point *k*, 0 means not;
- $YR_k = 1$ means set up re-manufacturing center at point *k*, 0 means not;
- X_{ki} : Product demand at Customer *i* is met by the re-manufacturing k or manufacturing k, or both;
- XR_{ijk} : Portion of waste products, that reaches manufacturing *k* from customer *i* through intermediate center *j*;
- M , M' : Infinite positive integer.

3.3. Grey prediction of product holdings

- *Generate series*

Grey prediction method is a method to predict a system containing uncertain factors. Grey model is used to predict the product holdings of customer. In order to weaken the randomness of the original time series, before the establishment of gray forecasting model, we must process data in the original time series. Time series through data processing is called the generate series.

- *Correlation*

a) Correlation coefficient

Set $\hat{X}^{(0)}(k)=\{\hat{X}^{(0)}(1),\hat{X}^{(0)}(2),...,\hat{X}^{(0)}(n)\}$, $X^{(0)}(k)=\{X^{(0)}(1),X^{(0)}(2),...,X^{(0)}(n)\}$. The correlation coefficient is defined as:

$$\eta(k)=\frac{\min\min\left|\hat{X}^{(0)}(k)-X^{(0)}(k)\right|+\rho\max\max\left|\hat{X}^{(0)}(k)-X^{(0)}(k)\right|}{\left|\hat{X}^{(0)}(k)-X^{(0)}(k)\right|+\rho\max\max\left|\hat{X}^{(0)}(k)-X^{(0)}(k)\right|}$$

Where: ρ is called the resolution, $0<\rho<1$, usually set $\rho=0.5$; Of the different units, different initial sequences, the correlation coefficient in the calculation should first be initiatived, that is all the data about the sequence data should be divided by the first.

b) Correlation

$$r=\frac{1}{n}\sum_{k=1}^{n}\eta(k)$$ is known as the correlation of $X^{(0)}(k)$ and $\hat{X}^{(0)}(k)$.

- *Constructing of GM (1, 1) model*

c) We assume there are n observed value(shown as Table I) in the time series $X^{(0)}$, $X^{(0)}=\left\{X^{(0)}(1),X^{(0)}(2),...,X^{(0)}(n)\right\}$, by accumulating we generate a new sequence, $X^{(1)}=\left\{X^{(1)}(1),X^{(1)}(2),...,X^{(1)}(n)\right\}$, then the corresponding differential equation GM (1,1) model is: $\frac{dX^{(1)}}{dt}+aX^{(1)}=\mu$

Where: α is called the development of gray number; μ is the endogenous control gray number.

d) Let the parameter $\hat{\alpha}$ to be estimated, $\hat{\alpha}=\begin{pmatrix} a \\ \mu \end{pmatrix}$, which can be got by using least squares method.

Solutions are: $\hat{\alpha}=\left(B^{T}B\right)^{-1}B^{T}Y_{n}$.

Where:

$$B=\begin{bmatrix} -\frac{1}{2}\left[x^{(1)}(1)+x^{(1)}(2)\right] & 1 \\ -\frac{1}{2}\left[x^{(1)}(2)+x^{(1)}(3)\right] & 1 \\ \cdots & 1 \\ -\frac{1}{2}\left[x^{(1)}(n-1)+x^{(1)}(n)\right] & 1 \end{bmatrix}, \quad Y=\begin{bmatrix} x^{(0)}(2) \\ x^{(0)}(3) \\ \cdots \\ x^{(0)}(n) \end{bmatrix}$$

By soluting the differential equations we can get prediction model:

$$\hat{X}^{(1)}(k+1)=\left[X^{(0)}(1)-\frac{\mu}{a}\right]e^{-ak}+\frac{\mu}{a},\ k=0,1,2...,n$$

3.4.Total cost model for re-manufacturing system

Total cost of system is constituted of the following parts: the facility cost of intermediate center, manufacturing and re-manufacturing center, cost of disposal unit product, transportation cost between each facility. The goal of the location model is to minimize the total cost.

