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Research Article

Solving a Reverse Logistic Model for Multilevel Supply Chain Using Genetic Algorithm

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Abstract

In this paper, we present a new mathematical model for designing a reverse logistic network. The model is multiproduct, multilevel, and multiperiod. It minimizes transportation and facilities establishing cost, and lowers purchasing from suppliers. The price of products depends on the cost of purchases and suppliers present different discounts on their products. Because the presented problem belongs to Np-hard problems, we use genetic algorithm to solve it.

Keywords : Supply chain; Reverse logistic; Discount; Genetic algorithm.

1 Introduction

In this paper, we present a reverse logistic network for returned items to minimize the cost of returning, refurbishing, disassembling, and recycling centers as well as the cost of transportation between centers and purchasing items from external suppliers with considering discounts on their prices. In this paper, we consider different types of discounts presented by suppliers. Table 1 summarizes literature review on logistic and reverse logistic models. This paper comprises five parts. The first part is introduction. The second part defines the problem. Third part is allocated to solving method and part four is a numerical example. Finally, part five is devoted to conclusion and further studies.

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2 Problem definition

2.1 Assumptions

- If the volume of parts produced in a renewal center is not enough, the producer must buy them from external suppliers,
- The number of returned centers, product centers, and recycle centers are predefined,
- The number of candidate locations for disassembly, control, cleaning, and sorting centers are predefined,
- Some products that do not need to disassemble, will directly be sent to control, cleaning, and sorting centers from returned centers, and

- Some products are directly sent to recycle center.

2.2 Nomenclature

2.2.1 Indexes

I : Number of returned centers ($i \in I$),

J : Number of candidate disassembling centers ($j \in J$),

K : Number of control, cleaning, and sorting centers ($k \in K$),

F : Number of production centers ($f \in F$),

R : Number of recycling centers ($r \in R$),

P : Set of products ($p \in P$),

M : Set of parts ($m = 1, 2, \ldots, M$),

S : Set of suppliers ($s = 1, 2, \ldots, S$),

T : Periods ($t = 1, 2, \ldots, T$),

E : Discount levels ($e = 1, 2, \ldots, E(m, s)$),

2.2.2 Parameters

Rud_m**:** Source value used for disassembling one unit of part type m,

RuR_{mk}**:** Source value used for renewing (or renewal) one unit of part type m in renewal center k,

Ru_{ms} : Internal source value from supplier s for producing one unit of part type m,

$MCAP_{mt}$: Maximum capacity of renewing center of part m in time interval t,

$MCAP_{mkt}$: Maximum capacity of renewing center k for renewing part type m in time interval t,

$MCAP_{st}$: Maximum storage capacity of supplier s in time interval t,

$Cap1_{ipt}$: The capacity of returned center i for production type p in time interval t,

$Cap2_{jmt}$: The capacity of disassembling center j for part type m in time interval t,

$Cap3_{kmt}$: The capacity of control, cleaning, and sorting center k for part type m in time interval t,

V_{st} : Minimum purchase value from supplier s in time interval t,

UM_m : Maximum recyclable percentage of part type m,

WI_{ms} : Importance weight of supplier s for part type m,

n_{mp} : Number of part type m created by disassembling one unit of product type p,

DP_{fmt} : Demand of production center f for part type m in time interval t,

DB_{rpt} : Demand of recycling center r for product type p in time interval t,

DR_{rmt} : Demand of recycling center r for part type m in time interval t,

CD_{mt} : Disassembly cost of part type p in time interval t,

Cd_{mt} : Disposal cost of part type p in time interval t,

CR_{mkt} : Renovation cost for part type m in renewal center k in time interval t,

CB_{mest} : Cost of part type m in discount interval e that is purchased from supplier s in time interval t,

CRJ_{ijpt} : Transportation cost of one unit of product p from returned center i to disassembling center j in time interval t,

CRR_{ikpt} : Transportation cost of one unit of part m from returned center i to control, cleaning, and sorting center k in time interval t,

CJR_{jkmt} : Transportation cost of one unit of part m from disassembling center j to control, cleaning, and sorting center k in time interval t,

