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ATTRACTION AREA DIVISION AND FREIGHT FLOW ORGANIZATION OPTIMIZATION OF INLAND RAILWAY CONTAINER TERMINAL

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Abstract. The attraction area division is the foundation of distribution and organization of freight flow among railway stations. The development of railway container terminal, large railway freight distribution center, is closely related to logistics planning and economy development of local city. In this study, we divide freight flow attraction area of inland railway container terminal by using gravity model, break-point model and weighted-Voronoi-diagram with SPSS and ArcGIS. And then under the target of minimal cost and time window limitations, we develop 0–1 integer programming model for freight flow organization optimization between inland terminal and its attraction area. Finally, this paper takes railway container terminal in Harbin as an example to test model feasibility under different speeds from different transportation modes. The results show that it is necessary to divide attraction area when choosing reasonable transportation mode from feeder nodes to railway container terminal. The improvement of feeder transportation speed is an effective method to improve freight volume, increase railway revenue and realize sustainable development of China Railway (CR) Express.

Keywords: freight transportation, China Railway Express, gravity model, break-point model, 0–1 integer programming.

Introduction

The China Railway (CR) Express is a fast-freight group of trains that is suitable for container transportation between China and Europe. Among the cities where CR Express operates, inland cities with rapid development take up the majority. Moreover, CR Express builds up some new forms of businesses and pushes inland cities to the forefront of opening-up and cooperation with outside world.

With the development of CR Express and gradual improvement of inland transportation network, local governments develop different freight subsidy standards for CR Express to attract more businesses. Consignors are willing to invest a lot of transportation resources to get more freight subsidy, by even choosing farther operation railway stations of CR Express to transport goods (Table A1 in the Appendix). However, this brings about chaotic transportation rules, leading to disordered competition in the CR Express freight organization, and it fails to take the most advantage of various freight modes. And it also leads to serious waste of transportation resources to a large extent and restricts the sustainable development of CR Express. The key problem in this paper is the division of attraction region. On the basis of the division of attraction area, the further research on the optimization of freight flow organization will give the decision makers a clearer idea of decision-making.

Our contributions are as follows. In this paper, we divide freight flow attraction area of inland railway container terminal by using gravity model, break-point model and weighted-Voronoi-diagram with SPSS (*https://www.ibm.com/analytics/spss-statistics-software*) and ArcGIS (*https://www.arcgis.com*). Then we establish a 0–1 integer programming model of freight flow organization optimization between inland terminal and its attraction area, with minimal transportation cost and time window

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limitations. Moreover, we take railway container terminal in Harbin as an example to test the model feasibility under different speeds from different transportation modes. Therefore, in this research, by gravity model, break-point model and weighted-Voronoi-diagram, we make comprehensive analysis and establish freight organization optimization model with time window constraint to solve this problem. The research results are not only applicable to the CR Express, but also can provide a guidance for the general block train operation.

This study is organized as follows. Section 1 describes the related literature review of attraction area division of terminals, transportation mode selection and freight flow organization. Section 2 makes a comprehensive analysis based on spatial interactions. Section 3 illustrates a freight organization optimization model from attraction area to the terminal of CR Express. In Section 4, the model feasibility under different speeds from different transportation is tested through a case study in Harbin. The final section presents the conclusion of this study.

1. Literature review

The research is embodied in three aspects: attraction area division of terminals, transportation mode selection and freight flow organization.

In the aspect of the research on attraction area division of terminals, it can be divided into the attraction area of passenger and freight transportation station. In the attraction area division for passenger transportation station, passenger walking distance, time, behaviour differences and passenger transport operators are considered to design model (O'Sullivan, Morrall 1996; Kim *et al.* 2010; El-Geneidy *et al.* 2014). The algorithm usually has the shortest distance algorithm, minimum real-time algorithm and the improved p-median algorithm (Wang, Shi 2017). In addition, Yu *et al.* (2014) classify and quantify a series of urban agglomerations based on object automatic detection and night-time satellite map. In the attraction area division for freight transportation station, Galvão *et al.* (2006) use multiplication weighted-Voronoi-diagram to solve the problem of attraction area in the logistics progress. Factors such as land use, transportation network and business size are usually taken into account in the model establishment (Lawson *et al.* 2012; Sánchez-Díaz *et al.* 2016). The methods adopted in the analysis include spatial econometric techniques, ambivalence model, gravitational model, weighted-Voronoi-diagram and discrete generation algorithm (Abellanas *et al.* 2003; Wei *et al.* 2008).

In the aspect of transportation mode selection, as different transportation modes have different unit costs, cost minimization is usually one of the objectives of optimization (Banomyong, Beresford 2001). In addition, the optimization objects of the model include time, risk, carbon emission and environmental protection (Choong *et al.* 2002; Verma, Verter 2010; Verma *et al.* 2012; Demir *et al.* 2016; Jiang, Zhang 2016; Seo *et al.* 2017; Xia *et al.* 2019). In terms of model establishment, the models are mainly in the form of integer programming, multi-model decision-making and mixed integer programming (Choong *et al.* 2002; Qu *et al.* 2008; Bierwirth *et al.* 2012; Demir *et al.* 2016). In algorithm design, adaptive neural network system, iterative decomposition method, tabu search algorithm and other heuristic algorithms are used to solve the problem (Qu *et al.* 2008; Verma, Verter 2010; Verma *et al.* 2012). Besides, Jiang *et al.* (2012) use carbon dioxide emission calculation model published by Intergovernmental Panel on Climate Change (IPCC) to measure carbon dioxide emissions. They provide data support and practical guidance for the low-carbon development of multimodal transport in building low-carbon ports.

