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Network Planning of Reverse Logistics: Based on Low-carbon Economy

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Abstract: Reverse logistics is one of the most effective tools to realize the low-carbon economy, which is far different from traditional forward logistics. It can make a full use of resource, protect natural environment and diminish carbon emission in the process of material mining, procurement, producing, etc. This study, based on domestic and overseas researches of reverse logistics, analyses the relationship between reverse logistics and low-carbon economy, constructs a model of network planning reverse logistics based on low-carbon economy and then quantifies the problem, finds out a well-performance solution with Genetic Algorithm (GA).

Key words: Low-carbon economy, reverse logistics, network planning, GA

INTRODUCTION

With the development of modern economic theory and the popularization of the sustainable development concept, there is a growing concern about carbon emission and whose external economic effects. It is an important component of public policies of almost every countries over the world that, i n total amount control as the breakthrough point, gradually realize a significant change of the dioxide emission management. Meanwhile, it becomes a focus of society and economy life that getting a Win-win of economy development and environment optimization. Under this circumstance, low-carbon economy rises in response to the proper time and conditions and is about to be popular over the world in a short time, as a new development mode.

Logistics holds a special position of low-carbon economy, because that it consumes large amounts of energy sources and releases much carbon. According to the statistic data of International Climate Organization, in the 2008 world's energy consumption, transportation accounts for 26%; in the 2008 world's carbon emission, transportation occupies 16%. On the other hands, it is because that developing logistics is a key measure to come true the low-carbon economy, for example, resource integration, process optimization, informatization and standardization will be energy conservation and emission reduction. Advanced logistics mode can support way of production and life under low-carbon circumstance (Anonymous, 2009).

Reverse logistics is one of the most effective tools to realize the low-carbon economy, which is far different from traditional forward logistics. It can make a full use of resource, protect natural environment and diminish carbon emission in the process of material mining, procurement, producing, etc. (Bloemhof-Ruwaard and Beullens, 2002).

David Bojarski is focus on carbon emission of all processes of green supply chain and build a relative model to solve the problem (Bojarski *et al*., 2009). Hon Loong Lam's research is about how to reduce carbon emission among regional ecological supply chains (Lam *et al*., 2010a, b). They divided into each process of regional ecological supply chains a certain number of groups by using "regional energy clustering algorithm", find the information and size of energy groups according to "regional energy surplus curve" and then, provide a program about how to manage surplus sources in a region and find the unbalance of the energy. Later, they optimize the supply chain network by building a model, research how to reduce the amount of the carbon emission. (Sundarakani *et al*., 2010) The researches of carbon emission among every process of the supply chain make a metric model by using the "lagrange box". From this model, one can calculate the amount of carbon emission in every process of supply chain. Krikke has got some accomplishments in green supply chain and cycle supply chain fields. He comes up with the difference location outcomes between just considering the economic cost and taking account of both economic cost and resource consuming, when researches supply chain network optimization (Krikke *et al*., 1999; 2003).

NETWORK OF REVERSE LOGISTICS BASED ON LOW-CARBON ECONOMIC

Description: As to a whole reverse logistics system, it can be described by linking a lot of nodes, each node might be a recycling market, recycling center, remanufacture factory, distribution center and arcs among them mostly present the transportations (Fig. 1).

Reverse logistics is a integrate concept, the cost of which is mainly decided by construction of the reverse logistics network. Optimal design of reverse logistics

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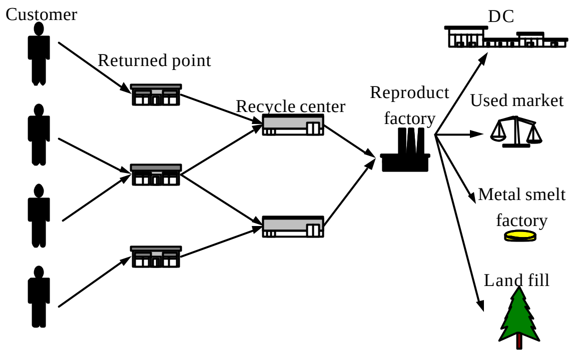

