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Research Article

Location Selection of Chinese Modern Railway Logistics Center Based on DEA-Bi-level Programming Model

Fenling Feng, Feiran Li and Qingya Zhang
School of Traffic and Transportation Engineering, Central South University,
Changsha, 410075, China

Abstract: Properly planning the modern railway logistics center is a necessary step for the railway logistics operation, which can effectively improve the railway freight service for a seamless connection between the internal and external logistic nodes. The study, from the medium level and depending on the existing railway freight stations with the railway logistics node city, focuses on the site-selection of modern railway logistics center to realize organic combination between newly built railway logistics center and existing resources. Considering the special features of modern railway logistics center, the study makes pre-selection of the existing freight stations with the DEA assessment model to get the alternative plan. And further builds a Bi-level plan model with the gross construction costs and total client expenses minimized. Finally, the example shows that the hybrid optimization algorithm combined with GA, TA, SA can solve the Bi-level programming which is a NP-hard problem and get the railway logistics center number and distribution. The result proves that our method has profound realistic significance to the development of China railway logistics.

Keywords: Bi-level programming, DEA, location problem, modern railway logistics center

INTRODUCTION

According to China Ministry of Railways "Twelfth Five-Year Plan" of "Logistics Adjustment and Revitalization Planning", China will build a national, regional and local railway logistics nodes network in future five years and accelerate the railway comprehensive logistics center planning and construction work in railway logistics nodes. Rational utilization and transformation of the traditional railway freight station is the key of planning the construction of railway logistics center. And the location problem of railway logistics center is the foundation of develop modern railway logistics center. A proper location method can make full use of existing resources, can realize the seamless connection among location center, marshalling station, freight station, railway logistics enterprise and also can give better modern logistics service to customers.

Many scholars both domestic and foreign have studied the location problem of logistics center and they determined many models like continuous model location model (Antonio *et al*., 2009; Li and Ouyang, 2010; Mounir *et al*., 2011; Jean-sébastien *et al*., 2012; Julia and Uwe, 2011) discrete location mode (Kenneth *et al*., 2012; Shahin and Stefan, 2011; Limbourg and Jourquin, 2009; Zhu *et al*., 2010; Chou, 2010; Liao, 2009) and the comprehensive factors of location model (Liu *et al*., 2009; Wang and Zhang, 2011; Anna *et al*., 2012; Husheng and Xiaoyan, 2011; Lucio *et al*., 2009; Manish *et al*., 2012; Zhou *et al*., 2011). Most of the scholars use one method of tradition or improved location model to let the decision maker's maximum benefit as the ultimate goal, which can not reflect the importance of customers demand in modern logistics development. At the same time, the method they chose cannot solve cases with a large number of optional sites effectively.

The China Ministry of Railways "Twelfth Five-Year Plan" brought up the operation thought of developing the railway transportation market vigorously, extending the chain of rail transport services industry and accelerating the development of railway logistics. According to the operation thought, the study using DEA model and the Bi-level programming model together to construct the location model, which rely on the existing freight station of railway logistics nodes. The study using DEA model to consider a variety of railway freight station index factors and using the qualitative judgment and quantitative analysis combined. To select the DEA - effective railway freight station as options, this method can simplify the work site and narrow research scope. At the same time, the Bi-level programming model is capable of analysis decision makers and customers simultaneously, which are the two in the interests of

Corresponding Author: Fen-ling FENG, School of Traffic and Transportation Engineering, Central South University, Changsha, 410075, China