CBR_{kmt} : Transportation cost of one unit of part m from recycling center r to control, cleaning, and sorting center k in time interval t,

CPR_{kfmt} : Transportation cost of one unit of part m from production center f to control, cleaning, and sorting center k in time interval t,

CJ_{jm}^{wc} : Fixed construction cost of disassembling center j for part type m,

CR_{mk}^{wc} : Fixed construction cost of control, cleaning, and sorting center k for part type m,

B_{mest} : Upper discount level e from discount interval of supplier s in time interval t for part type m,

2.2.3 Decision variables

UP_{mest} : Purchased units of part type m from suppliers with discount level e in time interval t,

$UPD2_{mk}$: Units of part type m get from disassembly centers in time interval t,

UPR_{mkt} : Units of part type m that are renovated from renewal center k in time interval t,

$UPD1_{mt}$: Units of part type m that are disposed in time interval t,

fRJ_{ijpt} : Product type p flow from return center i to disassembly center j in time interval t,

fRR_{ikpt} : Product type p flow from return center i to control, cleaning, and sorting center k in time interval t,

fJR_{jkmt} : Part type m flow from return center i to control, cleaning, and sorting center k in time interval t,

fJB_{jrmt} : Part type m flow from disassembly center j to recycling center r in time interval t,

fRP_{kfmt} : Part type m flow from control, cleaning, and sorting center k to production center f in time interval t,

fRB_{krmt} : Part type m flow from control, cleaning, and sorting center k to recycling center r in time interval t,

y_{jm} : A binary variable, if the disassembly center j for part type m construct is equal to 1, else 0,

x_{mk} : A binary variable, if the control, cleaning, and sorting center k for part type m construct is equal to 1, else 0,

u_{st} : A binary variable for supplier s in time interval t,

Z_{mest} : Discount coefficient for discount levels.

3 Mathematical model

$$
\begin{aligned}
\min Z = & \sum_{m=1}^{M} \sum_{e=1}^{E(m,s)} \sum_{s=1}^{S} \sum_{t=1}^{T} CB_{mest}.UP_{mest} \\
& + \sum_{m=1}^{M} \sum_{t=1}^{T} CD_{mt}.UPD2_{mt} \\
& + \sum_{k=1}^{K} \sum_{m=1}^{M} \sum_{t=1}^{T} CR_{kmt}.UPR_{kmt} \\
& + \sum_{m=1}^{M} \sum_{t=1}^{T} CD_{mt}.UPD1_{mt} \\
& + \sum_{j=1}^{J} \sum_{m=1}^{M} CJ_{jm}^{wc}.y_{jm} \\
& + \sum_{k=1}^{K} \sum_{m=1}^{M} CR_{mk}^{wc}.x_{mk} \\
& + \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{p=1}^{P} \sum_{t=1}^{T} CRJ_{ijpt}.fRJ_{ijpt}
\end{aligned}
$$

Table 1: Summarized literature review about logistic and reverse logistic models

Authors	Method/Model	Factors for forecasting	Sector	Disposition
Goh and Varaprasad [6]	Statistical methodology	Trippage, trip duration, loss rate, expected useful life	Containers	Reuse
Kelle and Silver [9]	Simulation model	Quantitative	Reusable Containers	Reuse
Tokta, et al. [20]	Discrete-time distributed-lag model	Quantitative	Kodak Camera	Reuse
Marx-Gomez et al. [14]	A neuro-fuzzy system	Quantitative	Photo copiers	Remanufactured, Recycling
Srivastava and Srivastava [18]	Decomposition methods and heuristics	Product ownership data, life cycle of, products, sales, forecasted demand, environmental policy, green indexes	Electronic	General
Peralta and Fontanos [15]	Mathematical equations	Number of devices in use, current end-of-life, serviceable years of the product, disposal behavior of consumers	Electronic	Recycling
Hanafi et al. [7]	Petri Net Forecasting model	Product life, social and sales factor, Marketing and advertising budget, Population density, Age	Mobile phone	General
Liu and Fang [10]	Transfer function, Noise model	Quantitative	–	–
Xiaofeng and Tijun [21]	Wave function	Quantitative	Electronic	General
Efendigl et al. [5]	Artificial intelligence approaches	Demand with incomplete information	Durable consumer goods	Closed-loop supply chain

