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Promote Development of Rural Logistics in China by a Bi-Level Programming Model Work

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Abstract

In consideration of effectively balancing government financial subsidies and customer satisfaction rate of rural logistics services in China, a bi-level programming model is newly developed to improve the cooperation between government and logistics enterprises. A heuristic algorithm is used to obtain the optimal solution to the new model. It is found that the proposed model has a good performance to obtain applicable and effective schemes for the prosperous development and progress of Chinese rural logistics.

Keywords*: bi-level modeling; heuristic algorithm; Chinese rural logistics; prosperous development*

1. Introduction

In recent years, the rapid development of e-commerce in Chinese rural areas has promoted the demand for rural logistics services in China. However, due to relatively long transport distances of the freights with mostly low prices in rural areas of China, investments in the logistics there do not have adequate rewards. Moreover, Chinese rural roads still do not reach every village. Therefore, logistics companies in China are not willing to put efforts into the development of their rural markets. In this context, government subsidies are strongly needed to help logistics enterprises to carry out services in the countryside. Moreover, a new analysis approach is also necessary to make a trade-off between the level of logistics services and the amount of the limited subsidies.

In order to improve logistic services, a large number of valuable research has been focusing on the location optimization problem of logistics distribution centers in urban areas (Melo et al. 2009; Snyder 2006). In the late 1970s, researchers tried to use location models to address planning issues in logistics systems for complex multiple objective problems. Farahani et al. (2010) review the various criteria, objectives and solutions used in the facility location problem, which plays a critical role in the supply chain network design (SCND) problem. The distributors select suppliers for each warehouse to assign warehouses to different customers so that the requirements of all parties are met to the greatest extent possible. Hervet et al. (2013) present a bi-level programming model for determining the locations of logistic distribution centers in view of the benefits of both customers and logistics planning departments. The planners and customers are divided into different levels for the analyses of different and even conflicting objectives at the same time in the decision-making process. Altiparmak et al. (2006) present a supply chain model with three objectives(i.e., the minimization of the total operating cost, the maximization of customer satisfaction and the maximization of the capacity utilization balance for distribution centers). They propose a solution procedure based on a genetic algorithm to obtain the set of Pareto optimal solutions and implement different weight approaches to enable the decision makers to evaluate a great number of alternative solutions. Furthermore, uncertain demand is also gradually introduced into the SCND model (Amin and Zhang 2013; Liste and Dekker 2005; Santoso et al. 2005).

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However, because there is an enormous gap between China and developed countries in terms of the rural development environments, the rural logistics problems in China are very different to those in developed countries. Jiang et al. (2014) establish a method to evaluate the rural logistics system in China according to the algorithm of membership degree transformation. Xie and Wang (2012) demonstrate the important role of network resources in the evolution and development of enterprises from the viewpoint of rural logistics service enterprises. Zhu (2013) studies the existing operation mode of Chinese rural logistics in the background of new Chinese rural construction policies. Zheng et al. (2011) establish a location optimization model for rural logistics distribution centers from the operation perspective of the enterprises, but they do not fully consider the helps from the government.

For the development of rural logistics, a bi-level programming model taking the traveling salesman problem (TSP) into consideration is established to ensure the valid exploitation of government subsidies in this research. The remaining parts of this paper are organized as follows. The study area is introduced in Section 2. Next, Section 3 develops the proposed bi-level programming model. Thereafter, evaluations of the development potentials of different rural logistics plans are made according to the model proposed in Section 4. Finally, Section 5 provides the conclusions and discusses some future research issues.

2. Study Area and Data

The study area of this research is concentrated in Hainan province of China. Figure 1 shows the change of the rural and urban logistics in Hainan province in recent 5 years. It is noted that while urban logistics growth is slowing down, the growth rate of rural logistics has been increasing significantly by nearly 50%. As a typical agricultural province in China, the demand for the development of rural logistics is very urgent in Hainan province. However, according to the official statistics, less than 10% of the logistics enterprises registered in Hainan province provide rural logistics services. Most rural residents have to go to towns to receive and send their own parcels, which is very typical in most underdeveloped provinces in China.