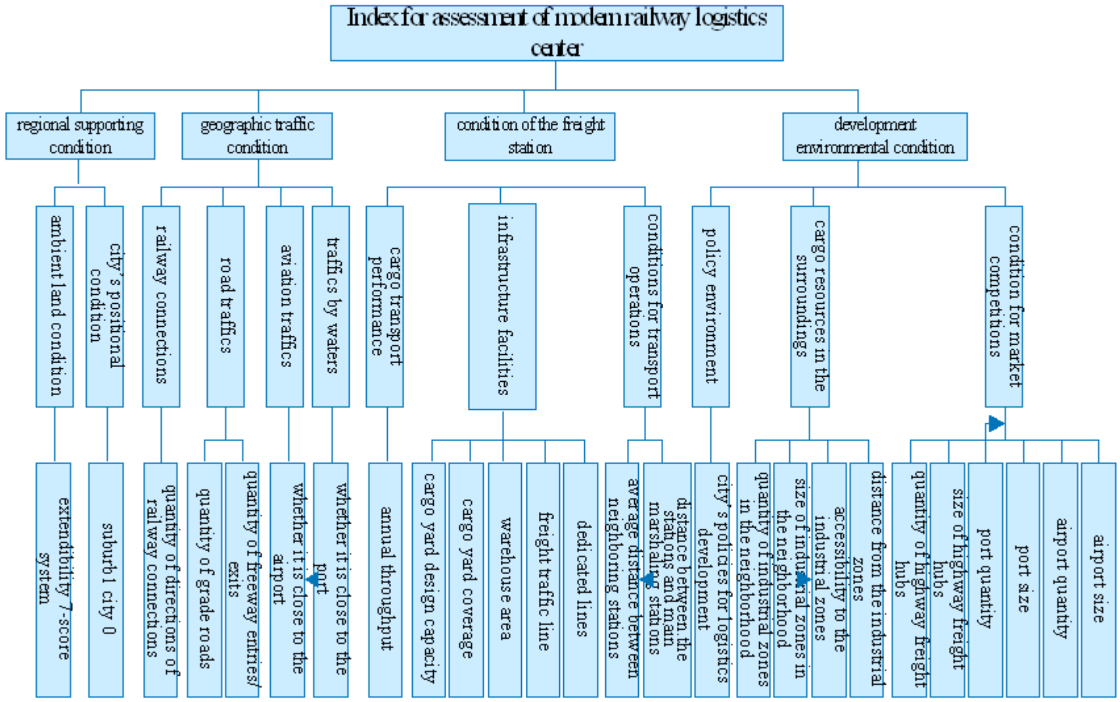

Fig. 1: Structural chart for index system for assessment of modern railway logistics center site- selection plan

confliction object. The objective function of Bi-level programming model can realize maximum benefits in.both of them. The study using Bi-level programming model solve the location problem at last, in the model, minimum modern railway logistics center construction cost is the goal of the upper model and minimum customers cost is the goal of the lower model. And to solve the example through the hybrid optimization algorithm can finally obtains the precise modern railway logistics center quantity and spatial distribution in the research area.

RAILWAY LOGISTICS CENTER DEA MODEL

Design of index system: The study takes into consideration the influences of different factors influencing the initial selection of modern railway logistics canter based on the available data. Based on the practical researches, indexes that influence the location of modern railway logistics centre are determined, including the supporting system and geographic transport condition, the operational condition of freight station and development and environmental condition (26 indexes for 12 items). This is given as in Fig. 1.

DEA model: Data Envelopment Analysis (DEA) was created by Chames and Cooper in 1978. It is a systematic analysis mode for comparative assessment of the comparative operation efficiency of the Decision Making Units' multiple inputs and outputs. The most widely applied is C^2R, which takes into consideration the technology efficiency and scale efficiency during the decision-making process.

The model is expressed as below:

Suppose there are n DMU, each having m inputs and s outputs, the input variable X_j and output variable Y_j of No.j DMU_j are:

$$X_j=(x_{1j},x_{2j},\ldots,x_{mj})\geq 0; j=1,2,\ldots,n \tag{1}$$

$$Y_j=(y_{1j},y_{2j},\ldots,y_{rj})\geq 0; j=1,2,\ldots,n \tag{2}$$

x_{ij} is the No. i input index for DMU_j (cost variable), the smaller the better. y_{rj} is the No. r output index for DMU_j (efficiency variable), the bigger the better ($j=1,2,\ldots,n$; $i=1,2,\ldots,m$; $r=1,2,\ldots,s$).

$v=(v_1,v_2,\ldots,v_m)^T$, $u=(u_1,u_2,\ldots,u_m)^T$ is used to indicate the weight variable of input and output. The components of input and output variables of different roles and positions are summed up, each having a proper weight.