$$+\sum_{i=1}^{I}\sum_{k=1}^{K}\sum_{p=1}^{P}\sum_{t=1}^{T} CRR_{ikpt}.fRR_{ikpt}$$
$$+\sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{m=1}^{M}\sum_{t=1}^{T} CJR_{ikmt}.fJR_{iikmt}$$
$$+\sum_{j=1}^{J}\sum_{r=1}^{R}\sum_{m=1}^{M}\sum_{t=1}^{T} CBJ_{jrmt}.fJB_{jrmt}$$
$$+\sum_{k=1}^{K}\sum_{f=1}^{F}\sum_{m=1}^{M}\sum_{t=1}^{T} CPR_{kfmt}.fRP_{kfmt}$$
$$+\sum_{k=1}^{K}\sum_{r=1}^{R}\sum_{m=1}^{M}\sum_{t=1}^{T} CBR_{krmt}.fRB_{krmt} \qquad (3.1)$$

$S.t:$

$$u_s.v_{st} \le \sum_{m=1}^{M}\sum_{e=1}^{e(m,s)} Ru_{ms}.UP_{mest} \le u_s.Mcap_{st} \quad \forall s,t \qquad (3.2)$$

$$\sum_{k=1}^{K} UPR_{mkt} + UPD1_{mt} = UPD2_{mt}, \quad \forall m,t \qquad (3.3)$$

$$Rud_m.UPD2_{mt} \le Mcap_{mt}, \quad \forall m,t \qquad (3.4)$$

$$Rur_{mk}.UPR_{mKt} \le Mcap_{mKt}.X_{MK}, \qquad (3.5)$$

Table 1. Continue

Authors	Method/Model	Factors for forecasting	Sector	Disposition
Chen and He [3]	Simplex gray forecast with time series model	Quantitative	House hold appliances	General
Yu et al. [22]	Logistic and material flow analysis	Quantitative	Personal Computers	Recycling
Shih et al. [17]	Analytic network process	Consumer behavior, marketing mix	Printers	Recycling
Potdar and Rogers [16]	Data Envelopment Analysis	Consumer behavior	Electronic	General
Benedito and Corominas [2]	Markov Decision model	Product demand, product life cycle, return rate of end of life	–	Remanufactured, recycling
Clottey et al. [4]	A generalized approach	Quantitative	–	Remanufactured
Krapp et al. [11]	Bayesian estimation techniques	Quantitative	–	Closed -loop supply chain
Krapp et al. [12]	A generic framework	Quantitative	Electronic	Closed-loop supply chain
Agrawal et al. [1]	Graphical evaluation and review technique	Quantitative	E-waste	Recycling
Temur et al. [19] [19]	Fuzzy Expert system	Quantitative	General	Closed- loop supply chain
Kumar et al. [13]	ANFIS	Quantitative	–	Closed- loop supply chain

$$\forall m, K, t$$

$$\sum_{j=1}^{J} fRJ_{ijpt} \leq cap1_{ipt} \quad \forall i, p, t \tag{3.6}$$

$$\sum_{k=1}^{K} fRR_{ikpt} \leq cap1_{ipt}, \quad \forall i, p, t \tag{3.7}$$

$$\sum_{k=1}^{K} fJR_{jkmt} \leq cap2_{jmt}.y_{jm}, \quad \forall j, m, t \tag{3.8}$$

$$\sum_{r=1}^{R} fJB_{jrmt} \leq cap2_{jmt}.y_{jm}, \quad \forall j, m, t \tag{3.9}$$

$$\sum_{r=1}^{R} fRB_{krmt} \leq cap3_{kmt}.y_{mk}, \quad \forall k, m, t \tag{3.10}$$

$$\sum_{f=1}^{F} fRP_{kfmt} \leq cap3_{kmt}.x_{mk}, \quad \forall k, m, t \tag{3.11}$$

