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Optimization Research on Rail Freight Station Layout According to Situation Development

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Abstract: With the development of railway freight station, there must be some optimization problems of resources allocation under different situations. Different layout optimization objectives which aimed at minimizing the total cost based on the different situations are put forward under the constraints of freight demand, capacity of rail freight station and scale of the whole station. SoftwareILOG is used to solve this mixed integrate programming model. This study showed that the optimization ideas and method of this study can provide basis for decision making of freight station optimization problem.

Key words: Rail freight station, optimization layout, logistic center,integration

INTRODUCTION

Nowadays, the model of rail freight station is basically formed. Since the Two Integrated Strategy (integration of stations with small quantity, private lines and less-than-carload goods business) was put forward in 2006, the emphasis has been transferred to the important station to structure a large logistic center. Considering the different patterns illustrated above, the study built different optimization models due to various situations. There are many research literatures related to railway hub and layout optimization of stations. Related studies on railway hub selection and the technical station layout included (Alumur and Kara 2008; Assad 1980; Ahuja *et al.*, 2005; Lin and Xu 2002; Shi and Fang 2003; Li and He 2011; Yang and Wang 2011; Wang *et al.*, 2013) studied on the objective of different stations layout. Based on the previous researches, a new model to optimize the rail freight stations is presented due to its development characteristics. ILOG software is used to confirm the model and an example is given to show the effectiveness of this model.

MIXED INTERGRATE PROGRAMMING OPTIMIZATION MODEL

Rail freight station started from scratch and changed its development focus continuously because of the service requirement. There are different objectives and constraints on developed situations when building models. The study built models according to its main developed focus.

Situation 1: optimizationof station selection. Considering the current rail stations' layout has been basically formed, the emphasis is focused on optimizing the integration of existing stations construction. The content of the optimal selection is slightly skipped.

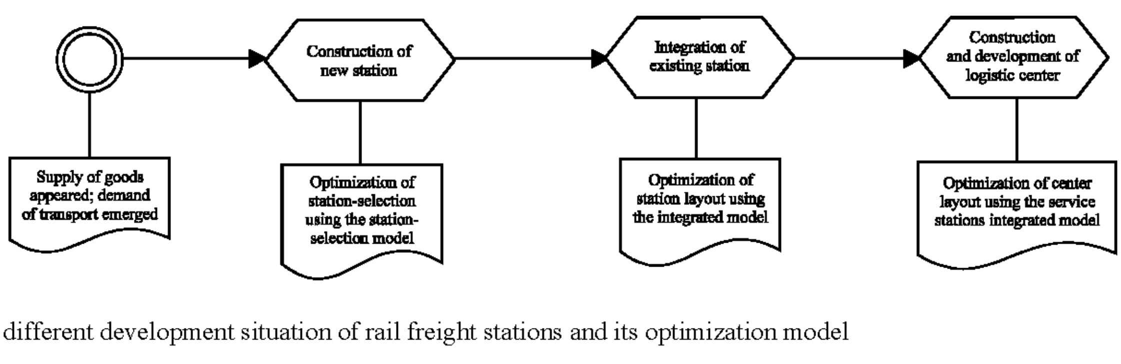

Fig. 1 different development situation of rail freight stations and its optimization model

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Situation 2: integration of existing stations. When strengthening the construction of freight station, optimizing the layout of freight station has been satisfied in order to lower the cost of existing stations based on the fact that the freight demand in coverage of regional freight station.

Optimization model

Parameters and variables sets: i: index for freight demand emerging point I = 1,2,…,n, j: index for freight demand attracting point j = 1,2,…,m, k: index for freight stations or the alternative freight station k = 1,2,…,l, S_i: freight volume of demanding point i. D_j: freight volume of attracting point j, W_k: Work capacity of alternative freight station k, S_k: investment scale of alternatives station k. Mdenotes the planning periods,ëdenotes the discount rate:

$$\alpha = \sum_{m=1}^{M} \frac{1}{(1+\lambda)^m}$$

and the investment per year can calculate using the formula:

$$\alpha \cdot S_k;\ c_{ij}^k$$

transport cost per unit from emerging point i to attracting point j through the a lternative freight station k; c_k: work cost of alternative freight station k. The value depends on its capacity. On general, the bigger the work capacity, the smaller the work cost per unit will be. To simplify the model, the study sets the work cost as a step function, i.e. different work capacity has a correspondent work cost. θ: daily operation management cost of freight station. X_{ij}^i: decision variables,transport volume from emerging point i to attracting point j through the alternative freight station k; z_k: 0-1 decision variables, if freight station k is selected as construction station, then $z_k = 1$ else $z_k = 0$; N: denotes the set of alternative freight stations; n: denotes the number of station that choosing as construction station; p: layout regulate scheme, i.e. scheme of investment and construction p = 0,1,2,…,P. To simplify the problem, p = 0 imposed that alternative station has stop the freight service and the work capacity is zero; p = 1 impose that there is no investment and reconstruction on the corresponding station; S^p_k: the investment scale of initiative freight station k when the scheme is p. $S^U{}_k = S^1{}_k = 0$. The investment cost per year can calculate using the formula:

$$\alpha \cdot S_k^p;\ \overline{W_k^p}$$

Work capacity of initiative freight station k when the scheme is p. when p = 0, $\overline{W_k^0} = -W_k$ and when p = 1,$\overline{W}^1{}_k$; $Z^p{}_k$: 0-1 decision variables, impose that whether the freight station k should be layout regulated.$Z^p{}_k = 1$ denotes yes, or $Z^p{}_k = 0$ denotes no.

Model building: To optimize the layout integrated optimization problem, the model takes minimizing the total transport cost, work cost of freight station and construction discount charge as its objective:

$$\min \sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{k=1}^{l} c_{ij}^k \cdot x_{ij}^k + \sum_{k=1}^{l}(\overline{c}_k \cdot \sum_{i=1}^{n}\sum_{j=1}^{m} x_{ij}^k) + \frac{1}{365} \sum_{k=1}^{l}\sum_{p=0}^{P} \alpha \cdot S_k^p \cdot z_k^p \text{-} \theta \cdot \sum_{k=1}^{l} z_k^0 \tag{1}$$

Constraints:

$$\sum_{j=1}^{m}\sum_{k=1}^{l} x_{ij}^k \le S_i \quad \forall i = 1,2,...,n \tag{2}$$

$$\sum_{i=1}^{n}\sum_{k=1}^{l} x_{ij}^k = D_j \quad \forall j = 1,2,...,m \tag{3}$$

$$\sum_{i=1}^{n}\sum_{j=1}^{m} x_{ij}^k \le W_k + \sum_{p=0}^{P} z_k^p \overline{W}_k^p \quad \forall k = 1,2,...,l \tag{4}$$

$$\sum_{p=0}^{P} z_k^p = 1 \quad \forall k = 1,2,...,l \tag{5}$$

$$\sum_{k=0}^{l} z_k^p \le N \quad \forall p = 2,...,P \tag{6}$$

$$x_{ij}^k \ge 0 \quad \forall i = 1,2,...,n; j = 1,2,...,m; k = 1,2,...,l \tag{7}$$

$$z_k^p \in \{0,1\} \quad \forall k = 1,2,...,l; p = 0,1,2,...,P \tag{8}$$

Constraints (2) and (3) denote the transport volume constraints of freight demand emerging point and the attraction point.Constraint (4) denotes the work capacity constraint of freight station. Constraint (5) denotes the incompatible investment constraints and imposes that each freight station has no more than one scheme during a fixed plan period; Constraint (6) denotes the freight station integrated scale constraint. i.e. there are only N (N≤l) freight stations to be chosen as regulated stations;Constraints (7) and (8) are the logic constraints.

Situation 3: Prolongation and development of logistic center. With the development of situations, new demands of regional logistic service are appeared. To meet these demands, it is necessary to choose some proper stations from existing stations aslogistic center.

Optimization model

Parameters and variables sets: V^h_k: Variable stock cost per unit for goods category h in freight service station k; ∂: empirical value which can obtained from actual data, generally equal (0~1); G^h_k: Total stock amount of goods category h in station k, j; D^h_k: Deferred charge for delayed time T^h_j when distribute goods category h to freight demand attraction station k. c^{kh}_{ij}: Transport cost per unit for delivering the goods category h from demand emerging point i to attraction point jthrough alternative freight station k; θ_n: the added daily operation management cost of the diversified freight station in scheme p; x^{kh}_{ij}: decision variables, transport volume of category hfrom emerging point i to attracting point j through the alternative freight station k; other same as above.

Model building: It takes minimizing the total transport cost, the work cost of freight station, various stock charge of various services, deferred cost for service delay, management cost and discount charge as its objective to build service layout optimization of rail freight station model:

$$\begin{aligned}\min\ & \sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{k=1}^{1}\sum_{h=1}^{f} c_{ij}^{kh}\cdot x_{ij}^{kh} + \sum_{k=1}^{1}(\overline{c}_k \cdot \sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{h=1}^{f} x_{ij}^{kh}) \\ & + \sum_{k=1}^{1}\sum_{h=1}^{f}(V_k^h)^{\partial}\cdot G_k^h + \sum_{k=1}^{1}\sum_{h=1}^{f} D_k^h(T_j^h) \\ & + \frac{1}{365}\sum_{k=1}^{1}\sum_{p=1}^{P}\alpha\cdot S_k^p\cdot z_k^p + \sum_{k=1}^{1}\sum_{p=1}^{P}\theta_p\cdot z_k^p\end{aligned} \tag{9}$$

