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Research on Integrated Optimization of the Reverse Logistics Network

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Abstract

Considered the integrate of forward and reverse logistics, the separability of recycle products, the timeliness of recycle products, the paper established a location-routing-inventory control optimization model with batch transportation of recycle products. A matching hybrid genetic algorithm containing heuristic rule was introduced according the characteristics above. The algorithm used three-stage real-code that represents the transport order of vehicles. And the quantity of new products and recycle products will be determined too. The unreasonable solution will be eliminated in the iterative process of genetic algorithm. The simulated test analysis shows the validity and the correctness of the model and algorithm.

Keywords: *reverse logistics, location-routing-inventory problem, hybrid genetic algorithm*

1. Introduction

Reverse logistics is the planning, implementation and control of the flow direction from manufacturers, distributors or consumers to recycle site or appropriate place, include raw materials, semi-finished products, finished products and packaging, *etc* The purpose is to extract value or for the final appropriate process. Mainly includes the product use again, manufacture again , repair, material regeneration, waste disposal and other activities, along with it there are the collection, transportation, inventory management and other logistics activities.

Because of the characteristics of high complexity, diversity, the unbalance of supply, the reverse logistics system depend on the logistics network more. So the first task is the optimizing of the reverse logistics network. Facility location, transportation schedule and inventory strategy is the three key issues of reverse logistics network optimization. Traditionally the three problem was researched as a independent decision-making [1-6] or two problem was combined to study [7-12]. But there are close connection among the three. Any one changes will affect the other two. So it is necessary to integrate the "Location - Routing - Inventory Problem(LRIP)" to optimize.

At present, the integration of logistics network optimization research focused on the positive LRIP [13-18], only a few scholars studied the reverse LRIP. Dragan Simić, Svetlana Simić, presents an evolutionary approach to modeling and optimization on inventory routing problem of inventory management, logistics distribution and supply chain management. The aim of this research is to present different individual evolutionary approach, and to obtain power extension of these hybrid approaches [19]. Reza Tavakkoli-Moghaddam *etc* considered a single-sourcing network design problem for a three-level supply chain. A novel mathematical model is presented considering risk-pooling, the inventory existence at distribution centers under demand uncertainty [20]. Corchado, E., Wozniak, M., Abraham, A. analyzes the state of the art of the progress in information management in the SC, the relationship of inventory policies and the demand

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information, modeling demand and use of optimization methods in the search for the appropriate solutions [21]. Farhaneh Golozari, Azizollah Jafari, Affiliated apply fuzzy numbers to determine customer demands, travelling time and drop time. The objective is to open a subset of depots to assign customers to these depots and to design vehicle routes, in order to minimize both the cost of open depots and the total cost of the routes [22].

There are two types of deficiencies in the reverse LRIP model above: (1) Most of the research is about the independent reverse logistics system. They have not included the traditional logistics system. (2) Have not considered the separability of recycling products. Because of the recovery product have not so strong timeliness requirements, they could be recycled for partial recovery according to the actual capacity to reduce costs. The paper established a LRIP model of reverse logistics to reduce the operating costs of reverse logistics system, set up reasonable logistics nodes of facilities, optimize the transport routes, and adjust the stock solution. Part of the path optimization considering integrate the normal distribution and reverse back. Considering the separability of recycled products, the paper established punishment of inventory constraints and inventory cost in order to solve more complex problem of reverse logistics network.

