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OPTIMIZING THE SCALE AND SPATIAL LOCATION OF CITY LOGISTICS TERMINALS

Zhongzhen YANG
Professor
Transport College
Dalian Maritime University
1 Ling hai Road, Ganjingzi, Dalian
116026, China
Fax: +86-411-8472-6756
E-mail: yangzhongzhen@263.net

Chong LIU
Graduate Student
Transport Program
Dalian University of Technology
2 Ling gong Road, Ganjingzi, Dalian
116024, China
Fax: +86-411-8472-6756
E-mail:liuchong1980@163.com

Xiangqun SONG
Associate Professor
Port Economy Lab.
Dalian University of Technology
2 Ling gong Road, Ganjingzi, Dalian
116024, China

Abstract: Here city logistics terminal is defined as the facility consisting of warehouse center, marketing center, freight detaching center, distributing center and the information center. It is a link of freight transport between transport terminal such as port, railway freight station and highway entrance and the retailing facilities. The purpose of this study is to optimize the size and spatial distribution of city logistics terminals with location model and Genetic Algorithms (GAs) to minimize the total freight transport cost in the city. Freight transport system in the city is analyzed, and transport cost and construction cost are formulated. Choice behavior of retailing facilities for logistics terminal is modeled. At last a case study is carried out.

Key Words: Logistics Terminal, Genetic Algorithms, and Location Model

1. INTRODUCTION

Due to the urban economic growth, urbanization in China processes quickly, and freight transport in cities is increasing and attracts more attentions. Transport demand management for urban freight transport effectually is important to transport planners. If urban freight transport is not managed carefully, it will bring a city many negative impacts, such as traffic congestion, environmental pollution, unnecessary energy consumption and quick road damage due to the heavy loaded truck. Therefore, it is thought that construction of city logistics terminals is one of the efficient means to control freight traffic demand, since they may not only mitigate traffic congestion, lighten air pollution and save energy but also improve freight transport system, reduce the cost of urban freight transport. Optimized city logistics terminals can transfer the center of gravity of freight transport from city center to suburb, and alleviate traffic pressure in the center and improve the efficiency of the whole urban transport system.

City logistics terminal in this study does not equal to warehouses, it is a facility consisting of warehouse center, marketing center, freight detaching center, distributing center and city

logistics information center. It serves not only third-party logistics and private companies but also the whole urban freight transport system. Large-scale city logistics terminal is a warehouse firstly, which collects the freights from other areas. In this way land in city center is saved and traffic demand in the center is managed. Since city logistics terminal consists of warehouse center, trading center, detaching center, distributing center and information center, we can use the centralized information to design the best strategy to deliver freights and the most efficient route for distributing freights to optimize freight flow and minimize the cost of freight transport in the city. Rational logistics terminal distribution means the optimal spatial locations of the terminals and corresponding scales.

Location problem is a classical planning problem, many literatures concerned this topic. Early studies concentrated at linear planning field, Efroymson and Ray (1966) developed a discrete choice model for plant location, while Francis and White (1974) solved Euclidean distance location problem with centre of gravity method. As the theoretical progress, various non-linear planning theories were used for location model. Holmbery (1999) considered non-linear transport cost and solved the problem with branch-bound algorithm. Barahohna and Jensen (1998) developed a warehouse location model with mixed integer planning. Taniguchi (1999) established a bi-level optimal model of logistics center location with bi-level planning theory and solved the problem with GAs. Gao(2003) explained various logistics location model in detail in his book, especially bi-level optimal model. In addition to the static models, many dynamic models are also developed. Kasilingam (1996) solved a single facility location problem with dynamic model, and Campbell (1994) established a continual proximity location model that is used for relocate a logistics terminals. These models have well considered transport cost, construction cost happened in locating logistics terminals and dynamic location problem. However, few of them tackled storage cost, delivery cost to shopping center, probabilities of shopping center selecting logistics terminals.