Suppose h_j is the efficiency assessment index, used to assess the relative efficiency degree of varied DMU. It is expressed as:

$$h_j=\sum_{r=1}^{s}u_r y_{rj}\Big/\sum_{i=1}^{m}v_i x_{ij}, \quad j = 1, 2, \ldots, n \tag{3}$$

C^2R model for No. j_0 $DMU_{j0}(j_0=1,2,\ldots n)$ is:

$$\max h_{j0}=\sum_{r=1}^{s}u_r y_{rj0}\Big/\sum_{i=1}^{m}v_i x_{ij0} \tag{4}$$

subject to:

$$\sum_{r=1}^{s} u_r y_{rj} \Big/ \sum_{i=1}^{m} v_i x_{ij} \le 1,\ j = 1,2,\ldots,n\ ,\ u \ge 0, v \ge 0 \quad (5)$$

With the Charnes-Cooper switch, the model is turned into an equivalent linear planning issue. Suppose:

$$t = 1 \big/ v^T X_{j0}\ ,\ \omega = tv\ ,\ \mu = tu \quad (6)$$

Then the C^2R model with a fraction form is turned into:

$$\max \mu^T Y_{j0} = h_{j0} \quad (7)$$

subject to

$$\omega^T X_j - \mu^T Y_j \le 0, j = 1, 2, \ldots, n \quad (8)$$

$$\omega^T X_{j0} = 1 \quad (9)$$

$$\omega \ge 0, \mu \ge 0 \quad (10)$$

Add the slack variable S^- and surplus variable S^+, the dual programming of linear planning is:

$$\max \theta \quad (11)$$

subject to:

$$\sum_{j=1}^{n} X_j \lambda_j + S^- = \theta x_{j0} \quad (12)$$

$$\sum_{j=1}^{n} Y_j \lambda_j - S^+{}_{Y_{j0}} \quad (13)$$

$$\lambda_j \ge 0, j = 1,2,\ldots,n, S^- \ge 0, S^+ \ge 0$$

One index (annual throughput and gross output of the origin of cargo resources) of the selected railway freight station (yri, r = 1) are used as the output index for DEA model and other 25 indexes (xij, i = 1, 2,…, 25) as the output indexes. Input the indexes into the linear planning model DC2R and solve it, to judge the effects of DMUj:

In the optimal solution, when θj0 = 1, S- = S+ = 0, DMUj0 is explained as DEA-effective, which means expanding Fj0 in the network system as composed of n DMU and thus the output Yj0 obtained on the basis of input Xj0 will be an optimized result;

In the optimal solution, when θj0 = 1 and S- ≠ 0 or S+ ≠ 0, DMUj0 is explained as DEA-weakly effective.

Through the first-phase DEA assessment and analysis, effective candidate freight stations are selected out from multiple railway freight stations and further effective candidate freight stations are analysed in the Bi-level programming model to obtain the optimal plan for site-selection.

RAILWAY LOGISTICS CENTER BI-LEVEL PROGRAMMING MODEL

Bi-level programming model is a mathematic model for description of leader-follower and for systematic optimization of two-story structure. The scholars from home and abroad have been familiar with the Bi-level programming model and have applied it in multiple industries. For the site-selection of modern railway logistics center, the railway logistics center's management is the Leader and the customers' demands for freight service are Follower. The modern railway logistics center may adjust the charges of railway freight services by pricing and service qualities, to attract more customers to select the railway transport service. It is described with the Bi-level programming model.

Upper model: Upper model is described as the railway freight company (the decision-making unit) decides the best location of modern railway logistics center within the permissible fixed scope and on the premise of guaranteeing the minimization of gross construction costs. Suppose the quantity of existing logistics zones/logistics center is l, the quantity of candidate railway freight station (initial plan obtained by DEA model) is n, expressed as j; the quantity of origin of cargo resources is h; the number of customers is m; the selectable logistics center is r. The model is expressed as:

$$\min f = \sum_{j=1}^{n} W_j Z_j + \lambda \sum_{j=1}^{n}\sum_{i=1}^{h} x_{ij} - \lambda \sum_{j=1}^{n} (Q_j + Y_j) Z_j + \theta \sum_{j=1}^{n}\sum_{i=1}^{h} s_{ij} x_{ij} \quad (15)$$

subject to:

$$\sum_{i=1}^{m} x_{ij} \le P_j, i = 1,2,\ldots,m\ ;\ j = 1,2,\ldots,n \quad (16)$$

$$\sum_{i=1}^{m}\sum_{j=1}^{n} x_{ij} - \sum_{j=1}^{n} (Q_j + Y_j) Z_j \ge 0, i = 1,2,\ldots,m\ ;\ j = 1,2,\ldots,n \quad (17)$$

$$\sum_{i=1}^{m} Z_j \le g, j = 1,2,\ldots,n \quad (18)$$

$$Z_{ij} \in \{0,1\}\ ;\ x_{ij} \ge 0 \quad (19)$$

In the formula:

- m = Number of origins of cargo resources in the neighborhood of modern railway logistics center
- n = Number of candidate sites of modern railway logistics center
- W_j = Expenses for renovation of modern railway logistics center in the candidate site j, minimum investment expenses selected (RMB,Yuan)

Z_j = 0-1 variable, 1 when the modern railway logistics center is to be planned and constructed at the candidate site j, o otherwise
λ = Expenses for the expansion of railway freight station for unit operation capacity
x_{ij} = Origin of cargo resource, annual throughput at the candidate site j (ton)
Q = Available operation capacity of the candidate freight station j (ton/year)
Y_j = To expand, the increased basic operation capacity at the candidate freight station j is to be calculated by the minimum designed operation capacity (ton/year)
θ = Transport expense coefficient of the unit mileage (ton/km) in the road transport
s_{ir} = Distance (km) between origin of cargo resource j to candidate site r (including the candidate site and existing logistics site)
P_j = Upper limit for designed capacity (10,000 ton) at the candidate freight station j
g = Upper limit for the quantity of modern railway logistics center

$\sum_{j=1}^{n} W_j Z_j$ = Expenses for renovation of the candidate freight station into a modern railway logistics center
$\lambda \sum_{j=1}^{n} \sum_{i=1}^{m} x_{ij}$ = To meet the customer demands, expenses for expansion of the operation scale at the candidate freight station *j*
$\lambda \sum_{j=1}^{n} (Q_j + Y_j)\, Z_j$ = Expenses saved after expansion of the candidate freight station into a modern railway logistics center
$\theta \sum_{j=1}^{n} \sum_{i=1}^{m} s_{ij} x_{ij}$ = Expenses for short-distance road transport for delivering the goods from origin of cargo resources to the modern railway logistics center Restrictive conditions are:

- Sixteen (16) guarantees the gross operation capacity of candidate freight station will not exceed the upper limit of the planned operation capacity
- Seveenteen (17) guarantees the basic operation capacity of selected railway freight station will be full exploited
- Eighteen (18) specifies the upper limit for the constructions of modern railway logistics center In addition, x_{ij} in U is obtained from L

Lower model: As not all the customer demands can be satisfied with one railway logistics center, it will have to deal with the competitions from existing logistics centres, logistics zones and distribution centers in the city. In the lower model, to guarantee the customer's expenses are minimized when selecting the logistics center, the lower-layer problem can be expressed as:

$$\min T = \sum_{i=1}^{m} \sum_{r=1}^{n+l} x_{ir} y_{ir} \qquad (20)$$

subject to:

$$\sum_{r=1}^{n+l} x_{ir} = d_i, i = 1, 2, \ldots, m\ ;\ r = 1, 2, \ldots, n+l \qquad (21)$$

$$\sum_{i=1}^{m} x_{ir} \le v_r, r = 1, 2, \ldots, n+l \qquad (22)$$

$$MZ_j - x_{ij} \ge 0, i = 1, 2, \ldots, m; j = 1, 2, \ldots, n \qquad (23)$$

$$x_{ir} \ge 0 \qquad (24)$$

In the formula:
x_{ir} = Satisfying the customer's demands for logistics at selected site *r*(including the modern railway logistics center to be planned and existing logistics center)
y_{ir} = The unit service charges to be paid by customer *i* for the selected logistics center *r*
d_i = Customer *i*'s demands for logistics service
v_r = Upper limit for the logistics center *r*'s operation capacity
M = The value close to infinite
Zj = 0-1variable, 1 when the modern railway logistics center is to be planned and constructed at the candidate site j, 0 otherwise

Restrictive conditions are:

- Twenty one (21) Guarantees all user demands will be satisfied
- Twenty two (22) Gross user demands for logistics services will not exceed the upper limit of the operation capacity of some logistics center
- Twenty three (23) Guarantees the candidate freight station having been allocated the cargo carrying volume must plan and construct modern railway logistics center

EXAMPLE ANALYSES

DEA model pre-selection: Suppose there are 20 railway freight centers in a city, 26 DEA index values are given. With the below-mentioned mode, solve it with MATLAB software. The assessment results are given as in Table 1.