Fig. 1 Reverse logistics system

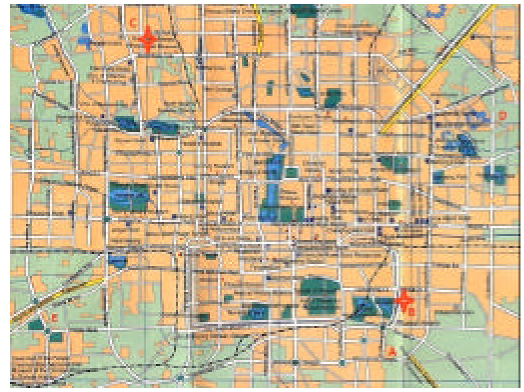

Fig. 2: Location map of Gome recycling centers

network, realizing the rationalization of network constructions and arrangements is to determine the position and capacity of each node. When design a remanufacture reverse logistics network, we always using different methods to lowest the network total cost. In general, when a company builds a reverse logistics network, it will mainly focus on inventory cost, transportation cost, handling cost and network fixed cost, etc.

Under low-carbon economy circumstance, it is far from enough to just consider the cost factor in planning reverse logistics network. Reverse logistics, as a special sort of logistics family, produces carbon emission problems as running, though it surely saves resources for whole society and relatively reduces the carbon emission, too. So, it is a key contain that put carbon emission factor into model based on the low-carbon economy concept to balance the economic profits and environment protection.

Accordingly, this paper builds a model to include two parts of cost over all reverse logistics network: The cost of initial recycling fees (rent charge and inventory cost) and recycling center fees (center building fees, handling fees); the cost of whole system transportation fees.

Remanufacture reverse logistics system is consisted of initial recycling node (for example, in household applicant market, this node almost set at the big retailer of a normal supply chain) and recycling center. This centralized recycling format is benefit for making a full use of resources and getting a scale economic effect. Moreover, the initial recycling node is helpful to diminish the uncertainty of reverse logistics and saving customers' time, even make sure the recycling products to an economic transportation batch. Of course, it ignores the cost and time of that customers send products to the initial recycling centers.

Initial recycling node will be established cohabitating with other organizations and institutions, so it unnecessary to consider the building cost but rent fees and inventory cost. Because of their limited capacities, recycling commodities should be send from initial node to recycling center in time for next test, classification, packing and transporting to manufactures.

Recycling goods are testing in the recycling center (Fig. 2), some of which with non-damages or intact will be repacked, relabeled and then sent to distribution channels for retailing. So, they are different from the general inventories that just have storage function. In real problems, determining the location of recycling center is impossible casual to decide. Generally, it will first find out some alternative address and then pick out the best one from them. So, this paper will accord to this and build a model to find out the well-performance location program and transportation routines.

According to circumstance above, there are several questions to consider when we build the model:

- How to decide the position of the initial recycling node to keep the distance between customers and them be closest
- How to decide the position of the recycling center to lowest the transportation cost of recycling goods from initial node to recycling center
- The frequency of sending the recycling goods from initial nodes to lowest the cost
- How many recycling centers will be needed to lowest the total cost of this reverse logistics network

To sum up, the questions this model caring about are the position, period and capacity of the recycling center and the transportation routine, to lowest cost of handling sales return and satisfy the customers' convenience.

MODELING

Modeling assumption: In order to facilitate the analysis and illustration, we will make some assumptions of the remanufacturing reverse logistics network first:

- The period of the model is one year. We only consider the measurable economic cost of single product operating period and ignore the time cost and other cost
- Customers can only transfer the recycling goods to initial recycling nodes. One is not allowed to send the merchandise back to recycling center
- We assuming that the initial recycling nodes have enough capacity to store the recycling goods
- All of the recycling goods in initial recycling nodes should be sent to recycling center
- We ignore the transportation cost occurred when customers send goods to the nearest initial recycling node

Based on the above assumptions, we build the mathematical model.

Objective function:

$$\text{MinTC} = hw\sum_i r_i + \sum_k q_k G_k + \sum_k \frac{w}{T}\left[G_k \sum_j X_{jk} \times f(X_{jk}, d_{jk})\right] \quad (1)$$

$$\text{MinTCO}_2 = aw\sum_i r_i + \sum_k b_k G_k + \sum_k \frac{w}{T} G_k \sum_j X_{jk} \times \beta - w\sum_i r_i \times \mu \quad (2)$$

- i : Customer demand node;
- j : Initial recycling node;
- k : Recycling center
- T : Recycle time of initial recycling node;
- w : Workday of one year
- r_i : Everyday recycling number of customer i;
- h : Handling cost of one recycling goods;
- q_k : fFxed cost of building recycling center;
- d_{jk} : Distance between initial recycling node j and recycling center k;
- l : Maximum allowable distance from the customer to initial recycling node;
- $f(X_{jk}, d_{jk}$: Transportation cost function;

$$f(X_{jk}, d_{jk}) = E\alpha d_{jk},\ \alpha = \begin{cases} 1, X_{jk} \le p \\ \alpha_1, X_{jk} > p \end{cases}$$