$$\sum_{k=1}^{K} UPR_{mkt} \leq u_m.UPD2_{mt}, \quad \forall m, t \tag{3.12}$$

$$UPD_{mt} \leq (1 - u_m).UPD2_{mt}, \quad \forall m, t \tag{3.13}$$

$$\sum_{j=1}^{J}\sum_{r=1}^{R} fJB_{jrmt} \leq n_{mp}.\sum_{i=1}^{I}\sum_{j=1}^{J} fRJ_{ijpt}, \quad \forall m, p, t \tag{3.14}$$

$$\sum_{j=1}^{J}\sum_{k=1}^{K} fJR_{jkmt} \leq n_{mp}.\sum_{i=1}^{I}\sum_{j=1}^{J} fRJ_{ijpt}, \quad \forall m, p, t \tag{3.15}$$

(3.16)

$$p\sum_{k=1}^{K} fJR_{jkmt} \geq DP_{fmt},\ \forall f,m,t$$

$$p\sum_{i=1}^{I}\sum_{k=1}^{K} fRR_{ikpt} \geq \sum_{r=1}^{R} DB_{rpt},\quad \forall p,t \tag{3.17}$$

$$p\sum_{k=1}^{K} fRR_{kfmt} \geq DP_{fmt} \quad \forall f,m,t \tag{3.18}$$

$$p\sum_{k=1}^{K} fRB_{krpt} \geq DB_{rpt} \quad \forall r,p,t \tag{3.19}$$

$$p\sum_{j=1}^{J} fJB_{jrmt} \geq DR_{rmt} \quad \forall r,m,t \tag{3.20}$$

$$p\sum_{e=1}^{E(m,s)}\sum_{s=1}^{S} UP_{mest} \geq \sum_{f=1}^{F} DP_{fmt},\quad \forall m,t \tag{3.21}$$

$$B_{m(e-1)st}.Z_{mest} \leq UP_{mest} \leq B_{mest}.Z_{mest},\quad \forall m,e,s,t \tag{3.22}$$

$$p\sum_{e=1}^{E(m,st)} Z_{mest} \leq 1 \quad \forall s,t \tag{3.23}$$

(3.24)

$$Z_{mest} \in \{0,1\} \tag{3.25}$$

(3.26)

$$m = 1,2,\ldots,M;$$

(3.27)

$$\begin{cases} e = 1,2,\ldots,E\,(m,s) \\ s = 1,2,\ldots,S \end{cases} \tag{3.28}$$

(3.29)

$$fRJ_{ijpt},\ fRR_{ikpt},\ fJR_{jkmt},\ fJB_{jrmt},$$

(3.30)

$$fRP_{kfmt}, fRB_{kmt},\ UP_{mest},\ UPD1_{mt},$$

(3.31)

$$UPD2_{mt},\ UPR_{mkt} \geq 0$$

(3.32)

$$\forall i,j,k,m,f,r,p,t \tag{3.33}$$

(3.34)

$$y_{jm}, x_{mk}, \quad u_{st} \in \{0,1\}\,,\ \forall j,m,k,s,t$$

The objective function of Equation (3.1) is to minimize the cost of constructing centers, the cost of activities in all centers and the transportation cost of the parts and products between all centers. Equation (3.2) is the minimum limit of purchasing from supplier and maximum capacity of suppliers. Equation (3.3) indicates that the number of disassembled parts is equal to the number of parts that can be used again. Equations (3.4) and (3.5) indicate that maximum capacity of disassembly and renewal centers in time interval t. Equations (3.6) and (3.7) demonstrate that the amount of the products sent from each return center to disassembly and control, cleaning, and sorting centers must be less than the capacity of the centers. Equations (3.8) and (3.9) indicate that the number of parts sent from disassembly center (if constructed) to control, cleaning, and sorting centers must be less than the capacity of the centers. Equations (3.10) and (3.11) indicate that the number of the parts sent from control, cleaning, and sorting centers (if constructed) to production and recycle centers must be less that the capacity of the centers. Equations (3.12) and (3.13) represent the maximum acceptable percentage of reusable parts. Equations (3.14) and (3.15) are related to adjustment flow of the parts received from disassembling the products and n_{mp} is the adjustment coefficient. Equations (3.16) and (3.17) show that the demand from production and recycling centers are pulling demand. Equations (3.18) to (3.21) represent the demand of centers.