In the calculation result, the θ value of freight stations B_1, B_2, B_3, B_5, B_6, B_7, B_9, B_{10}, B_{11}, B_{12}, B_{17}, B_{19} is 1 and $S^- = S^+ = 0$, therefore the decision-making units of the 12 freight stations are DEA-effective and being the candidates for pre-selection.

According to existing data, firstly we found that the 12 railway freight station solved by DEA model is in line with Chinese logistics development policy. They have good land expansion, which is suitable for expansion into railway logistics centers. Secondly, the stations are seamless connection with highways, ports and airports, which is more conductive to develop railway logistics multimodal transport. Finally, the goods yards of the stations have high operational capability and they also have perfect infrastructure equipment, which can save the cost of rebuilding the railway logistics centers. In a word, the indexes of this 12 freight stations are superior to other stations and they can be used as a primary plan.

Solution with Bi-level programming model: Analyze the 12 candidate freight stations (Bj)after pre-selection of DEA assessment model and make second selection with the above-given Bi-level programming model origins of cargo resources (Hi)); In addition to the 12 candidate cargo freight stations, the customer may also select from other four logistics centers (Ll)in the region. Data about the Bi-level programming model is indicated in Table 2 Upper-layer planning model (genetic, taboo searches, analogue annealing, GTSA)

Table 1: DEA assessment result of candidate railway freight station

Candidate railway freight station	Score θ	Candidate railway freight station	Scoreθ
B_1	1	B_{11}	1
B_2	1	B_{12}	1
B_3	1	B_{13}	0.8292
B_4	0.7233	B_{14}	0.7905
B_5	1	B_{15}	0.9437
B_6	1	B_{16}	0.9263
B_7	1	B_{17}	1
B_8	0.9500	B_{18}	0.9573
B_9	1	B_{19}	1
B_{10}	1	B_{20}	0.7801

is solved with mix optimization algorithm. Set the initial parameter:SA initial temperature T_0 = 2000, end temperature T_f= 0.9, co-efficient of temperature drop A, bi-valve value F_1 = 5000, F_2 = 10000, maximum

Table 2: Upper planning model data

Optional site	B_1	B_2	B_3	B_5	B_6	B_7
Minimum investments(RMB10^8 Yuan)	12.1	12.2	8.3	9.9	11.4	16.3
Expenses for expansion of unit operation capacity (RMB10^8/10^4 tons)	0.061	0.041	0.017	0.033	0.023	0.033
Existing operation capa- city(10^4tons)	376	377	428	168	262	89
Increased basic operation capaCity(10^4tons)	500	450	200	300	450	500
Unit road transPortexpenses(ton/kilometer)	0.75	0.75	0.75	0.75	0.75	0.75
Upper limit for planning capacity(10^4 tons)	1200	1100	800	700	1000	700
Optional site	B_9	B_{10}	B_{11}	B_{12}	B_{17}	B_{19}
Minimum investments (RMB10^8 Yuan)	14.8	9.6	22.5	16.9	17.5	18.7
Expenses for expansion of unit operation capacity (RMB10^8/10^4 tons)	0.037	0.021	0.050	0.031	0.039	0.037
Existing operation capa- City(10^4tons)	253	200	39	119	202	67
Increased basic operation capacity (10^4tons)	400	450	500	550	510	300
Unit road transPortexpenses(ton/kilometer)	0.75	0.75	0.75	0.75	0.75	0.75
Upper limit for planning capacity(10^4 tons)	800	700	600	800	1000	500