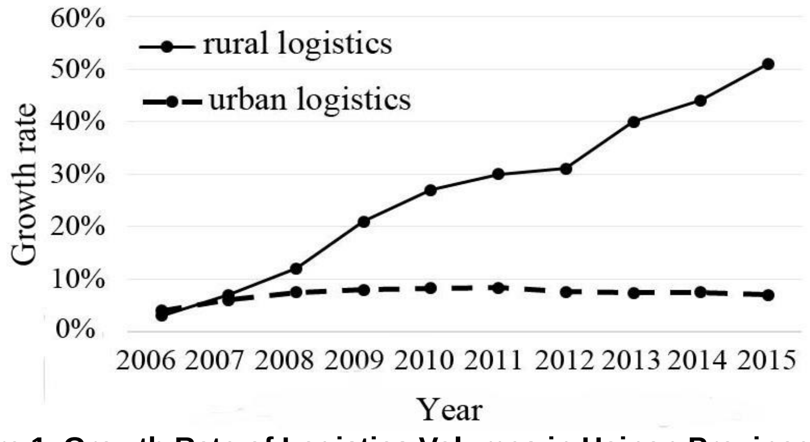

Figure 1. Growth Rate of Logistics Volumes in Hainan Province (Data Source: Hainan Statistical Yearbook Published every Year from 2007 to 2016)

3. Model Establishment

According to the investigation of the logistics in Hainan province, there are two potential modes of the rural logistics transports (i.e., rural public transport (RPT) and special car distribution (SCD)). The main operator of the RPT is the bus company. In this mode, each node on the distribution route should be equipped enough staff to provide receiving and dispatching services. The main operators of SCD are third party logistics companies providing rural express delivery services. Different from RPT which need to arrange the staff in each node on the route, this mode need special companies. The SCD has better performance than RPT in terms of timeliness, safety, and publicity effects.

3.1 Upper Level Model

In the upper level model, we take the maximum quotient of the customer satisfaction rate and government financial subsidies as the objective function value by equation (1), which can help us make a trade-off between them.

$$\max F = \frac{\sum_{i}^{I}(q_i + q_i')x_i \Big/ \sum_{i}^{I}(q_i + q_i')}{B} \tag{1}$$

Where,
F : Quotient of the customer satisfaction rate and the government financial subsidies,
I : Set of the nodes, including all of the rural nodes and a county node,
q_i : Logistics demand from the county node to rural node i, Unit: pcs,
q_i' : Logistics demand from rural node i to the county node, Unit: pcs,
S : Set of the nodes that be chosen on the distribution line, the country node will always be selected which act as the supply node,
x_i : 0-1 variable, 1 for the $i \in S$, otherwise 0,
B :Government financial subsidies, Unit: \$,
Equation (2) determines that the amount of subsidies should be enough to help logistics companies achieve the basic return rate of the logistics industry.

$$\frac{B+R-C}{C} \geq \eta \tag{2}$$

Where,
R : Total income of logistics enterprises, Unit: \$,
C : Total cost of logistics enterprises, Unit: \$,
η : Basic return rate of logistics industry, which is greater than 1,
As explained by equation (3) and equation (4), the R is decided by the logistics demand and logistics price, C varies with different modes of rural logistic transport.

$$R = y(\sum_{i=1}^{I} cq_i + \sum_{i=1}^{I} c'q_i')x_i + (1-y)\delta(\sum_{i=1}^{I} cq_i + \sum_{i=1}^{I} c'q_i')x_i \tag{3}$$

Where,
c : Price per kilometers of distance from county to rural, Unit: \$/km,
c' : Price per kilometers of distance from rural to county, Unit: \$/km,
y : 0-1 variable, 1 for the mode of RPT, 0 for the mode of SCD,
δ : Rate of the addition income in the mode of SCD, which is larger than 1,

$$C = y \times wf \sum_{i}^{I} x_i + (1-y)(ef + D\lambda) \tag{4}$$

Where,
wf : Staff wage of each node in the mode of RPT, Unit: \$,
D : Overall length of the distribution line, Unit: km, which is calculated in lower level model,
e : Number of vehicles needed in the mode of SCD, which is determined in lower level model,
f : Vehicle purchase cost in the mode of SCD, Unit: \$,
λ : Cost per kilometers of distance of the logistics companies, Unit: \$/km,
Equation (5) and equation (6) are the constraints on the customer satisfaction rate and the

government financial subsidies, which are influenced by the financial situation of the local government.