The research on freight transportation organization mainly includes optimization of dispatching routes, freight flow assignment and transportation network. As for dispatching routes optimization, the optimization goal is generally to minimize some factors such as transportation cost and transportation time (Chang 2008; Yang *et al.* 2011). Mixed integer programming, shortest path model, integer programming forms are mainly adopted in model establishment, and the algorithms adopted mainly include time series algorithm, dynamic programming algorithm and heuristic algorithm (Lozano, Storchi 2001; Zografos, Androutsopoulos 2008; Cho *et al.* 2012). In terms of freight flow assignment optimization, the main research is to optimize the objective of the distribution of goods in the transport network (Corry, Kozan 2006; Kalinina *et al.* 2013; Bhattacharya *et al.* 2014; Hübner, Ostermeier 2018). Transportation cost, time, carbon emission and other factors are generally considered as optimization targets. Dynamic distribution model, mixed integer programming model, mixed linear programming model are mainly used in the model establishment (Corry, Kozan 2006; Bhattacharya *et al.* 2014; Borndörfer *et al.* 2016). In algorithm design, dynamic programming algorithm, heuristic algorithm and hybrid heuristic algorithm are usually used to solve the model (Hao, Yue 2016). Furthermore, Talley and Ng (2018) build a behavioural model based on non-cooperative game theory, and study the influence of decision-making behaviours of major players on hinterland supply chain, namely ports, shippers and multimodal transport operators, on the choice of hinterland transport chain. In terms of transportation network optimization, the optimization targets are usually the efficiency, time and benefit of the transportation network (Butko *et al.* 2019; Feng *et al.* 2019). In general, it adopts the form of mixed integer programming, such as bi-objective and multi-objective optimization, and uses genetic algorithm and other heuristic algorithms to solve the problem (Wei, Dong 2019). In addition, Yao *et al.* (2002) establish an improved linear optimization model for multi-objective optimization considering both bidirection and empty-loaded train certain transportation requirement.

Attraction area division research mainly considered the influence of transport time, distance and cost, but researchers seldom consider influence that interaction between the city where freight flows are and the neighbouring city has on attraction area division. In terms of transportation mode selection, analysis is mainly carried out with the lowest transportation cost, the shortest transportation time, and the best environmental protection scheme, without taking into account the influence of hinterland freight flow organization on transportation mode selection.

At present, research on flow organization optimization mainly focuses on three aspects: dispatching routes, freight flow assignment and transportation network. However, research on freight flow organizational optimization in inland areas and freight flow from multiple origins to the same destination is relatively insufficient. On the basis of literature review, we first adopt comprehensive analysis based on spatial interaction, which means, gravity model, break-point model and weighted-Voronoi-diagram are applied, also SPSS and ArcGIS are combined to divide attraction area of terminal. Then, based on attraction area, we construct a 0–1 integer programming model for freight organization optimization on CR Express. Finally, we verify feasibility of research method by taking Harbin Railway Container Center Station (HRCCS) as an example.

The innovation of this study lies in comprehensive analysis based on spatial interaction, which combines gravity model, break-point model and weighted-Voronoi-diagram. Most of the traditional methods only consider distance or cost. The method of attraction area division proposed in this paper not only considers the distance between two cities, but also the comprehensive strength of the carrier city and the strength of economic connection with other cities. The method in this paper is more comprehensive than traditional method. In addition, we analyse the attraction area of inland railway container terminal and establish freight organization optimization model with time window constraint by combining with attraction area division. Thus, we obtain optimal freight organization mode in attraction area of CR Express, and verify the method feasibility through practical examples in the end.

2. Spatial interactions comprehensive analysis

Based on economic geography theory, this method considers that development of traffic lanes, stations or ports, as a part of the support for carrier city, cannot be separated. Attraction area of traffic lane, station or port is influenced by economic and social development of the carrier city. To reflect the interaction among a carrier city and its surrounding cities, commonly used models such as gravity model and break-point model are able to make sense. In gravity model, distance attenuation function is mainly used to reflect the attenuation law of gravity with increasing distance between two cities (Boukebbab 2015). While key idea of break-point model is that attraction area of a city is determined by city scale and distance between neighbouring cities. Moreover, the equilibrium point between two neighbouring cities is called the breaking point (Bowen 2012).

As there are many indexes in evaluation system, the comprehensive power of each city can be calculated with the concept of dimension reduction in principal component analysis (Moore 1981). We put its results into the corresponding formulas of gravity model and break-point model to obtain attraction area of carrier city.

2.1. Gravity model

Based on the universal gravitation in Newtonian mechanics, gravity model mainly uses the distance attenuation function to reflect attenuation law of gravity with increasing distance between two cities. What's more, one of characteristics about gravity model is that if we keep its basic form unchanged and reasonably define the parameters, it can be applied to other researches (Lu, Huo 2013). The formula of gravity model is usually defined as follows:

$$T_{ik} = K \cdot \frac{Y_i \cdot Y_k}{d_{ik}^2}, \quad (1)$$

where: T_{ik} is the intensity of gravity between two cities; K is constant (gravitational coefficient); Y_i, Y_k are endogenous variables; d_{ik} means distance between city i and city k.

We take urban comprehensive power to modify gravity model. As following calculation has faction reduction, we set K to 1, and consider the endogenous variables as comprehensive power of cities. In terms of the gravity model definition, economic connection degree between carrier city and its surrounding city is directly proportional to its comprehensive power and inversely proportional to its distance. The formulas are as follows:

$$F_{ik} = \frac{\sqrt{S_i \cdot S_k}}{D_{ik}^2}; \quad (2)$$

$$F_i = \sum F_{ik}, \quad (3)$$

where: F_{ik} refers to economic connection degree between city i and city k; S_i, S_k are comprehensive power of city i and city k; D_{ik} means the shortest distance between city i and city k; F_i means the aggregate economic connection degree among city i and all other cities in the region, namely the total external economic connection degree of city i.

The greater economic connection degree between one city and carrier city in the region is, the closer economic connections the city and carrier city have, namely the more attractive it is. In this study, based on gravity model calculation, we obtain economic connection degree between the carrier city and each city in the region, and then rank them in descending order. As usual, in this study, cities whose economic connection degree has reached 85% of total external economic connection degree, that is, cities whose membership degree has reached 85%, are included in attraction areas of carrier city. We can see calculation formula as follows:

$$\beta_{ik} = \frac{F_{ik}}{F_i}, \quad (4)$$

where: β_{ik} refers to proportion of economic connection degree in the total external economic connection degree, namely the membership degree on economy connection; F_{ik} refers to economic connection degree between city i and city k; F_i means total external economic connection degree of city i.

2.2. Break-point model

In the case of multiple attraction points, division based on gravity model does not consider influence of multilateral resistance, thus it cannot accurately describe attraction area boundary of multiple attraction points. However, break-point model can exactly solve this problem. The formula (Long *et al.* 2011) of break-point model is as follows:

$$d_i = \frac{D_{ik}}{1+\sqrt{\frac{P_k}{P_i}}}, \quad (5)$$

where: d_i, is the distance from break-point to city i; D_{ik} means the shortest distance between city i and city k; P_i, P_k are respectively the population scale of city i and city k.