Because each supplier presents different levels of discount, equations (3.22) and (3.23) control the value of purchase from each supplier and the related discount level.

4 Solving method

4.1 Genetic Algorithm

Holland [8] from Michigan University in 1975 presented the basic ideas of GA. This algorithm is based on human genetics and its steps are as follows:

- Producing n chromosomes (each chromosome represent a solution) that is called initial population,
- Calculating the fitness function of each chromosome,

Table 2: Levels and optimal values of GA parameters

Parameter	Low (-1)	Medium (0)	High (+1)	Optimum value
nPop	300	400	500	401
P_c	0.4	0.6	0.8	0.594373
P_m	0.1	0.25	0.4	0.4

- Producing the offspring by deploying three operators:
  - Crossover,
  - Mutation,
  - Elitism,
- Replacing the offspring with parents

4.2 Solution encoding

The problem chromosome contains 9 $UPD1_{m\times t}$, $UP_{m\times e\times s\times t}$, $fRJ_{i\times j\times p\times t}$, $fRR_{i\times k\times p\times t}$, $UPR_{m\times k\times t}$, $fJR_{j\times k\times m\times t}$, $fJB_{j\times r\times m\times t}$, $fRP_{k\times f\times m\times t}$, and $fRP_{k\times f\times m\times t}$ matrixes. Definitions of these matrixes are matched with definitions that are present in nomenclatures. The pseudo-code of Genetic algorithm is presented in Figure 1.

4.3 Genetic Algorithm parameters tuning

For tuning the parameters of GA, we used RSM[1]. The parameters levels of GA and the optimal values of these parameters are presented in Table 2.

5 Numerical example

For solving the presented model, the parameters were randomly generated and the values are presented in Tables 3 to 15.

Firstly we chose a small scale problem and solve it with branch and bound algorithm in Lingo and GA and the results were equal (the objective function of both methods are equal to 5756). After validation of GA, 12 different large scale

[1] Response Surface Methodology

```
Parameter Setting (number of iterations,
Pop Size, Selection Strategy, Crossover Size, Mutation
Size)

Best solution = [ ]

For I = 1 to number of Pop Size do
    Population (I) = Randomly

    Fitness Population (I) =evaluate (Population (I))

End

For it = 1 to number of iteration do

For I = 1 to number of Crossover Size do

   Parents=Roulette wheel Selection (Population)
   Childs of Crossover = Crossover (Parents)

    Fitness Childs of Crossover=evaluate (Childs of
    Crossover)

End

For I = 1 to number of Mutation Size do

   x = Roulette wheel Selection (Population)
   Childs of Mutation = Mutation (x)

    Fitness Childs of Mutation =evaluate (Childs of
    Mutation)

End

Population = merge (Population, Childs of Crossover,
Childs of Mutation)

Update (Best solution)

End
```

Figure 1: Pseudo-code of Genetic Algorithm

Table 3: Capacity of return centers

Return Centers	Products			
1	123	140	109	113
2	158	106	195	196

Table 4: Capacity and fixed cost of disassembling centers for each part

Disassembely centers capacity	Products					Fixed cost construction	
	1	2	3	4		1	2
1	135	182	101	173	1	182	187
2	104	117	165	165	2	108	140

Table 5: Capacity and fixed constructing cost of control, cleaning, and sorting centers for each product

Control, cleaning, and sorting centers	Parts				Fixed cost construction	
1	169	119	175	1	180	126
2	118	137	129	2	191	143
3	155	145				

Table 6: Demand information of products and recycling centers

Product center	Part demand		Recycle centers	Part demand		Recycle centers	Product demand	
1	12	16	1	2	3	1	11	15
	15	13		2	3		14	16
2	11	14	2	5	4	2	12	13
	18	15		19	5		17	11

Table 7: Transportaion cost from return centers to recycling and control, cleaning, and sorting centers

Return centers	Disassembly centers					Control, cleaning, and orting centers			
1	1	8	2	8	1	7	5	2	2
	9	1	1	3		7	3	8	8
2	1	10	4	7	2	5	2	2	7
	8	8	4	5		3	6	4	10

problems were solved that their values of parameters and optimal values of objective functions are presented in Table 16.