This paper focuses on optimization of the spatial locations and sizes of city logistics terminals. To reach the goal, we establish an optimal location model and design the algorithms for it, and then solve the optimizing problem in a case study. Model structure is based on discrete choice theory, queuing theory and nonlinear programming theory. Costs of whole city logistic system, such as freight transport cost, construction cost of logistics terminals, are taken into account, and the objective function is to minimize the total costs.

2. OPTIMIZATION MODEL OF LOCATION OF LOGISTICS TERMINALS

Fig.1 shows the ideal city logistics network (Taniguchi 1999). In the network, freights from outside firstly arrive at city’s transport terminals, namely port, railway freight station, airport, and exit of highway. A rational city logistics network should have a modern information center, therefore, when the freights outside the city arrive at the transport terminals, information center will collect data and analyze the data, then send the analyzed results to the logistics terminals. Base on the information, logistics terminals make scheme of delivery trucks and feedback the data to information centers, then information center will select the

optimized routes for trucks based on real time traffic data. In case of delivering freights from logistics terminals to retailing facilities, information center will offer the information, such as loading plans and the optimal routes, to delivery center. Then the trucks will transport the freights to the demand sites. It can be seen that due to the existence of the logistics terminals, freight transport is optimized and demand of freight traffic in the city will be managed. Since the spatial configuration and distribution of urban road network and retailing facilities (here they mean the logistics destinations) are relatively stable during a period of time, the spatial distribution and scale of logistics terminals, which act as the transshipment facilities, affect the freight traffic demand in logistics networks seriously. With the adjustment of the logistics terminals, freights may be delivered to the destinations in batches and installments, to avoid the rush hour. This study focuses on the optimized size and location of city logistics terminals, and tries to reduce the costs of freight transport, construction of logistics terminals and the cost of the occupied land. An optimization model, which is a nonlinear programming problem, is developed and a heuristic algorithm is designed. The heuristic algorithm can find the optimal logistics terminals from an initial situation, which is designed based on existing data and experience.

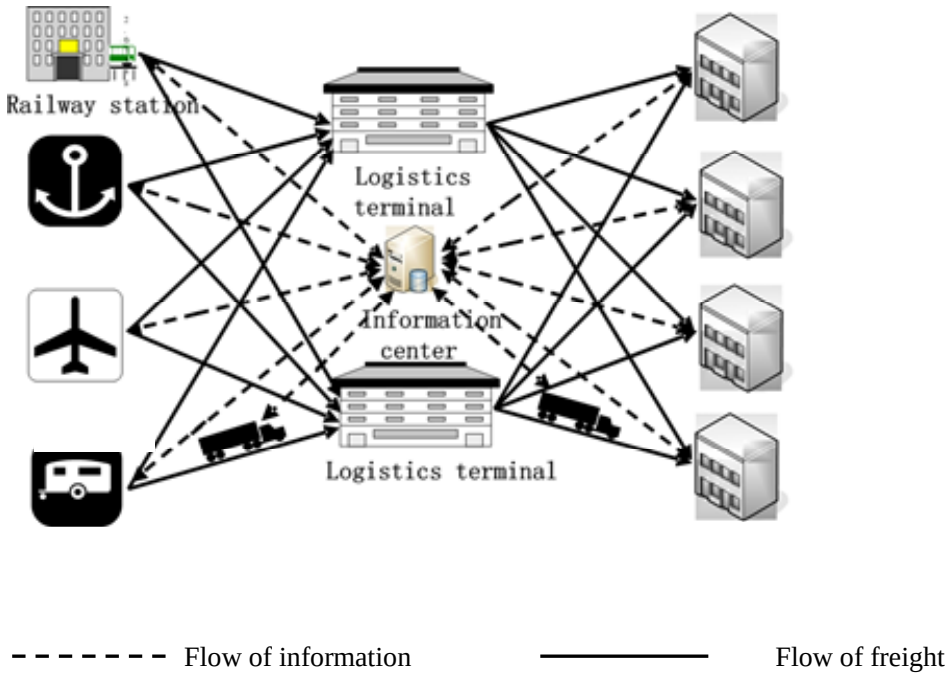

Fig.1. Structure of Ideal City Logistics Network

2.1 Freight from Transport Terminal to Logistics Terminal and its Cost Model

In the condition of a certain city size and economic level, the consumed goods, which is supplied by producers both in and out of the city, is constant. Local producers will deliver goods directly to retailing facilities, while other producers will transport the goods by highway, railway, and water way to the city. The delivery process can be divided into inter-city and intra-city ones. Producer is responsible for the former, and has nothing to with the intra-city transport and selling price, while the later relates to urban traffic and selling