2. Problem Description

The paper establish a closed-loop logistics network optimization system included a number of distribution center and the corresponding customer points. Consider positive distribution and back to the load can be divided, each cycle the motorcade will start from the distribution center to serve all the customers in the scope one by one. They will go back to the distribution center after complete delivery and recovery service of all customers. The amount of pick up/delivery from each customer must not exceed the vehicle load capacity and restricted by redundant inventory. According to the redundant inventory restrictions, recycling products can be divided into two parts: (1) Must be recycled to meet the redundant inventory; (2) Could be recycled in the current period or next period. But there will be inventory costs of the customer retention products. The problem is to solve the the number and the address of distribution center, vehicle routing arrangement in each period, and the number of customer retention products *etc.*

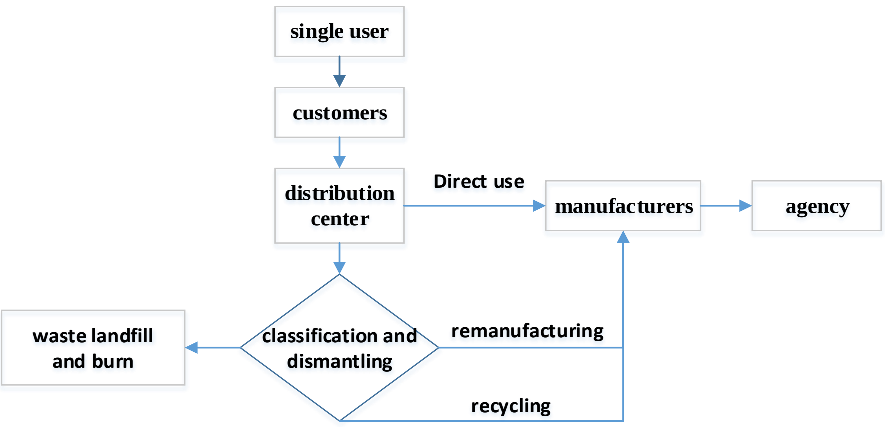

Figure 1. Reverse Logistics Network System

Figure 1. is the reverse logistics network system. Based on the network, the research work of this paper is based on the following assumptions: (1) The distance between every two nodes is known. (2)The transportation costs is a simple linear relationship to the distance.(3)There will be a cost when the vehicles start from the distribution center. (4)The delivery of recycled products from single user to customers have been completed. The transportation cost between single user and customers will not be considered. (5)The

distribution of new products must be finished in the current period. The recycled products meet the redundant inventory must be delivered, and the rest could be delivered or not. (6)The customer redundant inventory is known in every periods.(7)The inventory cost refers to the recycling product storage fee is not recycled in the current period.(8)the quantity of new products demanded by customer and recycling products need to be delivered is meet normal distribution.

3. Mathematical Model

The symbols are described below:

$P\{i \mid i = 1, 2, \cdots, I\}$: the set of customer points;

$D\{j \mid j = 1, 2, \cdots, J\}$: the set of distribution center points;

$\Omega = P \cup D$: the set of all points;

$T\{t \mid t = 1, 2, \cdots, TI\}$: the set of periods;

NQ_{it} : the new products quantity of customer point $i(i \in I)$ demand in period $t(t \in T)$;

RQ_{it} : the recycle products quantity of customer point $i(i \in I)$ generated in period $t(t \in T)$;

SQ_{it} : the recycle products quantity of customer point $i(i \in I)$ at the end of period $t(t \in T)$, $SQ_{it} = SQ_{i,t-1} + RQ_{it} - RG_{ikt}$;

$V\{k \mid k = 1, 2, \cdots, K\}$: the set of the vehicles serial number;

d_{ij} : the distance between the point i and j , $(i, j \in \Omega)$;

C_k : the capacity of vehicle $k(k \in K)$;

RQ_{it} : the redundant inventory of customer point $i(i \in I)$ in period $t(t \in T)$;

MQ_{it} : the max inventory of customer point $i(i \in I)$ in period $t(t \in T)$;

Ck : the cost of unit distance transportation ;

Cs : the cost of unit inventory in a period;