$$\sum_{i}^{I}(q_i + q_i')x_i \Big/ \sum_{i}^{I}(q_i + q_i') \geq \tau \tag{5}$$

$$B \leq B_0 \tag{6}$$

Where,

τ : Minimum requirement for customer satisfaction rate,

B_0 : The maximum financial subsidies could be provided by the government, Unit: $,

3.2 Lower Level Model

In the upper level model, the set S varies randomly in the genetic algorithm. How to calculate the D corresponding to each S in equation (4) is a TSP. In order to solve the TSP, this study use the ant colony algorithm which was first proposed in 1996 (Dorigo et al. 1996), and then improved by various methods, such as the MMAS algorithm (Stützle and Hoos 2000) and the ant colony algorithm based on the negative feedback (Malisia and Tizhoosh 2007). Many valuable studies attempt to achieve the best balance between the current, overall and historical shortest paths in the ant colony algorithm. (Cai et al. 2012; Du et al. 2014; Shen et al. 2014) and avoid the algorithm falling into local optimization in path selection (Guan and Lin 2016; Tang et al. 2013; Zhao et al. 2010). In the lower level model of this research, equation (7) is used to minimize the distribution distance in the TSP.

$$\min D = \sum_{i=1}^{|S|}\sum_{j=1}^{|S|} d_{ij} z_{ij} \tag{7}$$

Where,

d_{ij} : Distance between nodes $i \in S$ and $j \in S$, Unit: km,

z_{ij} : 0-1 variable, 1 for the distribution line include the path between the node i and j, otherwise 0.

Equations (8) and (9) jointly determine that each node must only be passed once by the planning line.

$$\sum_{i=1, i \neq j}^{|S|} z_{ij} = 1 \qquad \forall i, j \in S \tag{8}$$

$$\sum_{j=1, i \neq j}^{|S|} z_{ij} = 1 \qquad \forall i, j \in S \tag{9}$$

Equation (10) is the loop uniqueness constraint that ensures there is no other loop in the planning path.

$$\sum_{i \in S, i \neq j} \sum_{j \in S, i \neq j} z_{ij} \leq |S| - 1 \qquad S \subset I \tag{10}$$

A possible conflict between the computational results and the actual situation of the lower model is that: D is longer than the maximum distance (D_0) that can be traveled by a delivery vehicle in one day, which will seriously affect distribution efficiency and user experiences. In algorithm, if $D > D_0$, then the K-mean clustering with 2 clusters for all the rural nodes except the county node in the S will be performed to obtain the sub-sets S_1 and S_2 which are formed by the nodes in each cluster and the county node. Then, the sub-path lengths D_1 and D_2 corresponding to S_1 and S_2 will be calculated using the lower lever model. If $D_1 < D_0$ and $D_2 < D_0$, then D= $D_1 + D_2$; otherwise, we will carry out K-mean clustering with 3 clusters, and repeat the above test procedure. The cluster number will achieve m, when all of the sub-paths are shorter than D_0, and then update $D = \sum_{m=1} D_m$, $e = m$.

The design idea of the algorithm for the bi-level programming model is shown in Figure 2.