price very much. Intra-city freight transport is basically described in Fig. 1 (Taniguchi, 1999). Subject to storage cost and efficiency, freights may not be transported from transport terminal directly to retailing facilities, but they will be first transported to logistics terminal and then delivered to the destinations lot by lot based on demand situation and road traffic condition (Taniguchi, 2001). There may be many logistics terminals in a city, here the delivered freight between transport terminal k and logistics terminal j is represented as Q_{kj}, the shortest path on road network between them as q_{kj}, the unit price of freight transport as s, average storage time of goods as D days, unit price of storage as P_j, then the cost of transport and storage of freight in city logistics network can be formulated as:

$$\sum_{k=1}^{m}\sum_{j=1}^{n} Q_{kj} \times q_{kj} \times s + \sum_{j=1}^{n}\sum_{k=1}^{m} Q_{jk} \times D \times P_j \tag{1}$$

In formula (1), the first part means the freight transport cost between transport terminals and logistics ones, while the second part represents storage cost in logistics terminals.

2.2 Transport Cost Model from Logistics Terminals to Retail Facilities

Here the prerequisite is that the spatial locations of retail facilities are given. Since most of retail facilities are located at central parts or around residential blocks with good accessibility, to make full use of the expensive land, they will choose logistics terminals based on maximum utility theory in the condition of keeping the lowest storage stock. During the selection, intra-city transport cost, service level and reliability of logistics terminals are mainly considered. The utility function of a retailing facility selecting a logistics terminal is formulated as:

$$U_{ij} = \alpha \sum_{k=1}^{m} Q_{kj} / f(t_{ij}) + \beta P_j \tag{2}$$

Here U_{ij} = utility of facility i choosing logistics terminal j, t_{ij} = generalized cost of the shortest transport path between facility i and logistics terminal j, $f(t_{ij}) = 1/\mathrm{t}_{\mathrm{ij}}^{2}$ is a integrated cost function, α, β = parameters obtained from experience. Thus the probability of retailing facility i choosing logistics terminal j and the cost of freight transport are formulated as

$$P_{ij} = \frac{\alpha \sum_{k=1}^{m} Q_{kj} / f(t_{ij}) + \beta P_j}{\sum_{j=1}^{n} (\alpha \sum_{k=1}^{m} Q_{kj} / f(t_{ij}) + \beta P_j)} \tag{3}$$

$$F_1 = \sum_{i}^{l}\sum_{j}^{n} P_j Q_i q_{kj} s \tag{4}$$

Here, Q_i = quantity of sold goods by retail facility i.

2.3 Cost of holding a Logistics Terminal

Cost of holding a logistics terminal can be divided into three parts, namely construction cost,

land rent, and operation cost. Because cost of freight transport is calculated annually, construction cost and land rent should be allocated to every year by depreciating ratio of asset and interest rate. So holding cost of logistics terminals is formulated as:

$$F_2 = \sum_{j=1}^{n}[(\mu\sum_{k=1}^{m}Q_{kj})(P_j \times r + R_j) \tag{5}$$

Here, μ = storage space of a unit freight, P_j = unit construction cost of logistics terminal j, r = annual asset depreciating ratio, R_j = land rent of the logistics terminal j.