F_j : the construction costs of distribution center $j(j \in J)$

x_{lijk} equal 1 if vehicle $k(k \in K)$ traveled from point i to point j , else it equal 0, $(i \neq j; i, j \in \Omega)$;

y_{ik} equal 1 if vehicle $k(k \in K)$ traveled through customer points $i(i \in I)$, else it equal 0;

z_j equal 1 if distribution center $j(j \in J)$ was opened, else it equal 0;

b_{jk} equal 1 if vehicle $k(k \in K)$ belong to distribution center $j(j \in J)$, else it equal 0;

s_{ij} equal 1 if customer points $i(i \in I)$ was serviced by distribution center $j(j \in J)$, else it equal 0;

$$\min cost = \sum_{i \in \Omega} \sum_{j \in \Omega} \sum_{k \in K} \sum_{t \in T} Cd \cdot d_{ij} \cdot x_{ijkt} + \sum_{i \in \Omega} \sum_{j \in \Omega} \sum_{k \in K} \sum_{t \in T} K_k \cdot x_{ijkt} + \sum_{j \in J} z_j F_j + \sum_{i \in I} \sum_{t \in T} SQ_{it} \cdot Cs \quad (1)$$

$$\sum_{i \in I} RG_{ikt} = \sum_{i \in I} NG_{ikt} \qquad (t \in T, k \in K) \quad (2)$$

$$\sum_{t \in T} \sum_{i, j \in \Omega} x_{ijkt} NG_{ik} \leq C_k \qquad (k \in K) \quad (3)$$

$$\sum_{i\in I}\sum_{j\in J}\sum_{k\in K} x_{ijkt} \geq 1 \qquad (t \in T) \tag{4}$$

$$\sum_{i\in I} x_{ijkt} - \sum_{j\in J} x_{jikt} = 0 \qquad (t \in T, k \in K) \tag{5}$$

$$\sum_{i\in I} x_{ijkt} \leq b_{jk} \cdot z_j \qquad (j \in J, t \in T, k \in K) \tag{6}$$

$$\sum_{i,j\in\Omega}\sum_{k\in K} x_{ijkt} NG_{ikt} = \sum_{k\in K} RG_{ikt} \qquad (i \in I) \tag{7}$$

$$\sum_{i\in I}\sum_{j\in J}\sum_{k\in K} x_{ijkt} b_{jk} \leq \sum_{i\in I}\sum_{j\in J} s_{it} \qquad (t \in T) \tag{8}$$

$$SQ_{it} \leq RQ_{it} \qquad (i \in I, t \in T) \tag{9}$$

$$\sum_{j\in J}\sum_{k\in K} RG_{ikt} \cdot x_{ijkt} \leq SQ_{it} \qquad (i \in I, t \in T) \tag{10}$$

The objective aims at minimizing the cost of the system (1). The first part is the transportation cost. The second part is the fee of start. The third part is the construction costs of distribution center. The last is the inventory cost of not recycled product.

Constraints (2) and (3) ensure the car capacity will be met. Constraints (2) ensure the quantity of recycle product from the customer point is less than the current remaining capacity of the vehicle. Constraints (3) ensure the delivery quantity of vehicle $k(k \in K)$ on its road is less than the vehicle capacity in period $t(t \in T)$. Constraint (4) ensure every customer will be accessed at least once in every period. Constraint (5) is the continuity of vehicle traveling. Constraints (6) guarantee the vehicle start from the distribution center it belong to. And the vehicle can only start once in a period. Constraints (7) is for the demand of customer point each period. Constraint (8) ensure the vehicle service the corresponding customer to the distribution center the vehicle belongs to. Constraints (9) ensure the rest product quantity must meet the redundant inventory restrictions. Constraints (10) ensure the recycle product quantity is less than the quantity could be.

4. Hybrid Genetic Algorithm

Taking into account the special nature of chromosome code, and the the separability of recycling products, the quantity of some customers are large, before generating chromosomes, higher number customer points will be copied and become a number of points (called the original point, the points were copied and the point itself is named as virtual rescue point and call them homologous points), Only one vehicle will be arranged to a virtual point. First copy some point: Note the minimum capacity of all vehicle as $C_{\min}$. When the quantity of customer point i is greater than $C_{\min}$, if N_i is integer multiple of $C_{\min}$, copy point i as $N_i / C_{\min}$ virtual points, else copy point i as $[N_i / C_{\min}]+1$, all the parameters of each customer point are identical to original point i; $[\cdot]$ indicates the negative direction rounding. Assuming the virtual customer points set is H' and the number of set is I' after the copy is complete. Each chromosome consists 3 sub-strings. There is I' gene in sub-string 1st. its value is a natural number randomly select from 1to K (K is the number of vehicles); The length of sub-string 2nd is I'. its value is a natural number randomly select from 1to I'.There is K gene in sub-string 3rd. its value is a natural number randomly select from 1to K. The length of the chromosome is $I' + I' + K$.