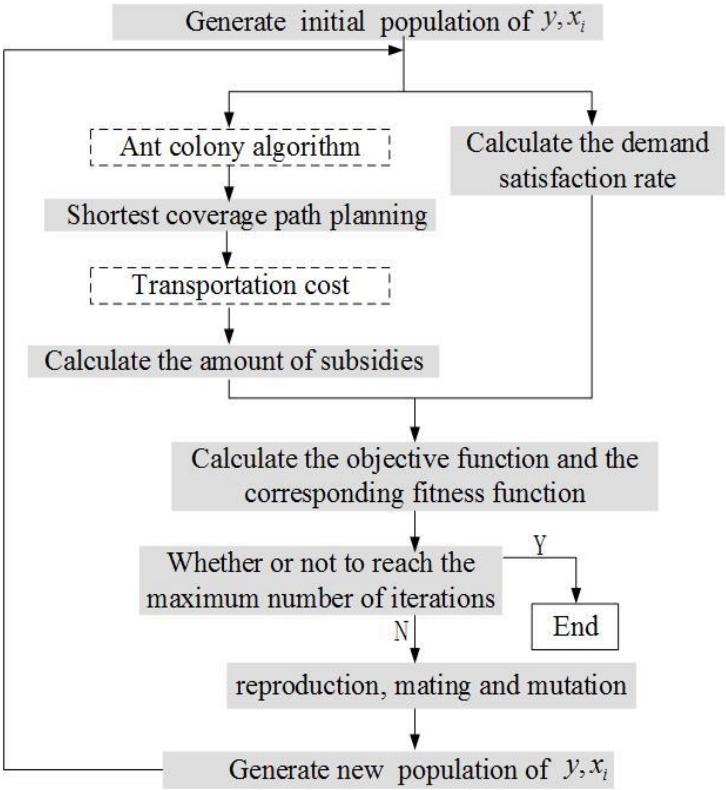

Figure 2. Algorithm Flow

4 Model Application

In this study, counties A and B in Hainan Province are selected as examples with which to describe the application process of the model and algorithm. The logistics demand of each rural node is forecasted by utilizing equations (11) and (12):

$$q_i = \sum_{n=1}^{5} (1+\sigma)^{n-1} f(Q, L_i, W_i) \tag{11}$$

$$q_i^{'} = \theta q_i \tag{12}$$

Where,

[a] σ : Annual growth rate of logistics in the country which contains the rural node i,
[a] Q_i : Logistics demand of rural node i for the first year, Unit: pcs,
[a] L_i : Population of rural node i,
[a] W_i : Ratio of the disposable income of the residents in the rural node i to the average level in the belonged county,
[b] θ : Ratio of logistics from rural to county and county to rural.

Other parameters in the model are obtained as follows: [b] $c = \$1.00$, [b] $c' = \$2.00$, [b] $wf = \$10000.00$, [b] $f = \$100000.00$, [b] $D_0 = 250.00$ km, [b] $\lambda = 0.50$ \$/km, [b] $B_0 = \$1000000.00$. The parameters in the genetic algorithm are set as follows: the maximum number of iterations is 200; the population size is 40.00. The convergence of algorithm is shown in Figure 3. The objective function values of the upper model are convergent at

[a] Data source: Hainan Statistical Yearbook published every year from 2011 to 2016.
[b] Estimated based on the investigation of the current rural logistics situation in Hainan.

110.00 and 140.00 iterations, respectively. The corresponding operation results of the two regions are shown in Table 1.

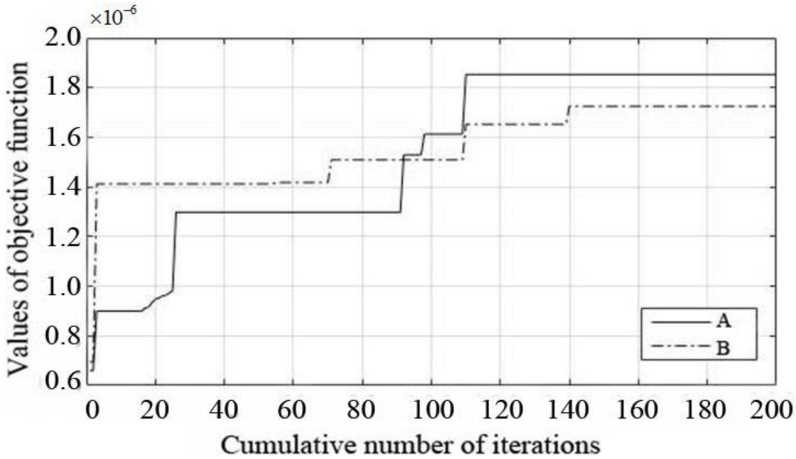

Figure 3. Convergence of Algorithm

Table 1. Model Calculation Results

	Objective function value	Demand satisfaction rate	Subsidy amount	Distribution Mode	Line number
A	1.85E-06	0.72	$390128.00	SCD	3.00
B	1.76E-06	0.61	$354742.00	RPT	2.00

Figure 4 shows the detail rural logistics distribution program for counties A and B. In the figure, different linetypes represent different distribution paths; the size of the point represents the size of the demand, and the points are solid when they are included in the path; otherwise, they are hollow. The graph intuitively shows that most of the nodes contained in the path have a large amount of demand, which means the model makes an effective trade-off between demand and cost.