2.4 Optimization Model

We aim to optimize the number, size and spatial location of logistics terminals in a city, and make them to be as a connector between transport terminals and retailing facilities. Thus freight transport can be managed based on data and analyses in information center, for example, lot dispatch, off peak delivery, optimization of truck path, improvement of trucks' efficiency, reduction of empty truck movement etc. However, since during the design stage we can not consider the effects of dispatching plan in detail, here the least costs of intra-city freights transport and logistics center holding mentioned above are taken as the objective of the optimization model.

$$\begin{aligned} &Min: F(Q_{ij}) = \sum_{k=1}^{m}\sum_{j=1}^{n}Q_{kj} \times q_{kj} \times s + \sum_{j=1}^{n}\sum_{k=1}^{m}Q_{jk} \times D \times P_j + \sum_{i}^{l}\sum_{j}^{n}P_jQ_iq_{ij}s + \sum_{j=1`}^{n}(\mu\sum_{k=1}^{m}Q_{kj})(P_j \times r + R_j) \\ &ST: \sum_{i=1}^{m}\sum_{j=1}^{n}Q_{ij} = Q \\ &\quad Q_{ij} > Q_{\min} \end{aligned} \tag{6}$$

3. THE ALGORITHM

GAs will be used to solve the model since that: 1) the probabilistic selection model (formula 2) within the objective function is a complex nonlinear one; 2) the number of logistics terminals and spatial location will be optimized simultaneously, while m and Q_{kj} are unknown. With GAs the non-linear program problem can be solved, moreover, during the evolution of GAs bad Q_{kj} will be eliminated and good Q_{kj} will be generated according to jungle rule from a relatively large parent population. At the end of the calculation, the optimized number, sizes and locations of logistics terminals will be found. It can be said that GAs is not only the solving algorithm but also an essential part of the problem. In order to generate as many as reasonable initial logistics terminal location patterns, urban spaces are represented with continuous grids, and we determine the grids where logistics terminal with certain size can be built based on land price, land use attributes and spatial location of the grids and experiences to obtain initial chromosomes and genes. Next we carry out GAs operation, namely crossover, mutation, selection based on crossover ratio p_c, mutation ratio p_m and size of the population P_{size} respectively. The GAs operation will be repeated until convergence. The operation method and steps are designed as follows:

Step1: Code initial chromosomes with decimal coding method.
Step2: Crossover gene between two parents' chromosomes, arithmetic crossover is used.

$$\begin{aligned} c_{i1}^{t} &= \alpha_i c_{i1}^{t-1} + (1-\alpha_i) c_{i2}^{t-1} \\ c_{i2}^{t} &= \alpha_i c_{i2}^{t-1} + (1-\alpha_i) c_{i1}^{t-1} \end{aligned} \tag{7}$$

Here, $c_{i1}^{t-1}, c_{i2}^{t-1}$ = parents chromosomes, c_{i1}^{t}, c_{i2}^{t} =child chromosomes, α_i =a random number between0 and 1, $i = 1,2,...,k$ (k is a pair number of chromosomes for crossover).

Step3: Mutation operation.

If $c = (c_1, c_2, \cdots, c_n)$ is a chromosome and c_k ($c_k \in [c_{k,\min}, c_{k,\max}]$) is a gene, which is selected to be mutated, the mutation result of c_k is

$$\bar{\boldsymbol{c}}' = (\boldsymbol{c}_1^{t-1}, \boldsymbol{c}_2^{t-1}, ..., \boldsymbol{c}_{k-1}^{t-1}, \boldsymbol{c}_k^{t}, \boldsymbol{c}_{k+1}^{t-1}, ..., \boldsymbol{c}_m^{t-1})$$

$$\boldsymbol{c}_k^{t} = \begin{cases} \boldsymbol{c}_k^{t-1} + \Delta(\boldsymbol{t}, \boldsymbol{c}_{k\max} - \boldsymbol{c}_k^{t-1}) & \textit{if} \quad \textbf{\textit{Random}}(0,1) = 0 \\ \boldsymbol{c}_k^{t-1} + \Delta(\boldsymbol{t}, \boldsymbol{c}_k^{t-1} - \boldsymbol{c}_{k\min}) & \textit{if} \quad \textbf{\textit{Random}}(0,1) = 1 \end{cases} \tag{8}$$

The formulation of $\Delta(t, y)$ is as (9) shown, it returns a value between [0, y], the value approach to 0 with evolution generations increasing.

$$\Delta(t, y) = y \times (1 - r^{(1-t/\mathrm{T}_{\max})^{\lambda}}) \tag{9}$$

Here, r = a likelihood value between 0 and 1, t =generation, λ =coefficient appointed by operator ($\lambda = 2-5$).