For example, there are 10 customer points, 3 vehicles, 3 distribution center. For chromosome follows: sub-string 1st:(3-1-1-2-1-3-2-1-1-2) sub-string 2nd:(9-7-4-10-5-1-6-3-8-2) sub-string 3rd:(3-1-2). Sub-string 1st and sub-string 2nd correspond to the gene locus, which means the delivery order of all vehicles. The position appears figure 1 in sub-string 1st has 2,3,5,8,9, which means the delivery order of vehicle 1 is 7-4-5-3-8, Sub-string 3rd represents all the vehicles were arranged routes by the order of 4-1-2-3. At this point the transport routes are not fully determined. The distribution center will be arranged into the routes according the capacity of vehicle, the capacity of distribution centers and the order 9-6-4-7-8. There are several possibility: (1) If the quantity of customer point 9 is greater than the capacity of vehicle 1, the vehicle 1 will fully loaded transport towards the right distribution center(the nearest and satisfy the constraint, the same below). At the same time if the point 9 is a virtual point, the number of all of its homologous customer points should be updated to 'the quantity of customer point 9 - the capacity of vehicle 1'. The vehicle 1 will transport victim to distribution center and transport again to point 6. (2) If the quantity of customer point 9 is not greater than the capacity of vehicle 1 and meet the load factor requirements of vehicle 1, all product will be transported to the vehicle and sail to a proper distribution center. At the same time if the point 9 is a virtual point, the quantity of all of its homologous customer points should be updated to 0. The vehicle 1 will transport victim to distribution center and transport again to point 6 after filled fuel. (3) If the quantity of customer point 9 does not meet the load factor requirements of vehicle 1, all victim will be transported to the vehicle and sail to point 6. At the same time if the point 9 is a virtual point, the quantity of all of its homologous transport points should be updated to 0. Perform the same operations to points 6-4-7-8 as described above, the route of vehicle 1 will be determined. If the update to the quantity of virtual transport points make the quantity of a point to be 0, this point will not be operated. The next operation is arrange the routes of vehicle 3 and 2 according sub-string 3rd. All routes of every vehicles will be determined.

About the population, its size is num .The initial population generated as follows: Generated a chromosome randomly, if it is illegal chromosome, generated a chromosome again. If it is not, credited it into the initial population until num chromosome were generated. The fitness function is $f_i = z_{\min} / z_i$, f_i is the value of fitness function of chromosomes i . $z_{\min}$ is the minimum objective function value of the same generation chromosome. z_i is the objective function value of the chromosome i . The fitness function value ranges is $(0,1]$.

To prevent the wrong chromosome code, it need to select a different chromosome crossover and mutation operations to the two sub-strings according the characteristics. In this paper, Two-point crossover, shuffle crossover and uniform mutation will be performed to sub-string 1st. Order crossover, section-matching crossover and reversed mutation will be performed to sub-string 2nd and 3rd.

To prevent to generate error chromosome, the two sub-string need to choose different crossover and mutation operation. The sub-string 1 need to perform Shuffle the deck cross and two-point crossover. The sub-string 2 and 3 need to perform order crossover and part of the matching crossover. The sub-string 1 need to perform uniformity mutation. The sub-string 2 and 3 need to perform reverse mutation.

The selection strategy use elite preserving combined with roulette wheel. Before generating the next population, the temporary population include parent population and the chromosome generated from crossover and mutation operation will be sorted by its fitness. The first one individual will be copied directly into the next generation of population. The other chromosomes of new population will be selected from parent population and temporary population use roulette wheel strategy.