Constraints:

$$\sum_{j=1}^{m}\sum_{k=1}^{1}\sum_{h=1}^{f} x_{ij}^{kh} \le S_i \quad \forall i = 1,2,\ldots,n \tag{10}$$

$$\sum_{i=1}^{n}\sum_{k=1}^{1}\sum_{h=1}^{f} x_{ij}^{kh} = D_j \quad \forall j = 1,2,\ldots,m \tag{11}$$

$$\sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{h=1}^{f} x_{ij}^{kh} \le W_k + \sum_{p=1}^{P} z_k^p \overline{W_k^p} \quad \forall k = 1,2,\ldots,1 \tag{12}$$

$$\sum_{p=1}^{P} z_k^p = 1 \quad \forall k = 1,2,\ldots,1 \tag{13}$$

$$\sum_{k=1}^{1} z_k^p \le N \quad \forall p = 2,\ldots,P \tag{14}$$

$$x_{ij}^{kh} \ge 0 \quad \forall i = 1,2,\ldots,n;\ j = 1,2,\ldots,m;\ k = 1,2,\ldots,l;\ h = 1,2,\ldots,f \tag{15}$$

$$z_k^p \in \{0,1\} \quad \forall k = 1,2,\ldots,l;\ p = 1,2,\ldots,P \tag{16}$$

Considering the models built above are mixed integer programming optimization models, LINGO software or ILOG software is used to solve the problem.

EXAMPLE STUDY

Integration of existing stations: Assuming new transport demand appears, there are different investments and regulated schemes such as integrating or expanding stations.

The relevant parameters are set as follows: W_k = {150, 450, 450, 250}. Assuming that the investment schemes of different stations are the same and are all equals {0, 0, 500, 1000, 1500}. The change of working capacity in each station under different investment scheme is {$-W_k$, 0, 50, 100, 150}, respectively. The result calculated through ILOG are summarized in Table 3 and Fig. 3. They showed that $Z^0_1 = 1$, $Z^2_2 = 1$, $Z^4_3 = 1$,.

Through analyzing, the results showed that freight station No.1 is integrated, freight station No.2 and NO.3 are expanded and reconstructed. Besides, the third investment scheme is applied to freight station No. 3 and the fifth investment scheme is applied to freight station No. 5. After being reconstructed, the work capabilities are 500 and 600 in station No. 3 and station No. 5, respectively. The freight station No.4 remains the same.

Construction and development of logistic center: Different kinds of goods lead to various logistic services.

Table 1: Transport volume of emerging and attraction points

Emerging points	O1	O2	O3	O4	O5
Transport volume	200	400	300	400	150
Attraction points	D1	D2	D3	D4	D5
Transport volume	300	250	350	200	250

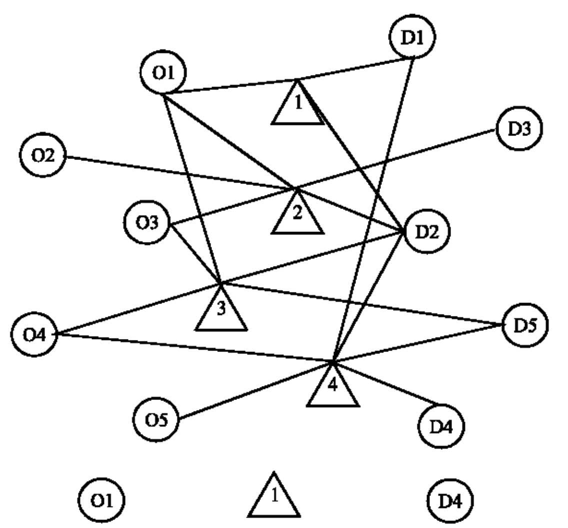

Fig. 2: Layout scheme of new selected station

Table 2: Transport costc_{ij}

	1-D1	1-D2	1-D3	1-D4	1-D5	2-D1	2-D2	2-D3	2-D4	2-D5
O1	17	17	15	13	22	26	26	24	22	31
O2	25	25	23	21	30	14	21	16	21	12
O3	22	22	20	18	27	22	29	24	29	20
O4	23	23	21	19	28	18	25	20	25	16
O5	16	16	14	12	21	16	23	18	23	14
	3-D1	3-D2	3-D3	3-D4	3-D5	4-D1	4-D2	4-D3	4-D4	4-D5
O1	22	22	20	18	27	30	30	28	28	26
O2	27	19	24	21	22	24	26	18	25	19
O3	25	17	22	19	20	26	28	20	27	21
O4	20	12	17	14	15	17	19	11	18	12
O5	33	25	30	27	28	18	20	12	19	13
	5-D1	5-D2	5-D3	5-D4	5-D5	6-D1	6-D2	6-D3	6-D4	6-D5
O1	29	30	31	29	28	28	32	29	29	30
O2	27	26	24	22	30	24	26	18	30	21
O3	26	22	22	18	28	25	30	25	29	21
O4	24	23	23	20	27	19	26	19	24	20
O5	34	23	31	27	30	19	24	17	24	18