Step4: Evaluating the fitness of chromosomes and knocking out poor chromosomes. The variable penalty method is used to build a fitness function, and the penalty coefficient will become bigger as the increment of the generation t as shown in (11).

$$F(q) = F(Q_{ij}) - M(t)(Q - \sum_{i=1}^{m}\sum_{j=1}^{n} Q_{ij}) \tag{10}$$

$$M(t) = \beta_1 t^{\beta 2} \tag{11}$$

Step5: Judge whether to continue the calculation.

4. NUMERICAL TEST WITH DATA OF DALIAN

In order to illustrate the effectiveness and feasibility of the model, we select Dalian as the study area to optimize the spatial location and size of its logistics terminals. Currently, Dalian has five city transport terminals (Fig.2), namely Dalian port, Dalian railway freight terminal, deep water port of Dayaowan, entrance of expressway and airport. Freight volumes of them are shown in Table 1. We also collected data of the existing logistics terminals in Dalian, and get to know that Dalian has five logistics terminals (Nanguanling logistics terminal, Gezhenpu logistics terminal, Xinzhaizi logistics terminal, Dayaowan logistics terminal and Xianglujiao logistics terminal).

Table 1 Freight Volumes of Transport Terminals

Terminal	Railway	Expressway	Airport	Dalian Port	Dayaowan Port
Freight (10^4 Ton)	400	450	29	355	1,800

In numerical test, we add another four potential sites to obtain nine potential terminal locations (Fig. 2). Then, we decide their original sizes with historical data and experiences. Based on the original sizes, upper and lower limits of them are determined, in which all of the lower sizes are set to zero and all of the upper limits are three times of the corresponding original sizes (Table 2). Therefore, a group of initial chromosomes are produced based on the rule that genes are a random numbers between the corresponding upper and lower limits and sum of the 9 genes in a chromosome should equal to the total freights from transport terminals. There are too many retailing facilities in Dalian, but most of them are located in central area and a few are in the outskirt. Therefore, not all retailing facilities can be included in the numerical test, and only the facilities over 2000m^2 are determined as the logistics destinations and considered in numerical test. Their spatial distribution is also displayed in Fig.2.