- a : Discount factor of transportation cost when freight volume reach one critical value;
- p : Critical value reach which one can have transportation cost discount;
- E : Freight unit;
- X_{jk} : The quantity of recycling goods from initial recycling node k to recycling center j
- μ : Carbon emissions produced by recycling one goods;
- b_k : Carbon emissions produced by building recycling center;
- β : Carbon emissions produced by a transport cart when it is doing carrier operations ;
- μ : Carbon emissions reduced by reproducing one goods;

$$G_k = \begin{cases} 1, \text{building the recycling center at node k} \\ 0, \text{building the recycling center at other node} \end{cases}$$

$$Y_{ij} = \begin{cases} 1, \text{cusomer i send goods to initial recycling node j} \\ 0, \text{cusomer i send goods to other initial recycling nodes} \end{cases}$$

Constraint condition: This model mainly includes the following aspects of constraints:

- logistics quantity conservation;
- restrict of the facilities quantities;
- value range of variables

- z : Minimum number of initial recycling nodes
- g : Minimum number of recycling center
- M : Maximum capacity of recycling center

According to the above, we have the constraint condition:

$$\text{st.}\left\{\sum_j Y_{ij} = 1, \forall i \in I\right. \quad (3)$$

$$\text{st.}\left\{T\sum_i r_i Y_{ij} = \sum_k X_{jk}, \forall j \in J\right. \quad (4)$$

$$\text{st.}\left\{d_{ij} Y_{ij} \le l, \forall i \in I, \forall j \in J\right. \quad (5)$$

$$\text{st.}\left\{g \le \sum_k G_k\right. \quad (6)$$

$$\text{st.}\left\{R_k G_k \le M\right. \quad (7)$$

$$\text{st.}\left\{X_{jk} \ge 0, \forall j \in J, \forall k \in K\right. \quad (8)$$

$$\text{st.}\left\{T_j \in (0,1,2,3,4,5,6,7), \forall j \in J\right. \quad (9)$$

$$\text{st.}\left\{Y_{ij}, G_k \in (0,1), \forall i \in I, \forall j \in J, \forall k \in K\right. \quad (10)$$

Equation 1 is cost objective function with an objective of minimizing the network cost. It is the sum of handing cost, fixed cost and transportation cost. Equation 2 is low carbon objective function with an objective of minimizing the carbon emissions of the network. It is the sum of carbon emissions produced by building recycling center, a transport cart when it is doing carrier operations and reduced by reproducing one goods. Equation 3 ensures that each customer has a designated recycling node to accept the recycling goods. Equation 4 ensures that for every recycling node, the receiving amount equals sending amount. Equation 5 ensures that every initial recycling node is near the customer. Equation 6 ensures that the number of initial recycling nodes and recycling centers no less than the minimum allowable value. Equation 7 ensures that the handing capacity of the recycling center is less than the maximum capacity. Equation 7 ensures that X_{jk} larger than 0. Equation 8 limits the value range of T. Equation 9 ensures that Y_{ij}, G_k only have two values, 0 and 1.

MODEL SOLUTION

GA solution: According to the solving steps of genetic algorithm, we solve the problem and get the optimization solution (Fig. 3):

Step 1: Determine the decision variables and various constraints conditions

It is obvious that the problem is to make sure which nodes will be chosen to be reverse logistics network nodes and then make sure the flow direction of the network, that is which recycling center will receive the recycling goods.

Step 2: With the parameter values in last part and Eq. 1, we can obtain the Fig. 3

Step 3: Determine the parameters of GA

We use Visual c ++ programming language to solve the problem.