Table 3: Solution with mix optimal algorithm

Site-selection result	Origin of cargo resources attracted	Cargo attracted (104 tons)	Relevant freight station	cargo volume ratio
B_1	H_2, H_6, H_8, H_9	993	B_{10},B_{11},B_{19}	23.35%
B_2	H_1, H_7, H	911	B_3,B_5,B_7,B_{17}	21.42%
B_9	H_4, H_{15}	697	B_6,B_{12}	16.39%

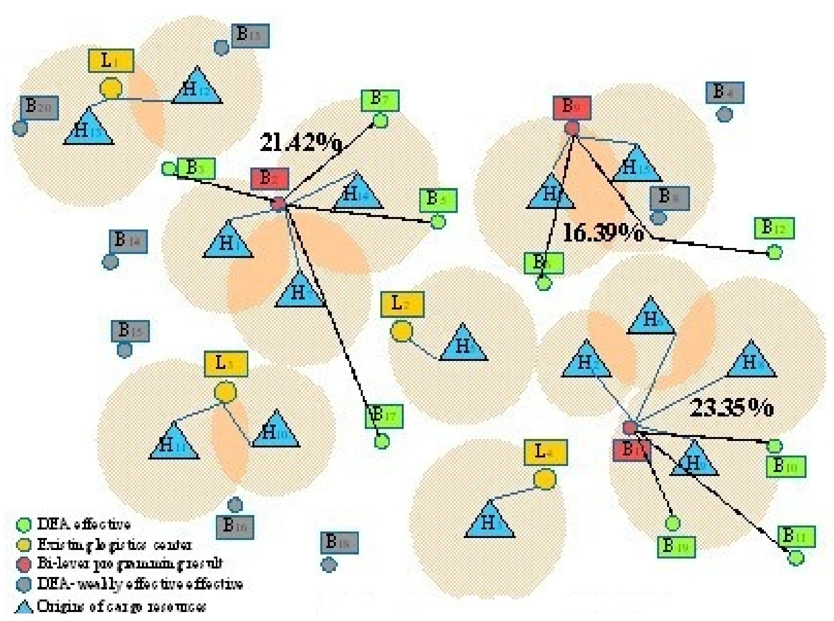

Fig. 2: Model of solution with mix optimal algorithm

iteration of inner circle T_{max} = 10000; GA's population size N_{pop} = 50, cross rate P_c=0.9, mutation rate P_m = 0.05; TS's taboo list length T_{max} = 4, maximum neighborhood quantity S_{max} = 5. The solution results are given as in Table 3 and Fig. 2.

According to the solving result:

- The site location is B_1, B_2 and B_9, When B_1 supply services to the origin of cargo resource H_2, H_6, H_8 and H_9. B_2 supply services to the origin of cargo resource H_1, H_7, H_{14}. B_9 supply services to the origin of cargo resource H_4, H_{15}.
- B1, B10, B11and B19 has similar origin of cargo resources attracted.B2, B3, B5, B7, B17 has similar origin of cargo resources attracted. And B9, B6, B12 has similar origin of cargo resources attracted. These three origins of cargo resources attracted can rely on B1, B2 and B9 to construct railway logistics centres andthe completed centres can separately deal with 23.23, 21.42 and 16.39%, respectively of the total cargo volume. Thus the three centres can deal with 61.16% of total cargo volume. The remaining cargo will be completed by the existing logistics centre L1, L2, L3, L4.
- B_1, B_2, B_9 has a reasonable reconstruction investment cost and they also have good basic operation abilities. At the same time, B_1,B_2,B_9 has several origins of cargo resources attracted with reasonable distance separately, which can concentrate railway transport capacity to deal with the regional 61.16% cargo volume and make the regional railway development tends centralized and logistics. It is worth to mentioning that, we considered the existing large-scale logistics centre by respecting the actual situation, which can achieve two of them integrated closely and to complete the regional cargo transport together.

CONCLUSION

DEA comprehensive assessment model and Bi-lever programming model combined together to analyze the location problem of modern railway logistics center in China railway logistics nodes, can avoid the single and one-sidedness for the current location problem solving method. And the method can provide the accurate and efficient distribution plan, also it can realize both minimum railway logistics cost and minimum customers cost, which reflects the importance of customer in for the development of modern logistics. Furthermore, the example shows that a hybrid optimization algorithm combined with GA, TA and SA can solve the NP-hard Bi-level programming model.

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