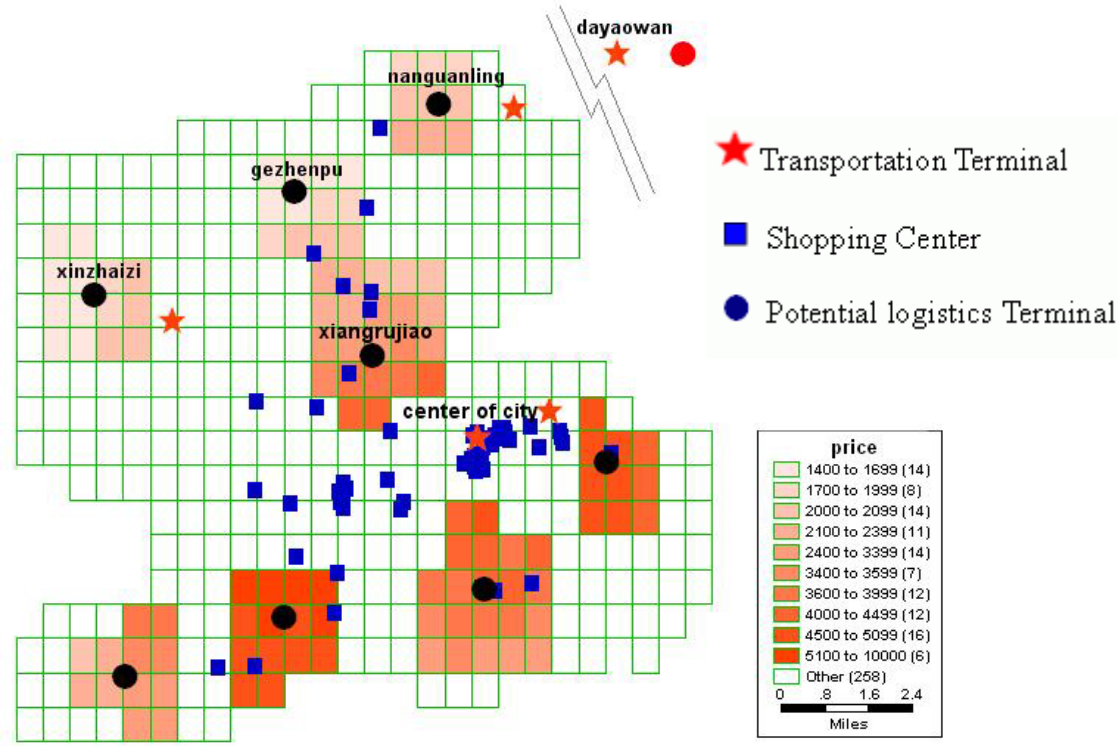

Fig.2 Location of Transport Terminal, Logistics Terminal and Shopping Center

Table 2 Original Scale of the City Logistics Terminal (10^4 ton)

Location	1	2	3	4	5	6	7	8	9
Upper Limit	60	234.8	271.8	475.2	915.2	881.2	574.2	24	5,653.6
Lower Limit	0	0	0	0	0	0	0	0	0

During GAs operation we set $p_c = 0.6, p_m = 0.05, P_{size} = 30, T_{\max} = 90$, and we found that before 50 generations of operations fitness decreased quickly, while fitness of 51-90 generations changed slightly. It can be seen from Fig.3 that after 90 generations, the fitness got stable and calculation got convergence, thus we stop the calculation and obtained the results (Table 3 and Fig. 4).