However, in practical application, break-point model still has the following shortcomings:

- it is not comprehensive to consider population scale as the attraction of a city in the formula, so population scale is replaced by comprehensive power in this paper;
- we only get one point between two cities through the formula, but in fact, it is not very possible to get the boundary of attraction area between two cities by one point arbitrarily.

For above deficiencies, we can modify it based on the assumption that attraction area boundary between two cities is an arc from weighted-Voronoi-diagram.

Definition of weighted-Voronoi-diagram is as follows.

Voronoi has the function of spatial partition (Figure 1). The distance from any point in Voronoi grid to the center of the grid is less than that from other grid centers. Set $X=\left(X_1, X_2, ..., X_n\right)$, $3 \le n \le \infty$ to a control point aggregate in 2D Euclidean space. Set $w_i\left(i=1,2,...,n\right)$ to n certain positive real numbers, and x to a random point in the area. The formula is as follows:

$$V_n\left(X_i, w_i\right) = \bigcap_{j \ne i} \left(x \middle| \frac{d\left(x, X_i\right)}{w_i} \le \frac{d\left(x, X_j\right)}{w_j} \right),$$
$$i = 1, 2, 3, ..., n. \quad (6)$$

Firstly, we divide the plane into n parts. Then the plane division that is determined by $V_n\left(x_i, w_i\right)\left(i=1,2,...,n\right)$ is weighted-Voronoi-diagram, where w_i is called the weight of X_i. Unlike old Voronoi-diagrams, weighted-Voronoi-diagram breaks the rule that Voronoi-diagrams are homogeneous, and it is suitable for spatial segmentation in cases where weights of each site are obviously different. We can assume that all points in the region defined by weighted-Voronoi-diagram are mostly affected by the site in that region. In this study, we take the central city in one region as a site, and the other cities within the region are affected more by it than the central city in the adjacent region.

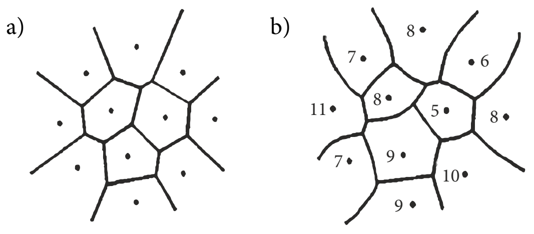

Figure 1. Diagrams: a – regular-Voronoi-diagram; b – weighted-Voronoi-diagram

The following inferences can be obtained by analysing the break-point formula: We take two cities as the sites, its attraction weigh is proportional to square root of the comprehensive external economic connection degree of two neighbouring cities, which is shown in the following formula:

$$\frac{w_i}{w_k} = \sqrt{\frac{F_i}{F_k}}. \quad (7)$$

Based on Equation (7), we can get Voronoi-diagrams weighted by square root of comprehensive external economic connection degree of each city. The formula combining break-point model with weighted-Voronoi-diagram is shown below:

$$V\left(X_i, \sqrt{F_i}\right) = \left(x \in V\left(X_i, \sqrt{F_i}\right) \middle| \frac{d\left(x, X_i\right)}{\sqrt{F_i}} \le \frac{d\left(x, X_j\right)}{\sqrt{F_j}} \right),$$
$$j = 1, 2, 3, ..., n; \; j \ne i. \quad (8)$$

To visually represent attraction area, which is formed by break-point model and weighted-Voronoi-diagram, we use ArcGIS to work on it. The specific steps are as follows:

- *Step 1*: create a constant grid after loading the data, and then set the constant to 1 and pixel to 3000; after creating the grids, turn them into points;
- *Step 2*: create a distance diagram to calculate the distance from the grid point to central city; next add the field "time" to attribute table to weigh every distance; that is, the weight of central city is regarded as speed; and the "time" equals to the distance divided by city attraction weight;
- *Step 3*: connect attribute table of central city with comprehensive power table of central city by *Microsoft Excel*; then connect the two attribute tables of distance and central city, and calculate values of field "time";
- *Step 4*: to obtain the shortest time from each grid point to every central city, summarize the distance table and get statistical table of minimum distance; next connect it with attribute table of central city;
- *Step 5*: turn the points to grid, then to the plane, and turn elements to the lines; finally, we can get the weighted-Voronoi-diagram through modification.

3. Freight organization optimization model

In the above, we have divided final attraction area by using gravity model, break-point model and weighted-Voronoi-diagram, with SPSS and ArcGIS. The following part builds up the freight organization optimization model from attraction area to the terminal of CR Express.

3.1. Problem description

In the freight organization optimization, problem of the freight routine and transport mode selection can be described as follows: suppose that a certain amount of freights are transported from the origin to the destination, and there are two modes of transportation: one is that freights are transported directly from original station to the destination without transfer, the other is that freights are firstly transported to the transfer station, changed transport mode, and then to the destination. Due to the different cost and time of each transport modes, when transport mode is converted at a certain node, transit time and fee happen. Therefore, we need to consider above factors and the timeliness, choosing the optimal routine and transport mode to minimize total cost in the whole transportation process.

3.2. Assumptions

Assumptions are:

- during the transportation process, freight cannot be separated, that is, only one mode of transportation can be selected between two adjacent stations;
- the freight can only be transferred at the station not more than once;
- the yard, facilities and other conditions of all stations meet the transfer operation requirement;
- the time limit of transportation is known.

3.3. Parameter definition

N – set of station, $i, j, s \in N$;
Q – set of transportation mode, $p, q \in Q$;
$m_{i,j}$ – the amount of freight transported from point i to point j [t];
$m^p_{i,j}$ – transportation capacity of mode p adopted between point i and point j [t];
m^{pq}_s – transfer capacity of transfer station s where transportation mode changes from p to q [t];
$c^p_{i,j}$ – unit mileage freight rate between point i and point j with transportation mode p, $p \in Q$ [yuan/t·km];
c^{pq}_s – unit transfer cost of station s where transportation mode changes from p to q, $p, q \in Q$ [yuan/t];
$l^p_{i,j}$ – distance between point i and point j with transportation mode p [km];
$v^p_{i,j}$ – speed between point i and point j with transportation mode p [km/h];
t^{pq}_s – transfer time at station s where transportation mode changes from p to q [h];
$T_{\min}$, $T_{\max}$ – lower limit and upper limit of time window.