$$\begin{aligned} MinZ = & \sum_{k}^{K} F_k Y_k + \sum_{k}^{K} FR_k YR_k + \sum_{j}^{J} F_j Y_j + \sum_{k}^{K}\sum_{i}^{I} T_{ki} D_i X_{ki} + \\ & \sum_{k}^{K}\sum_{i}^{I} CP_k D_i X_{ki} + \sum_{i}^{I}\sum_{j}^{J}\sum_{j}^{K} T_{ij} R_i XR_{ijk} + \sum_{i}^{I}\sum_{j}^{J}\sum_{j}^{K} \lambda CT_j R_i XR_{ijk} \\ & + \sum_{i}^{I}\sum_{j}^{J}\sum_{j}^{K} \lambda T_{jk} R_i XR_{ijk} + \sum_{i}^{I}\sum_{j}^{J}\sum_{j}^{K} \lambda CT_k R_i XR_{ijk} \\ & - \sum_{i}^{I}\sum_{j}^{J}\sum_{j}^{K} \lambda P_k R_i XR_{ijk} \end{aligned}$$

s.t. $\sum_{k}^{K} X_{ki} = 1, \forall i$ (1)

$\sum_{k}^{K}\sum_{j}^{J} XR_{ijk} = 1, \forall i$ (2)

$\sum_{i}^{I} D_i X_{ki} \ge \lambda \sum_{j}^{J}\sum_{i}^{I} R_i XR_{ijk}, \forall k$ (3)

$\sum_{i}^{I} D_i X_{ki} - \lambda \sum_{i}^{I}\sum_{j}^{J} R_i XR_{ijk} \le Y_k M, \forall k$ (4)

$XR_{ijk} \le Y_j, \forall i,j,k$ (5)

$\lambda R_i XR_{ijk} \le YR_k M', \forall i,j,k$ (6)

$Y_j, Y_k, YR_k = 0,1, \forall j,k$ (7)

$X_{ki}, XR_{ijk} \ge 0, \forall i,j,k$ (8)

(1) provides customer demand for products must be met; (2) provides retirement products from customer must be fully recovered; (3) point out the relationship between forward logistics and reverse logistics, products quantity from manufacturing and re-manufacturing must not be less than the number

of client retirement products, essence is to limit the number of manufacturing; (4) means that only the located manufacturing can do the activity of production; (5) means that only the located intermediate center can handle the recycling products; (6) that only the located re-manufacturing center can do re-manufacturing process; (7) for the 0-1 variable constraint; (8) is a non-negative variables bound.

4.Solution and analysis of examples

4.1.Data Preparation

TABLE I. PRODUCT HOLDINGS (Q_{it}) OF EACH CUSTOMER IN THE TIME 1-5

Q_{it}	1	2	3	4	5
1	10230	11345	12456	13421	14000
2	9045	10123	11452	11985	12647
3	14056	15678	16089	17890	19247
4	9853	10254	10897	11324	12078
5	15962	16089	17800	19900	21900
6	34500	39070	43048	46078	50456
7	10230	11456	11950	12980	13820
8	18570	19480	21050	22400	23080
9	28078	29780	30580	31780	32045
10	17026	18040	19450	20456	21920
11	8040	8345	8890	9004	9112
12	15905	16508	17802	19011	22456
13	19789	22265	23456	24545	25040
14	21564	22456	24120	26127	27901
15	18040	19204	20140	21000	23041
16	18045	19056	20311	21050	22900
17	45700	49070	55460	59450	63056
18	50464	55070	60745	65804	72040
19	24006	28056	31465	33064	34045
20	20405	24506	35040	41600	45064

From Table Ⅰ, we can get the values in next five consecutive periods by using gray prediction method, show as Table Ⅲ.

4.2.Product demand at each customer i(Di)

I	*Di*	*I*	*Di*
1	18000	11	124543
2	14567	12	26423
3	26535	13	28443
4	14313	14	29424
5	25313	15	25424
6	54433	16	26423
7	16313	17	67756
8	25432	18	79787
9	36423	19	36543
10	24434	20	49345

TABLE II. RECOVERY PREDICTION SEQUENCE OF DISABLED PRODUCTS AT CUSTOMER I WITHIN TIME 6-10

P_t	6	7	8	9	10
1	15675	16800	17030	18600	19045

2	13451	13879	14040	14450	15145
3	20145	21314	23080	23860	24031
4	12500	12801	13504	139013	149013
5	22080	22890	23504	24820	26131
6	51455	52456	53402	54080	59051
7	13980	14506	15045	16078	17646
8	23880	23980	24058	24098	25100
9	32089	32980	33080	33450	33950
10	22560	22800	22980	23080	23045
11	9200	9315	9415	9498	9500
12	23450	24500	25809	26890	27089
13	26087	27800	28908	29089	29802
14	27808	27990	28800	29780	29980
15	23470	23890	24880	24980	25090
16	22990	23090	24490	25850	26990
17	65089	66080	67090	68580	68980
18	78087	79045	85890	95040	99478
19	34980	35670	36780	37890	38456
20	46870	47890	49450	50023	52466

To simplify the model, we take the mean forecast series of data for the model, shown as Table Ⅳ.