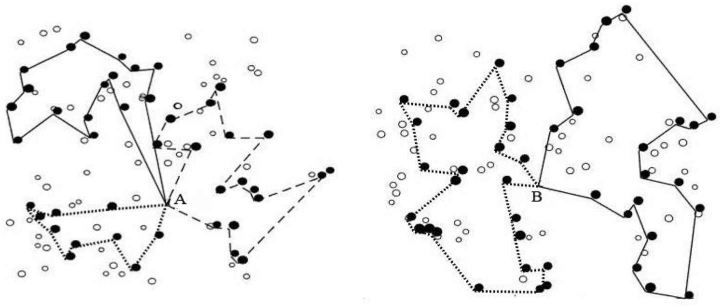

Figure 4. Node Selection and Path Planning

In the upper level model, we use equations 5 and 6 to limit the amount of subsidy and the satisfaction rate which are mainly based on the special financial situation of the local government. On the contrary, we can use them to compare the development potential of rural logistics in different counties. The county that can achieve a higher satisfaction rate using the same amount of subsidies is more valuable to be subsidized. However, government financial subsidies and the requirements of the demand satisfaction rate are not constant. They vary on the basis of the region's economic development, policy environment, financial income, and other factors. Therefore, policymakers of the provincial government will face a problem; when the constraints of equations 5 and 6 are removed, how can a destination for the subsidy object selection among the alternative counties be determined.

This kind of problem can be solved by drawing a coordinate system of the subsidy and the satisfaction rate. First of all, we calculate the different maximum demand satisfaction rates that can be achieved by a number of subsidies. For example, for a county, if the subsides are \$10000.00, \$20000.00, \$30000.00, and \$40000.00, then the corresponding maximum demand satisfaction rates that can be achieved are 30.00%, 40.00%, 50.00%, and 60.00%. Secondly, we mark these “subsidy-demand satisfaction rate” combinations in the coordinates as the coordinate points and obtain the “subsidy-demand satisfaction rate” curve by performing nonlinear regression on these coordinates. The area of the geometric figure constituted by the “subsidy-demand satisfaction rate curve” and the coordinate axis in Figure 5 is an index with which to evaluate the development potential of rural logistics in different counties.

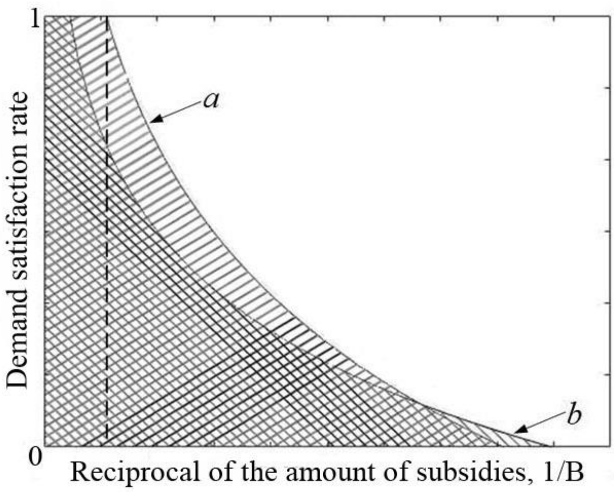

Figure 5. Evaluation of Rural Logistics Development Potential

In Figure 5, the vertical coordinates express the demand satisfaction rate, and the horizontal coordinate shows the reciprocal amount of subsidies. Curve *a* and *b* are respectively representative of countries *A* and *B*. The chart intuitively shows that the shielded area that is constituted by curve *a* and the coordinate axis are larger than the shielded area that is constituted by curve *b* and the coordinate axis, which means Region A has greater potential for rural logistics development than Region B.

5. Conclusions

Taking Hainan province of China as the study area, a bi-level model has been newly developed to improve the rural logistic services of the logistic enterprises with the limited subsides from the government. The proposed model is capable of making rural logistic planning in view of transport route node selection, path planning, cost control, and logistic operation mode choices. Moreover, a new approach based on the proposed model is designed to evaluate the development potentials of rural logistics in different counties, which can help the government make destination choices concerning subsidy objects.

In this study, the rural logistics pricing principle applied in the model is directly given in advance. For residents in rural areas, the acceptable pricing of rural logistic services ought to be calculated and predicted on the foundation of a wide range of data and analyses, which will be made in future research to valid the study results in this work. In addition, it is also necessary to analyze logistics demand in the future in consideration of the induced demand caused by the emergence of the rural logistics services.

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