Decision variables:

$$x^p_{i,j} = \begin{cases} 1, & \text{using transportation mode } p \text{ from point } i \text{ to point } j; \\ 0, & \text{otherwise;} \end{cases}$$

$$y^{pq}_{i,j} = \begin{cases} 1, & \text{changing transportation mode } p \text{ to } q \text{ during the transportation from point } i \text{ to point } j; \\ 0, & \text{otherwise.} \end{cases}$$

3.4. Modelling

$$\min Z = \sum_{i\in N}\sum_{j\in N}\sum_{p\in Q} m_{i,j} \cdot l^p_{i,j} \cdot c^p_{i,j} \cdot x^p_{i,j} + \sum_{i\in N}\sum_{j\in N} m_{i,j} \cdot c^{pq}_s \cdot y^{pq}_{i,j} \quad (9)$$

subject to:

$$\sum_{p\in Q} x^p_{i,j} = 1,\ i, j \in N; \quad (10)$$

$$\sum_{p\in Q}\sum_{q\in Q} y^{pq}_{i,j} \le 1,\ i, j \in N; \quad (11)$$

$$x^p_{i,j} \cdot m \le m^p_{i,j},\ i, j \in N,\ p \in Q; \quad (12)$$

$$\sum_{j} y^{pq}_{i,j} \cdot m_{i,j} \le m^{pq}_s,\ i, j \in N; \quad (13)$$

$$T_{\min} \le \sum_{p} \frac{l^p_{i,j}}{v^p_{i,j}} \cdot x^p_{i,j} + t^{pq}_s \cdot y^{pq}_{i,j} \le T_{\max},\ \forall i, j; \quad (14)$$

$$x^p_{i,j} \in [0,1],\ y^{pq}_{i,j} \in [0,1],\ i, j \in N,\ p \in Q. \quad (15)$$

Equation (9) is the objective function, which aims to minimize total transportation and transfer cost from origin to destination. Equation (10) guarantees the integrity of freight. Equation (11) limits that freight in any station does not transfer more than once. Equations (12) and (13) respectively ensure transportation capacity between point i and point j and transfer operating capacity of transfer station s. Equation (14) restricts arrival time within the time limit. Equation (15) determines the value of decision variables, that is, $x^p_{i,j}$ means freights are transported from city i to city j by transportation mode p, $y^{pq}_{i,j}$ means freights are transferred or not during the transport process from city i to city j, subject to 0 or 1.

4. Case study

HRCCS is one of key cooperation projects between China Railway Corporation and Heilongjiang Province. Now it has been listed as a major infrastructure construction project of Heilongjiang Province party committee and government to construct "China – Mongolia – Russia" economic corridor and Heilongjiang land and sea silk road economic belt. After HRCCS being put into operation, Harbin will be regarded as the core region to form a modern international logistics center oriented to Russia, radiating to east Europe and northeast Asia, which is of great significance to promote development of CR Express.

4.1. Evaluation system establishment of HRCCS

Evaluation system of comprehensive power has 11 indicators, including regional Gross Domestic Product (GDP), fixed asset investment, retail sales of consumer goods, local public financial revenue, total industrial output value, proportion of non-agricultural industries to GDP, proportion of non-agricultural industry employees, population size, the scale of built-up areas, freight volume, and posts and telecommunications services. According to these indicators, using principal component analysis, with data of 38 cities in northeast economic zone in *China Statistical Yearbook 2016* (CSP 2016), we can obtain the eigenvalues, variance contribution rates, and cumulative contribution rates of correlation matrix through SPSS, as shown in the Table 1.

11 principal components refer to 11 variables. Extraction of principal components is based on eigenvalue and cumulative contribution rate of each indicator. Larger the eigenvalue is, larger the contribution rate will be, indicating that the factor is more capable to represent the comprehensive power of city. Only if the eigenvalue is greater than 1 and cumulative contribution rate is greater than 85%, can the factor be selected as principal factor. As is shown in the Table 1, cumulative contribution rate of the first two principal components is 87.098%, and their eigenvalues are both greater than 1, while percentage of the following nine factors is relatively small. It is indicated that information contained in the first two factors can reflect most information of 11 parameters in the original data. Therefore, the first two factors are denoted as R_1 and R_2, to replace the original 11 indicators. Their corresponding eigenvalues are denoted as λ_1 and λ_2, ψ_1 and ψ_2 denote as the variance contribution rates.

We get the principal factor loading matrix via SPSS, and coefficients through Equation (16). The result is shown in Table 2.

Table 1. Eigenvalue and principal component contribution rate

Principal component	Eigenvalue	Variance contribution [%]	Cumulate contribution [%]
1 – regional GDP	8.269	75.169	75.169
2 – fixed asset investment	1.312	11.929	87.098
3 – retail sales of consumer goods	0.506	4.604	91.702
4 – local public financial revenue	0.304	2.759	94.462
5 – total industrial output value	0.241	2.188	96.649
6 – proportion of non-agricultural industries to GDP	0.170	1.543	98.192
7 – proportion of non-agricultural industry employees	0.098	0.889	99.081
8 – population size	0.050	0.453	99.534
9 – the scale of built-up areas	0.025	0.226	99.760
10 – freight volume	0.021	0.189	99.949
11 – posts and telecommunications services	0.006	0.051	100.000

$$R_k = \frac{A_k}{\sqrt{\lambda_k}}, \quad (16)$$

where: R_k is the coefficient of principal component; A_k is the principal factor load; λ_k is the eigenvalue of principal factor, $k = 1, 2$.