RESULT ANALYSIS

There is no reverse logistics network in that company, the cost of reverse logistics can be estimated. The number of total demands is 251. The number of workday in one year is 350. Then we can obtain the total reverse logistics cost:

- Reverse logistics cost = transportation cost+recycling and handing cost

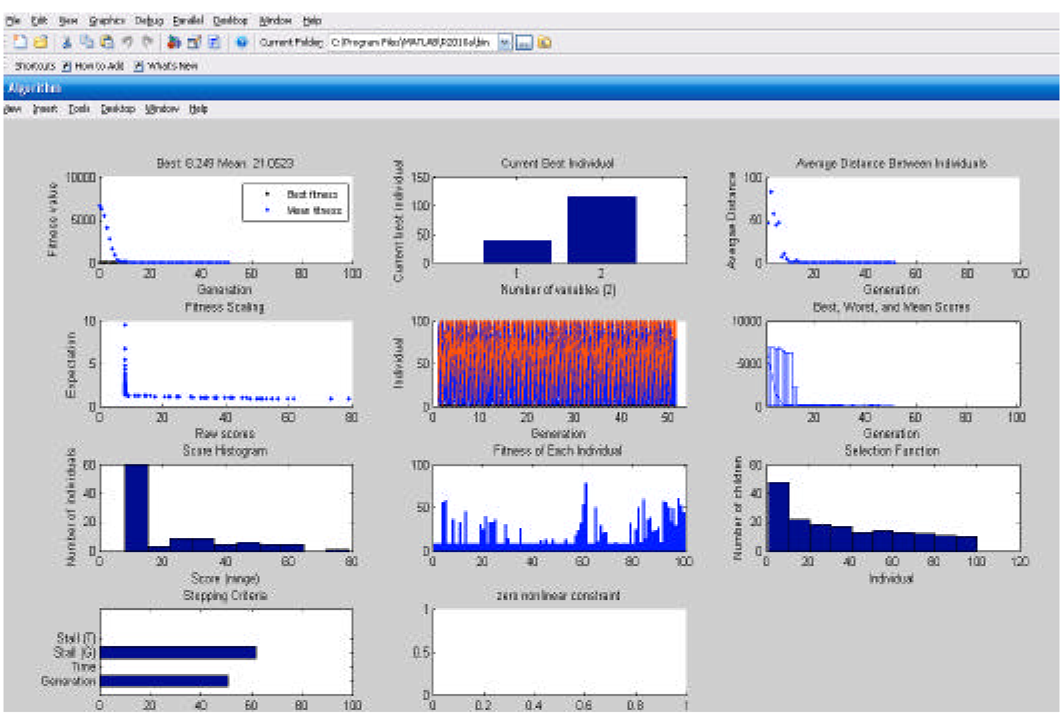

Fig 3: Genetic algorithm solution

Table 1: Carbon emissions calculation table

Item	Carbon emissions (kgCO2)
Recycling and handing	251×350×0.2×0.785
Building recycling center	2×5000
Transportation from initial recycling node to recycling center	111×cos40°×6×2.69×0.3×70
Material saved by reverse logistics (subtraction)	50%×251×350×1×0.785
Sum	9896

CEF: 2.69(kgCO2) L^{-1} (Fleischmann *et al*., 2004)

So reverse logistics cost is 1335320 yuan, (251*350*15+251*350*0.1 = 1335320).

Compared with the building reverse logistics network cost, which is 1016276 yuan, the company has a 31.4% cost saving. Thus it can be seen that the reverse logistics network built in this paper is effective:

- 20T truck fuel consumption = 0.3L km^{-1}
- Power consumption produced by recycling 1 household appliances = 0.2 kilowatt h day^{-1}
- Carbon emissions produced by generating electricity = 0.785 kg CO2/kilowatt hour.
- Material saved by reverse logistics = 50%
- Power consumption produced by producing 1 household appliances = 1 kilowatt hour
- Carbon emissions produced by building recycling center and smooth operations = 5000 kgCO2/year

The amount of carbon emissions produced by reverse logistics is 9896 kgCO2. As we can see in Table 1, the carbon emissions produced by building recycling center is far less than the carbon emissions reduced by reverse logistic.

CONCLUSION

- Building a single product, fixed recycling period reverse logistics network model

We simplify remanufacturing reverse logistics system to a network made by customers, initial recycling nodes, recycling centers and the transport route between them. Based on it, we build a single product, fixed recycling period goods return network model. The model considers minimizing the cost and considers the convenience of the customers, which fully embodies the service concept: concentrating all attentions on customers.

- Using dual-layer GA to solve the model

Considering the model features, we use GA to solve it. Because there are a lot of decision variables and they are related to each other, we improve the algorithm and solve the problem by using dual-layer GA.

There are some content that can be deeply studied: We just focus on the single product recycling problem, which can be extended to multiple products recycling problem.

The model fixes the recycling period of the initial recycling nodes. In fact, how the initial recycling nodes determine recycling period based on the amount of returned goods is an interesting problem.

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