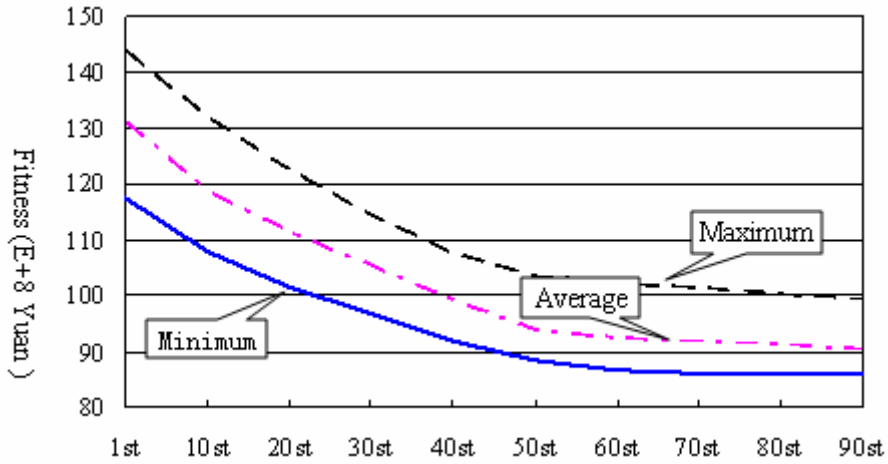

Fig.3 Changes of Fitness during GAs

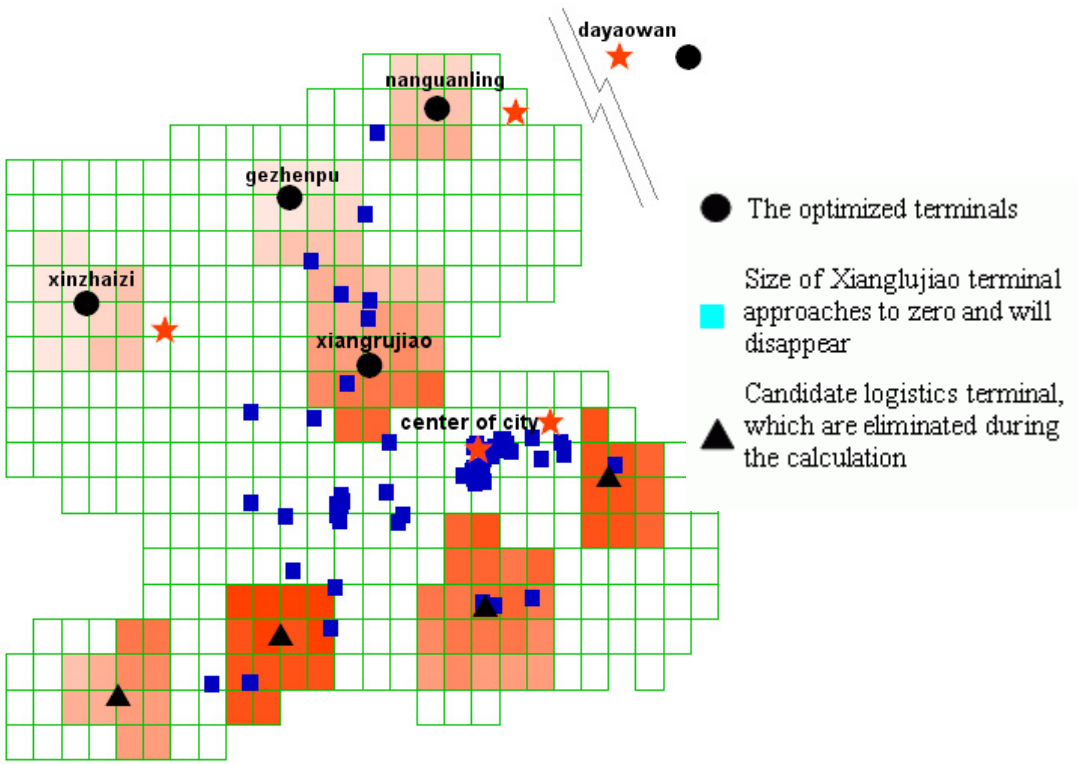

Fig.4 Distribution of Optimized Logistics Terminal

Table 3 Size of the Optimized Logistics Terminal

Location	1	2	3	4	5	6	7	8	9
Size(10^4 ton)	0.02	0.06	0.05	0.12	710.24	448.78	0.25	30.13	1,840.35

5. CONCLUSION

An optimal model is developed, which takes several factors concerning freights circulation in a city, such as transport, storage, construction and land price, into account and is based

probability choice theory. Due to the nonlinear and large scale of the calculation, we can not apply ordinary heuristics algorithm to solve the problem, then GAs is used to get proximity solutions.

Taking Dalian as case study area, we optimized the size and spatial location of logistics terminals in the city. Because land price is taken into account in numerical test, while land price in center area is very high (about three times of the land price in suburb) the sizes of the potential logistics terminals in central area became smaller and smaller after several generations of calculation. It can be concluded that almost no logistics terminal will be located in the center, and most of them select suburban area as locations. Because there is no transport terminal in southern part, no logistics center will be located at southern part (Fig.4) due to the high transport cost. As mentioned in section 4, there is a logistics terminal named Xianglujiao, which connects inner city and outer city. However, land price in Xianglujiao region is increasing fast due to urbanization, thus the size of this terminal decreased continually in our calculation. It is rational to think that Xianglujiao logistics terminal is not suitable and should be moved to suburb area. We conclude that most logistics terminals will be located at northern part, where is far from city center but near highway and artery roads. Because data used are real one, the optimized result is similar to the actual situation of Dalian city.

The model developed here and its GAs solving method has solved the problem of optimizing the spatial location and size of city logistics terminals. It is helpful to be applied to big and middle-size cities. At present, the model can not quantify the effects of logistics terminals location on the whole urban transport system. We also do not evaluate the impacts of logistics terminals on local environment. All of them might be our future study topics.

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