In the iterative process, before crossover and mutation operation of each generation, Some number of chromosomes with good gens will be generated to instead those poor to accelerate the algorithm convergence speed. The method of chromosome generated is as follows: (1) The customer points will be assigned to assigned to distribution center. If the nearest distribution center are more than one point, the customer points will be assigned to one of them randomly; (2) According to the current capacity of vehicles and distribution centers, the set of customer points belong to each vehicle will be insert some suitable distribution centers to generate a routing and the set will be translated into a corresponding chromosome.

The maximum number of iterations is $MAXGEN$, the genetic algorithm will end after iteration times $MAXGEN$.

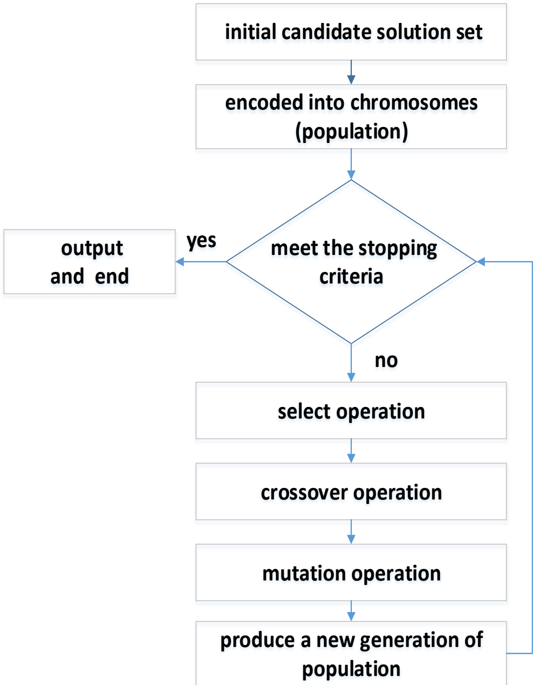

Figure 2. The Hybrid Genetic Algorithm

The process of hybrid genetic algorithm are described in Figure 2. Specific as follows:

Step1: Read original data of the problem;

Step2: Set the population size num of genetic algorithm, the maximum number of iterations $MAXGEN$, $\delta_1, \delta_2, \alpha, \beta$, crossover rate , mutation rate, and the number of chromosome in alternative strategies q ;

Step3: generate the initial population, its size is num , calculate the target and fitness function value of every chromosome, make it to the current population. The current generations $gen=0$;

Step4: choose chromosome with roulette wheel selection and retention of elite selection strategy;

Step5: using the substitution policy generated randomly q chromosomes to instead of poor adaptability individuals in population;

Step6: crossover chromosomes two two pairs according to the crossover rate;

Step7: choose individuals in population perform mutation according to the mutation rate;

Step8: $gen=gen+1$, calculate the target and fitness function value of every chromosome,

Step9: if $gen>MAXGEN$,end；else,to Step4.

5. Simulated Test

There are 20 customer points, 8 distribution centers, 8 vehicles. Data in Table 1-Table 3:

Table 1. Customer Points

NO.	x-coordinate /km	Y-coordinate /km	New Products Quantity Demanded	Recycle Products Quantity Generated
1	3	42	3	1
2	16	48	2	1
3	19	69	36	10
4	37	53	5	2
5	49	64	5	1
6	55	79	5	1
7	47	87	4	2
8	40	89	9	3
9	41	9	2	0
10	47	3	8	2
11	45	16	25	8
12	54	3	9	4
13	55	21	3	0
14	61	30	2	0
15	64	52	31	9
16	72	45	9	2
17	74	31	7	1
18	85	60	18	4
19	88	66	8	1
20	93	62	2	1

Table 2. Distribution Center

NO.	x-coordinate/km	Y-coordinate/km	Capacity	Construction Costs
1	30	28	50	3
2	75	80	50	1
3	12	60	100	1
4	38	77	100	2
5	62	13	100	1
6	68	33	50	2
7	87	49	50	1
8	95	97	50	3

Table 3. Vehicles

NO.	Capacity
1,3,6,7	30
2,4,5,8	60

The hybrid genetic algorithm parameters are as follows: num =100; $MAXGEN$ =300; $\delta_1 = 0.9$; $\delta_2 = 1.2$; $\alpha = 0.9$; $\beta = 1$; $q = 20$; Crossover rate is 0.9; mutation rate is 0.05.