Then score of each principal component and original score of comprehensive power can be calculated by Equations (17) and (18):

$$U_{ik} = H_i \cdot R_k, \quad (17)$$

where: H_i is the standard score matrix of original variables in city i after standardization via SPSS (the number

Table 2. The coefficient and load of principal factor

Original parameter	The first principal factor loading A_1	The second principal factor loading A_2	Coefficient of the first principal factor R_1	Coefficient of the second principal factor R_2
∂_1	0.984	–0.035	0.342	–0.031
∂_2	0.973	–0.061	0.338	–0.053
∂_3	0.913	–0.090	0.318	–0.079
∂_4	0.981	–0.075	0.341	–0.065
∂_5	0.882	–0.011	0.307	–0.010
∂_6	0.496	0.743	0.172	0.649
∂_7	0.359	0.832	0.125	0.726
∂_8	0.849	–0.110	0.295	–0.096
∂_9	0.936	–0.089	0.325	–0.078
∂_{10}	0.929	–0.095	0.323	–0.083
∂_{11}	0.972	–0.147	0.338	–0.128

of original variables is j); $H_i = \left(h_{i1}, h_{i2}, ..., h_{ij}\right)$, i = 1, 2, ..., 38, j = 1, 2, ..., 11; R_k is the coefficient of the kth principal component, $R_k = \left(r_{k1}, r_{k2}, ..., r_{kj}\right)^T$, k = 1, 2, j = 1, 2, ..., 11; U_{ik} is the score of the kth principal component in city i;

$$U_i = \frac{\sum \psi_k \cdot U_{ik}}{\sum \psi_k}, \quad (18)$$

where: U_i is the original score of comprehensive power in city i; ψ_k is the variance contribution rates; i = 1, 2, ..., 38, k = 1, 2.

Since there are negative numbers in comprehensive power scores, it is unreasonable to directly put them into the formula of break-point model, which has the square root operation. Therefore, we need to use the minimum-maximization norm method to transform the city comprehensive power original scores:

$$v' = \frac{v - \min A}{\max A - \min A} \times \left(new\_\max A - new\_\min A\right) + new\_\min A, \quad (19)$$

where: v' is the data after standardization; v is the original data; max A and min A are respectively the maximum and minimum value of original data; *new*_max A and *new*_min A are respectively the maximum and minimum value of the standardized data, which restrict comprehensive power scores of each city to the range [1, 10].

4.2. Attraction area division of HRCCS

4.2.1. Attraction area division

Table 3 shows the comprehensive power and its ranking of cities in the economic zone of northeast China. Among them, central cities in the region are selected with the score greater than 0. Therefore, central cities are Shenyang, Dalian, Changchun, Harbin, Jilin, Anshan, Daqing and Chifeng. By using ArcGIS, we can see the attraction area of Harbin in the Figure 2.

As we can see in the Figure 2, cities within the attraction area of Harbin include Heihe, Yichun, Hegang, Jiamusi, Shuangyashan, Qitaihe, Jixi, Mudanjiang, northwest of Hailar (Oroqen Autonomous Banner, Genhe, Ergun, Manzhouli, Prairie Chenbarhu Banner, XinBarag Right Banner and XinBarag Left Banner), east of Suihua (Zhaodong, Hailun, Suiling, Qinggang, Qingan, Lanxi, and Wangkui), Zhaozhou and Zhaoyuan of Daqing, Yufu of Songyuan and Yushu of Changchun.

4.2.2. Membership degree of economic connection

According to above methods and data of Table A1 in the Appendix, economic connection degree (between cities in the economic zone of northeast China and Harbin) and total external economic connection intensity of Harbin can be obtained, as shown in Table A2 in the Appendix.

In this study, cities whose economic connection degree with Harbin has reached 85% of the total degree, are included in attraction areas. From the Table A2 in the Appendix, 18 cities are included in the attraction area of Harbin. We can see in Figure 3, they are Suihua, Daqing, Songyuan, Changchun, Jilin, Mudanjiang, Qiqihar, Baicheng, Jiamusi, Fushun, Siping, Liaoyuan, Yichun, Shenyang, Qitaihe, Shuangyashan, Jixi and Hegang.

Table 3. The comprehensive power ranking of cities in northeast economic zone

City	Original score of comprehensive power	New score of comprehensive power	Rank
Shenyang	7.829	10.000	1
Dalian	6.431	8.802	2
Changchun	6.243	8.640	3
Harbin	5.566	8.059	4
Jilin	1.214	4.326	5
Anshan	0.816	3.985	6
Daqing	0.769	3.945	7
Chifeng	0.176	3.436	8
Yingkou	−0.011	3.276	9
Qiqihar	−0.013	3.275	10
Qinhuangdao	−0.100	3.200	11
Jinhzhou	−0.314	3.016	12
Fushun	−0.315	3.015	13
Tongliao	−0.358	2.978	14
HulunBuir	−0.483	2.871	15
Liaoyang	−0.494	2.861	16
Benxi	−0.527	2.833	17
Songyuan	−0.553	2.811	18
Tonghua	−0.569	2.797	19
Huludao	−0.603	2.768	20
Siping	−0.705	2.680	21
Mudanjiang	−0.713	2.674	22
Dandong	−0.772	2.623	23
Chaoyang	−0.803	2.596	24
Suihua	−0.960	2.462	25
Panjin	−0.997	2.430	26
Liaoyuan	−1.079	2.360	27
Tieling	−1.096	2.345	28
Baishan	−1.162	2.289	29
Baicheng	−1.212	2.245	30
Fixin	−1.229	2.231	31
Jiamusi	−1.234	2.227	32
Qitaihe	−1.550	1.956	33
Shuangyashan	−1.805	1.737	34
Jixi	−1.868	1.683	35
Hegang	−2.276	1.333	36
Yichun	−2.578	1.074	37
Heihe	−2.664	1.000	38

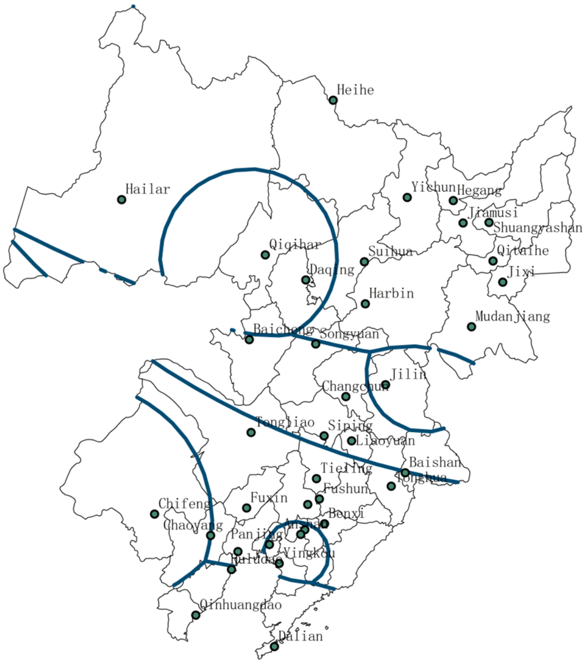

Figure 2. Attraction area division based on weighted-Voronoi-diagram and break-point model

Figure 3. Attraction area division based on gravity model

4.2.3. The optimal attraction area

Combining break-point model and gravity model, we take the intersection area of calculation results of two models and finally get the key attraction area of Harbin railway container terminal. It contains Yichun, Hegang, Jiamusi, Shuangyashan, Qitaihe, Jixi, Mudanjiang, east area of Suihua city (Zhaodong, Hailun, Suiling, Qinggang, Qingan, Lanxi, and Wangkui), Zhaozhou and Zhaoyuan of Daqing, Yufu of Songyuan and Yushu of Changchun. The result is showed in Figure 4.