Table 3: Freight flow distribution

Path	Flow	Path	Flow	Path	Flow
O1-3-D3	100	O3-3-D2	150	O4-4-D3	200
O1-3-D4	100	O3-3-D5	50	O5-2-D1	100
O2-2-D1	200	O4-3-D2	100	O5-4-D3	50
O2-2-D5	200	O4-3-D4	100		

Table 4: Transport volume in freight demand emerging and attraction points

Emerging points	O_1			O_2			O_3			O_4			O_5		
Service category	h_1	h_2	h_3	h_1	h_2	h_3	h_1	h_2	h_3	h_1	h_2	h_3	h_1	h_2	h_3
Transport volume	100	100	0	0	0	400	150	50	100	100	100	200	0	0	150
Attraction points	D1			D2			D3			D4			D5		
Service category	h_1	h_2	h_3	h_1	h_2	h_3	h_1	h_2	h_3	h_1	h_2	h_3	h_1	h_2	h_3
Transport volume	0	0	300	150	100	0	100	0	250	100	100	0	0	50	200

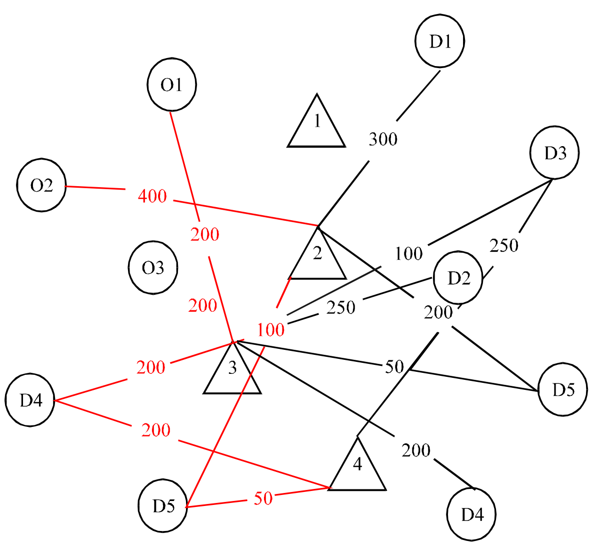

Fig. 3: Layout scheme of station integration

It’s necessary to choose one station from alternative freight stations to be reconstructed as logistic center within a fixed investment cost.

For example, categoryh_3 demands transportation, storage and distribution. Category h_2 and h_3 need added services like packing, manifest mortgage and financing.

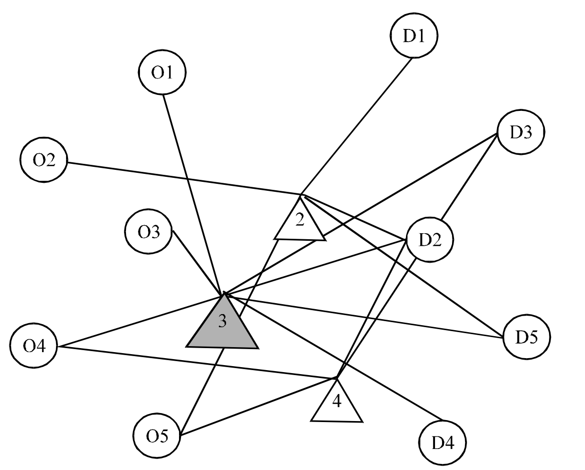

Fig. 4: Layout scheme of logistic center

Assuming the transport volume in emerging points and attraction point are as follows:

Due to the scale benefits, the composite station management cost differed as the collective total volume of different kinds of goods. Table 5 presented the detail cost:

Figure 4 showed that the final result of the model is $Z_3 = 1$, i.e., freight station No. 3 should be chosen as the key development object and reconstructed to be logistic center.

Table 5: Composite station management cost per unit according to service category

Service category	h_1		h_2		h_3	
Volume change	<350	≥350	<250	≥250	<550	≥550
Cost(per unit)	5	4.7	8	7.8	2	1.9

CONCLUSION

The allocation of resources in stations can be optimized through the optimization study on rail freight stations under different development situations. Results of the example showed that the method given in this study can be an effective assistance when making an optimization scheme in rail freight transportation. However, the definition of some parameters relevant to models above should be further studied which played an important role in scheme-making of freight station layout.

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