TABLE III. THE NUMBER OF PRODUCTS WILL BE DISCARDED AT CUSTOMER I (*AI*)

I	*Ai*	*I*	*Ai*
1	16000	11	94543
2	13567	12	23423
3	24535	13	23443
4	12313	14	23424
5	21313	15	23424
6	53433	16	23423
7	12313	17	65756
8	23432	18	78787
9	32423	19	34543
10	23434	20	45345

TABLE IV. UNIT TRANSPORTATION COST FROM MANUFACTURING CENTER (RE-MANUFACTURING CENTER) TO CUSTOMER

TC_{ki}	1	2
1	898.3	1256.12
2	984.2	1323.67
3	95.67	1498.3
4	1085.52	953.25
5	907.45	902.41

TABLE V. UNIT TRANSPORTATION COST FROM INTERMEDIATE CENTER TO MANUFACTURING CENTER (OR RE-MANUFACTURING CENTER) TC_{JK}

TC_{jk}	**1**	**2**
1	498.3	456.12
2	784.2	45.67
3	45.67	498.3
4	985.52	1453.25
5	1007.45	2002.41

TABLE VI. UNIT TRANSPORTATION COST FROM CUSTOMER TO INTERMEDIATE CENTER

TC_{ij}	1	2	3	4	5
1	1029.6	1017.8	1175.1	621.86	123.62
2	981.14	969.35	1126.6	573.4	75.16

3	916.97	905.18	1062.5	509.23	10.99
4	626.35	605.79	828.15	205.45	703.69
5	494.63	474.07	696.43	73.73	571.97
6	433.44	412.88	635.24	12.54	510.78
7	325.14	175.43	559.49	575.77	1069.6
8	329.91	180.2	564.26	580.54	1074.3
9	157.21	7.5	391.56	407.84	901.69
10	127.33	60.21	376.93	342.97	878.15
11	35.92	138.19	227.85	456.82	941.9
12	13.97	121.91	267.84	434.87	919.95
13	28.43	160.84	226.10	449.33	934.41
14	45.96	103.53	285.1	436.51	971.69
15	117.65	68.00	348.97	456.23	991.41
16	164.75	50.70	422.16	349.04	884.22
17	79.56	60.83	340.7	380.34	900.72
18	199.61	333.85	54.89	565.45	1085.8
19	147.94	254.38	193.32	566.0	1136.1
20	230.17	365.21	86.95	530.35	1044.6

TABLE VII. OPERATING PARAMETERS OF INTERMEDIATE CENTER

J	1	2	3	4	5
λ	0.46	0.46	0.46	0.46	0.46
Unit cost of processing	4567	7963	4564	5456	8753
Facility location cost	35004	264578	189455	187885	197821
Max Capacity	260000	450000	194512	2545578	123175
Min Capacity	191231	267943	156131	1831311	91131

TABLE VIII. RE-MANUFACTURING CENTER OPERATING PARAMETERS

K	1	2
Facility location cost	1456564.466	1987521.423
Max Capacity	796546	789654
Min Capacity	590000	650000
Unit cost of processing	754545	4522323

TABLE IX. MANUFACTURING CENTER OPERATING PARAMETERS

K	1	2
Facility location cost	5456564.466	4987521.423
Max Capacity	896546	889654
Min Capacity	690000	650000
Unit cost of processing	1754545	14522323

4.3.Simulation results

The mathematical model and the given data are sent into the Lingo software, get the following result: The total cost of system operation: 985 967 610, 2, 4 intermediate centers are selected, k = 2 means construct manufacturing center and re-manufacturing center at point 2. The flow between the central collection and intermediate center are shown as Table XI.

5.Conclusion

This paper considered location of intermediate center, manufacturing and re-manufacturing center facility at the same time, while distributing products positively to customers. System model changes from the single direction network of products recovery into a closed network, including the positive products distribution, in the process of product recall, by using gray prediction through the holdings of products of the past each period obtained the prediction number of products, so the system eventually transformed into MILP model.

TABLE X. COLLECTION POINTS AND THE INTERMEDIATE PRODUCT FLOWS BETWEEN THE CENTERS (%)

Portion	2	4
1	30	70
2	40	60
3	55	45
4	29	71
5	79	21
6	80	20
7	40	60
8	59	41
9	19	81
10	80	20
11	56	44
12	45	55
13	47	53
14	49	51
15	76	24
16	19	81
17	50	50
18	75	25
19	13	87
20	15	85

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