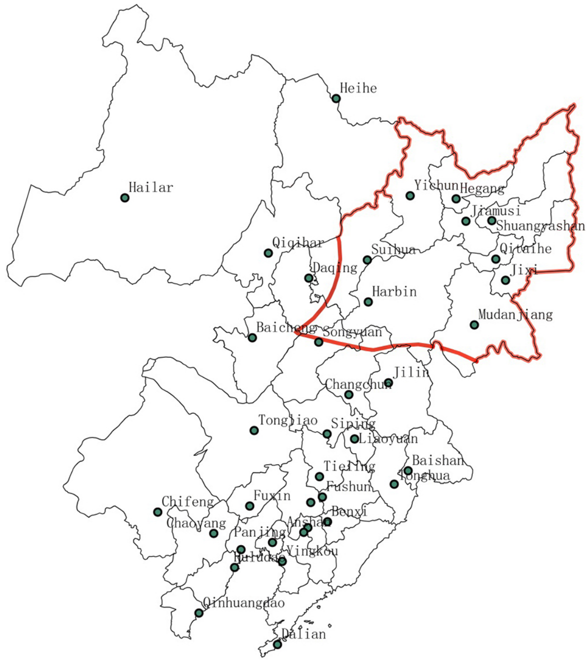

Figure 4. Attraction area of HRCCS

4.3. Data collection for freight organization

4.3.1. Freight volume forecast

Based on the gravity model, we figure out the attraction ratio of Harbin railway container terminal to the freight volume of each region in the attraction zone. Combining with the growth rate method, we firstly predict their freight volume, which will be transported to HRCCS in 2020. Then we calculate the proportion of Harbin – Europe Railway Express freight volume to total volume of HRCCS in 2020 (Table 4). At last, product of the two indicators is the freight volume transported to HRCCS on Harbin – Europe Railway Express from each city in the attraction area in 2020. Due to some data collection problems, the proportion of freight volume in several counties is determined by their share of the whole city's GDP.

4.3.2. Transportation costs

According to the *Heilongjiang Automobile Freight Rate Rule* issued by the Department of Transportation of Heilongjiang Province (DTHP 2020), *Railway Freight Rate Rule* of railway service and freight rate table (DTHP 2020), we set freight rate of railway as 0.16 yuan/t·km, and freight rate of highway as 0.4 yuan/t·km.

We assume that the transfer time and cost of each transfer station are the same, and each station meets the transport mode conversion requirements. The specific data is shown in Table 5.

4.3.3. Transportation speed

In this study, highway transport speed refers to the speed with the first level highway design standard, and railway transport speed refers to the speed of CR Express. In regards of time window restriction and current freight situ-

Table 4. The volume of freight transported to Harbin container center station on Harbin – Europe Railway Express in 2020

City		Freight volume on Harbin – Europe Railway Express [t]
Yichun		317.48
Hegang		445.74
Jiamusi		1937.71
Shuangyashan		364.42
Qitaihe		384.75
Jixi		1112.73
Mudanjiang		1732.41
Suihua	Zhaodong	1014.20
	hailun	302.68
	Suiling county	189.91
	Qinggang county	141.30
	Qingan county	215.29
	Lanxi county	144.69
	Wangkui county	179.51
Daqing	Zhaozhou county	136.06
	Zhaoyuan county	43.04
Songyuan	Fuyu	458.06
Changchun	Yushu	198.25

Table 5. Average transfer costs and time of different transportation modes

Cost (time) [yuan/h]	Highway	Railway
Highway	0	50 (1)
Railway	50 (1)	0

ations, highway transport speed ranges of 60…100 km/h, while railway transport speed ranges of 80…120 km/h. Therefore, we take the highway transport speed as 60 km/h, railway transport as 100…80 km/h respectively for calculation.

4.4. Calculation and analysis

In this example, we take the average daily freight volume shown in Table A4 in the Appendix as freight volume of each city in attraction area, and hard time window for transport is set as [0.5, 8]. According to freight organization optimization model in Section 3, we use LINGO (*https://www.lindo.com/index.php/products/lingo-and-optimization-modeling*) to work out the results. The logistics organization scheme is shown in Tables 6–8. Calculation results based on highway transport speed at 60 km/h and railway transport speed at 100 km/h are shown in Table 6. Moreover, calculation results of highway transport speed at 60 km/h and railway transport speed at 80 km/h are shown in Table 7.

Table 6. Transportation modes and costs of railway container terminal of every city in attraction area

City		Transportation mode	Transportation cost [yuan]
Yichun		railway	39138.93
Hegang		railway	63509.04
Jiamusi		railway	255002.60
Shaungyashan		railway	52389.02
Qitaihe		railway	55373.22
Jixi		railway	153378.70
Mudanjiang		railway	185021.40
Suihua	Zhaodong	railway	60933.14
	Hailun	railway	26127.34
	Suiling county	railway	15207.99
	Qinggang county	highway	6861.53
	Qingan county	railway	16930.41
	Lanxi county	highway	3981.87
	Wangkui county	highway	12515.44
Daqing	Zhaozhou county	highway	3379.73
	Zhaoyuan county	highway	3592.98
Songyuan	Fuyu	railway	30378.54
Changchun	Yushu	railway	18794.10

Table 7. Transport modes and costs of railway container terminal of each city in attraction area