The best solution of the calculation results and the convergence situation as shown in Figure 2-3 and Table 4-5. The program of algorithm based on Matlab. The calculation result is stable. The average deviation of the worst and the best solutions to the average is 1.2% and 1.33%.

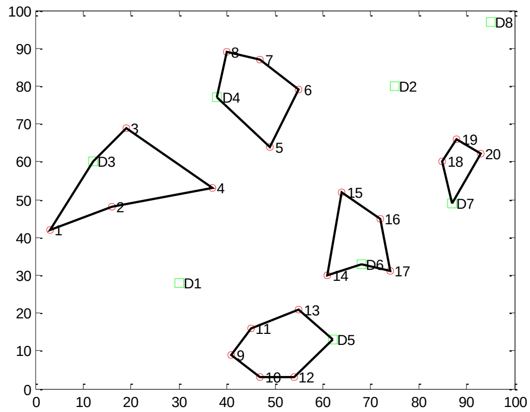

Figure 3. Calculation Results

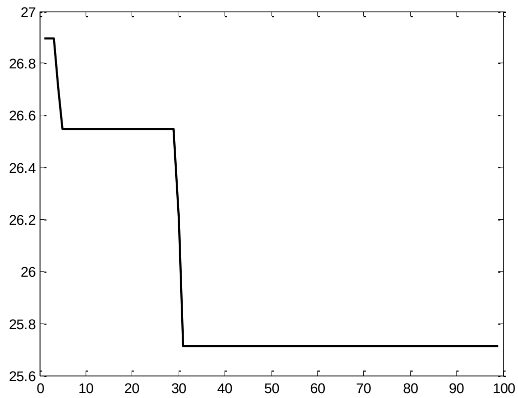

Figure 4. The Convergence State of Algorithm

Table 4. Routing of Best Solution

vehicle number	routing
5	D_3 -1-2-4-3- D_3
1	D_4 -5-6-7-8- D_4
2	D_5 -13-11-9-10-12- D_5
4	D_6 -17-16-15-14- D_6
3	D_7 -18-19-20- D_6

Table 5. Recycle Products From Custer Points

NO.	quantity	NO.	quantity
1	1	11	3
2	1	12	2
3	8	13	0
4	1	14	0
5	0	15	5
6	1	16	1
7	1	17	1
8	2	18	2
9	0	19	1
10	1	20	0

The calculate result of traditional mode (forward logistics and reverse logistics activities independently, and recycle products transport will be finished in the current period) and the LRIP mode in the paper show that although the inventory costs increased of the latter model, but the total cost is decreased by 20.3%. This is because the integration of positive logistics and reverse logistics reduced the transportation cost of the system greatly. In addition, the parts return load of recycling product and parts stranded inventory strategy reduced the number of vehicles start is the mainly reason of cost decreased.

6. Conclusion

Because of the characteristics of high complexity, diversity, the unbalance of supply, the reverse logistics system depend on the logistics network more. The paper established a location-routing-inventory control optimization model with batch transportation of recycle products to reduce the operating costs of reverse logistics system, set up reasonable logistics nodes of facilities, optimize the transport routes, and adjust the stock solution. Considered the characteristics of integrate of forward and reverse logistics, the separability of recycle products, the timeliness of recycle products, A matching hybrid genetic algorithm containing heuristic rule was introduced, A matching hybrid genetic algorithm containing heuristic rule was introduced. The simulated test analysis shows the validity and the correctness of the model and algorithm.

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