6 Conclusion and further studies

In this paper, we presented a reverse logistic model to minimize system cost (including purchasing the products, establishing the centers, cost of running centers, and transportation between the centers) considering some discount

Table 8: Transportation cost from control, cleaning, and sorting centers to production and recycling centers

Disassembly centers	Control, cleaning, and sorting centers				Disassembly centers	Recycling centers			
1	7	6	3	8	1	4	10	3	2
	2	6	10	9		6	3	5	7
2	3	9	3	2	2	1	8	9	4
	4	10	3	9		1	8	6	6

Table 9: Transportation cost from control, cleaning, and sorting centers to production and recycling centers

Control, cleaning, and sorting centers	Production centers				Recycling			
1	8	3	2	2	1	5	8	7
	2	10	7	8	9	2	10	3
2	5	6	3	4	5	1	10	6
	4	1	7	6	8	1	10	2

Table 10: Maximum capacity of renewal center k for renovating part m, maximum capacity of disassembling centers for part m and maximum storage capacity of supplier s in time interval t

Maximum capacity for control, cleaning and sorting centers	Product			Maximum capacity for disassembly centers	Product		Maximum storage capacity for supplier	Time interval	
1	224	224	242	1	135	151	1	3549	3549
2	212	291	295	2	140	107	2	3534	3590

Table 11: Rosource usage for renovating one part in renovation center and resource usage for demontaging one part and resource usage of suppliers for producing one unit of parts

Resource consumption for part renewal in renovation place	Renewal place		Resource consumption for disassembling one part		Resource consumption internal of supplier for producing one part	Supplies	
1	57	56	1	59	1	57	78
2	54	59	2	63	2	81	93

Table 12: Information of purchaing, percentage of reusable parts, and importance weight of suppliers

$\mathbf{V}_{st}$	**T**		$\mathbf{UM}_m$	$\mathbf{WI}_{ms}$	**s**		$\mathbf{N}_{mp}$	p	
s	7	8	0.8	m	0.22	0.24	m	4	6
	1	10	0.9		0.28	0.26		3	5

Table 13: Part purchase cost from suppliers

	1	2	3	4
1	30	35	38	28
	31	38	37	27
2	25	34	31	29
	27	34	37	21

Table 14: Cost of disassembling, disposal, and refurbishing centers

CD_{mt}	Cost of disassembling centers		CD_{mt}	Cost of disposal centers		CR_{mkt}	Cost of renovation centers			
	9	10		7	1		18	16	11	19
	2	10		3	6		20	17	14	15

Table 15: Parameters and objective function values of 12 different solved problem using GA

B_{mest}							
1000000	1000000	1000000	1000000	0	0	0	0
19	13	17	14	18	11	17	20

Table 16: Parameters and objective function values of 12 different solved problem using GA

	M	T	E	P	S	I	j	K	R	F	Objective Function Value
1	3	3	3	3	3	3	3	3	3	3	66561
2	4	4	3	4	4	3	3	3	3	4	73497
3	5	5	3	4	4	3	3	3	2	5	94112
4	6	6	3	5	6	3	3	3	2	6	101946
5	7	7	3	7	7	3	3	3	2	7	125332
6	8	7	3	7	8	3	3	3	2	8	141794
7	9	9	3	9	8	3	3	3	2	9	193256
8	10	10	3	10	9	3	3	2	2	10	224661
9	11	10	3	11	9	3	3	2	2	9	254346
10	15	12	3	16	12	3	3	2	2	16	316711
11	18	18	3	16	18	3	3	2	2	18	352664
12	20	20	3	17	18	3	3	2	2	20	403449

from each supplier. Because this problem belongs to Np-hard problems, we used GA for solving the model and for validation of GA we used branch and bound algorithm. For further studies, the transportation cost can be considered different with respect to part and products types. Also other various types of discount may draw the problem nearer to real conditions.

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