City		Transport mode	Transport cost [yuan]
Yichun		railway	39138.93
Hegang		highway	79377.38
Jiamusi		railway	255002.60
Shaungyashan		highway	66120.36
Qitaihe		highway	65930.76
Jixi		railway	153378.70
Mudanjiang		railway	185021.40
Suihua	Zhaodong	highway	25192.73
	Hailun	highway	25267.73
	Suiling county	highway	14942.12
	Qinggang county	highway	6861.53
	Qingan county	highway	14045.52
	Lanxi county	highway	3981.87
	Wangkui county	highway	12515.44
Daqing	Zhaozhou county	highway	3379.73
	Zhaoyuan county	highway	3592.98
Songyuan	Fuyu	railway	30378.54
changchun	Yushu	highway	9627.02

Table 8. Freight turnover and proportion at different speed

Highway speed 60 km/h, railway speed 100 km/h					Highway speed 60 km/h, railway speed 80 km/h				
City		Transportation mode	Freight turnover [t·km]		City		Transportation mode	Freight turnover [t·km]	
Yichun		railway	145405.8		Yichun		railway	145405.8	
Hegang		railway	257637.7		Hegang		highway	198443.4	
Jiamusi		railway	988232.1		Jiamusi		railway	988232.1	
Shaungyashan		railway	213550.1		Shaungyashan		highway	165300.9	
Qitaihe		railway	225848.3		Qitaihe		highway	164826.9	
Jixi		railway	610888.8		Jixi		railway	610888.8	
Mudanjiang		railway	615005.6		Mudanjiang		railway	615005.6	
Suihua	Zhaodong	railway	63894.6		Suihua	Zhaodong	highway	62981.82	
	Hailun	railway	68708.36			Hailun	highway	63169.32	
	Suiling county	railway	35703.08			Suiling county	highway	37355.3	
	Qinggang county	highway	17153.82			Qinggang county	highway	17153.82	
	Qingan county	railway	35113.8			Qingan county	highway	35113.8	
	Lanxi county	highway	9954.672			Lanxi county	highway	9954.672	
	Wangkui county	highway	31288.59			Wangkui county	highway	31288.59	
Daqing	Zhaozhou county	highway	8449.326		Daqing	Zhaozhou county	highway	8449.326	
	Zhaoyuan county	highway	8982.448			Zhaoyuan county	highway	8982.448	
Songyuan	Fuyu	railway	46722.12		Songyuan	Fuyu	railway	46722.12	
Changchun	Yushu	railway	55510		Changchun	Yushu	highway	24067.55	
Railway turnover and proportion			3327107	97%	Railway turnover and proportion			2406254	74.42%
Highway turnover and proportion			110942.7	3%	Highway turnover and proportion			827088	25.58%
Total freight turnover			3438049		Total freight turnover			3233342	

It can be seen from Table 6 that railway is the transportation mode of cities where transport distance is above 300 km, such as Yichun, Hegang and Jiamusi, while cities where transport distance is below 200 km, such as Hailun and Suiling, choose transport mode mainly depending on the freight volume. Although transport distance of Zhaodong (in Suihua) is relatively short, freight volume is relatively in large scale, so it chooses railway. As for Zhaoyuan (in Daqing), transport distance is short, but its freight volume is small, so the transport mode is highway.

From Table 7, it can be seen that proportion of railway transportation decreases, which indicates that increase of railway speed has an obvious effect on the share of railway freight in freight market.

According to freight volume shown in Table 4 and highway and railway distance from each city in the attraction area to Harbin shown in Table A3 in Appendix, we can easily figure out freight turnover at different speeds of railway freight, as it's shown in Table 8. Moreover, comparison of freight turnover between railway and highway under different transport speed is shown in Figure 5.

When railway transportation speed is 80 km/h, the number of cities that transport freight by railway is 5, accounting for 28%, and freight turnover is 2406254 tons, accounting for 74.42% of total freight turnover.

When railway transportation speed is 100 km/h, the number of cities that transport freight by railway is 13, accounting for 72%, and freight turnover is 3327107 tons, accounting for 97% of total freight turnover.

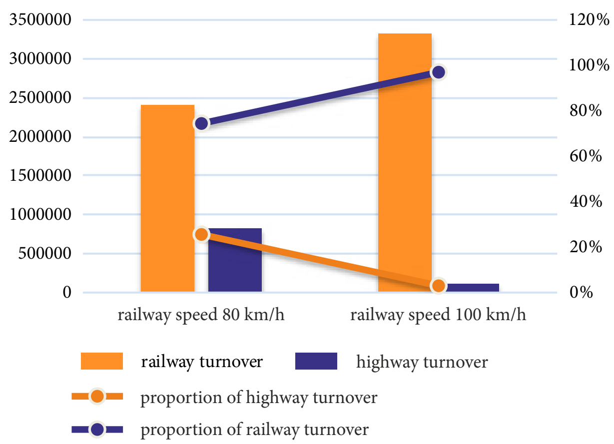

Figure 5. Comparison chart of freight turnover between railway and highway under different transport speed

It can be seen that highway transport still dominates the market of short distance and less volume transport, while in long distance and larger volume transport, total transport cost of railway is still less than that of highway. From perspective of freight volume, railway undertakes more freight volume than highway transportation. Meanwhile, through comparative analysis, it is found that speed is the key to affecting freight volume of railway transportation, which means that increasing the speed of railway transportation has a significant effect on enhancing railway freight volume. Therefore, it is necessary to further improve the construction of railway stations and other infrastructure, and increase the speed of freight trains. Government should also take measures to improve China's comprehensive transport system and promote the rational and rapid development of CR Express.

Conclusions

This paper aims at solving the problems of attraction zone division and logistics organization optimization for container terminal of land freight express. Firstly, based on the interaction between the carrier city and surrounding cities, gravity model, break-point model and weighted-Voronoi-diagram were used to determine the attraction area and attraction proportion of the carrier city. Secondly, on the basis of final attraction area divided by the railway container terminal, considering the limitation of hard time window and limited transportation capacity, a 0–1 planning model was established to minimize the total transportation cost, and LINGO was used to figure out this model. Finally, the feasibility and effectiveness of the above method and model were verified by taking Harbin railway container terminal as an example.

According to the current situation analysis of CR Express and results of the attraction area division, due to the normal operation and future sustainable development of CR Express, government cannot break the boundary of attraction areas of stations by financial subsidies. In the process of freight organization, government should make policies that encourage consigner to choose railway transportation from management aspect. In addition, government should gradually abandon relevant subsidy policies and rationalize station attraction areas on CR Express, so as to reduce the waste of transport resources and stabilize the transport market of CR Express.

On the basis of analysis results of attraction area division and freight organization optimization, feeder transportation service should choose reasonable transportation mode within attraction area, taking full advantages of various transportation modes, reducing cost and improving transportation efficiency.

In freight organization optimization, comparative analysis shows that influence of railway speed is the main factor of determining the proportion of railway transport in freight market, and improvement of railway speed has obvious effect on increasing freight volume of railway transportation. Therefore, in the freight organization process on CR Express, improvement of feeder transportation speed is an effective means to improve freight volume, increase railway revenue and realize sustainable development of CR Express.

However, method of this study still has some limitations. We only divide attraction area from macro perspective, without considering the influence of specific layout on the station and operation scheme. When we construct the freight organization optimization model, dynamic uncertainties such as weather and road conditions are not taken into account. In addition, it is necessary to carry out in-depth research.

Acknowledgements

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Appendix

Table A1. The mileage between Harbin and other cities in the northeast economic zone

No	City	Distance [km]
1	Shenyang	561.1
2	Dalian	946.4
3	Changchun	271.7
4	Jilin	355.9
5	Anshan	670.1
6	Daqing	153.3
7	Chifeng	861.1
8	Yingkou	748.3
9	Qiqihar	308.3
10	Qinhuangdao	961.9
11	Jinzhou	780.7
12	Fushun	586.8
13	Tongliao	522.3
14	Hulunbuir	751.9
15	Liaoyang	642.9
16	Benxi	606
17	Songyuan	196.7
18	Tonghua	539.8
19	Huludao	826.8
20	Siping	389.5
21	Mudanjiang	335.4
22	Dandong	811.2
23	Chaoyang	772.7
24	Huihua	112.5
25	Panjin	724.4
26	Liaoyuan	389.8
27	Tieling	506.1
28	Baishan	571.6
29	Baicheng	398.1
30	Fuxin	649.1
31	Jiamusi	381
32	Qitaihe	428.4
33	Shaungyashan	453.6
34	Jixi	478.4
35	Hegang	445.2
36	Yichun	323
37	Heihe	495

Note: data source – China Railway Harbin Group Co., Ltd. (CR 2019).

Table A2. Economic connection intensity between Harbin and other cities and cumulative percentage

No	City	Economic connection intensity F_{1k}	Cumulative percentage [%]	No	City	Economic connection intensity F_{1k}	Cumulative percentage [%]
1	Suihua	432.36	21.72	20	Baishan	23.34	89.05
2	Daqing	282.41	35.90	21	Tonghua	22.95	90.20
3	Songyuan	195.57	45.72	22	Tieling	21.44	91.28
4	Changchun	142.25	52.87	23	Benxi	17.19	92.14
5	Jilin	130.39	59.42	24	Anshan	15.90	92.94
6	Mudanjiang	64.49	62.66	25	Liaoyang	14.87	93.69
7	Qiqihar	63.02	65.82	26	Fuxin	12.89	94.33
8	Baichng	46.79	68.17	27	HulunBuir	11.91	94.93
9	Jiamusi	44.54	70.41	28	Heihe	11.59	95.51
10	Fushun	41.24	72.48	29	Yingkou	11.49	96.09
11	Siping	40.59	74.52	30	Dalian	11.09	96.65
12	Liaoyuan	38.11	76.43	31	Panjin	10.88	97.20
13	Yichun	37.43	78.31	32	Jinzhou	10.44	97.72
14	Shenyang	36.30	80.13	33	Dandong	10.34	98.24
15	Qitaihe	34.03	81.84	34	Chaoyang	9.79	98.73
16	Shuangyashan	31.47	83.42	35	Chifeng	9.63	99.21
17	Jixi	31.01	84.98	36	Huludao	8.76	99.65
18	Hegang	29.24	86.45	37	Qinhuangdao	6.89	100.00
19	Tongliao	28.40	87.88	Total external economic connection intensity of Harbin $F_1 = 1990.998285$			

Table A3. The railway and highway distance from each city in attraction area to Harbin [km]

City / Mode of transportation	Yichun	Hegang	Jiamusi	Shaungyashan	Qitaihe	Jixi	Mudanjiang
Highway	323	445.2	381	453.6	428.4	478.4	335.4
Railway	458	578	510	586	587	549	355
City	Suihua						
Mode of transportation	Zhaodong	Hailun	Suiling county	Qinggang county	Qingan county	Lanxi county	Wangkui county
Highway	62.1	208.7	196.7	121.4	163.1	68.8	174.3
Railway	63	227	188	–	179	–	–
City	Daqing		Songyuan	Changchun	–	–	–
Mode of transportation	Zhaozhoucouty	Zhaoyuan county	Fuyu	Yushu	–	–	–
Highway	62.1	208.7	196.7	121.4	–	–	–
Railway	–	–	102	280	–	–	–

Note: "–" means no railway between the two cities.

Table A4. Freight volume statistics of each city in attraction area to Harbin

City		Annual freight volume [10^4 t]	Average daily freight volume [10^4 t]	Attraction rate [%]	Average daily freight volume to Harbin [t]
Yichun		868	2.38	1.88	447.07
Hegang		1560	4.27	1.47	627.68
Jiamusi		4452	12.20	2.24	2728.61
Shaungyashan		1185	3.25	1.58	513.16
Qitaihe		1157	3.17	1.71	541.79
Jixi		3672	10.06	1.56	1566.90
Mudanjiang		2749	7.53	3.24	2439.51
Suihua	Zhaodong	240	0.66	21.72	1428.16
	Hailun	72	0.20	21.72	426.22
	Suiling county	45	0.12	21.72	267.42
	Qinggang county	33	0.09	21.72	198.97
	Qingan county	51	0.14	21.72	303.16
	Lanxi county	34	0.09	21.72	203.75
	Wangkui county	42	0.12	21.72	252.78
Daqing	Zhaozhou county	49	0.14	14.18	191.60
	Zhaoyuan county	16	0.04	14.18	60.61
Songyuan	Fuyu	240	0.66	9.82	645.02
Changchun	Yushu	143	0.39	7.14	279.17

Note: data source – China Statistical Yearbook 2016 (CSP 2016).

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