Analysis on the Applicability of Typical Railway Vehicle in Intermodal Transport

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ABSTRACT

In order to improve the transport efficiency of intermodal transport the suitability of intermodal transport in express cargo, this research takes intermodal express freight truck as the research object and newly develops a multi-objective optimization model. From the perspective of timeliness, cost and matching degree, the model finds out the railway vehicle model with the highest matching degree, which minimizes the total transportation timeliness and transportation cost of intermodal transportation and maximizes the relative matching degree of truck and cargo. In this research, the corresponding algorithm is designed to find the optimal solution of the model and find the optimal vehicle application scheme in different scenarios.

Keywords: intermodal transport, railway freight, railway vehicle, multi-objective optimization model, vehicle and cargo matching degree

1. INTRODUCTION

In recent years, China's intermodal transport has developed rapidly. The adaptation scheme for railway vehicles in intermodal transport is an important means and method to optimize the intermodal transport structure and improve the quality of development. In order to improve the operation efficiency of multimodal transport, scholars at home and abroad have made continuous efforts.

In view of the lack of competitiveness of intermodal transport compared with direct road transport, Konings[1] proposed to improve the handling system of container terminals and the connecting efficiency of railway and wharf as an important means to improve the competitiveness of intermodal transport. Groothedde et al.[2] studied the problem of rapid freight transportation in the Netherlands and concluded that economies of scale in transportation can be achieved and logistics costs can be reduced through cooperation between intermodal hubs. Ohnell and Woxenius[3] analyzed the fast freight market from the perspective of railway transportation by taking service scope, transportation quality and price as standards.

As an important part of intermodal transport equipment, the development of intermodal transport vehicles in China's railway is mainly concentrated in flat cars, express vehicles, road-rail vehicles, container vehicles and so on. Effective integration of railways with other modes of transport can improve the service level of intermodal transport, organizational efficiency, the level of seamless connection between different modes of transport and the quality of development. Choosing suitable vehicles of transport for different goods and different transport needs can effectively improve the service level of intermodal transport and reduce logistics costs.

In terms of means of transport selection, Qu et al.[4] established an accurate, flexible and efficient multimodal transport mode selection model under the framework of multi-criteria decision making. Based on the framework of multi-criteria decision-making, Wang and Yeo[5] define a selection model with total cost as the main factor and reliability, transport capacity, total time and safety as the auxiliary factor. Crainic[6] took the lowest cost as the objective function to establish a planning model, and deeply studies the influence of transport nodes, service frequency, transport routes and other factors. Talarico et al.[7] used the idea of game theory to construct a safe transport vehicle allocation model for various modes of transport. Han and Chen[8] studied the optimal configuration of railway transport vehicle for cars, and established comprehensive evaluation indexes to evaluate the applicability of vehicles from both technical and economic perspectives. Long et al[9] proposed a freight vehicle allocation optimization model and method from the perspective of node transfer delay risk, considering multi-mode coordination of freight node resources. Zhang and Shen[10] studied the application status

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of containers in railway multimodal transport and proposed that the future development direction of railway transport vehicles should be humpback container transport special vehicles and road rail vehicles. Dejak and Bookbinder[11] believed that high-speed rail express can relieve the pressure of road transportation and improve the environment. They considered incorporating high-speed rail express into the intermodal transport system, opening up a new idea of multimodal transport. Various valuable methods have been proposed to implement vehicle selection model, but there are still some deficiencies.

2. DATA SET

2.1 Technical parameters of the vehicles

According to the current operation situation of express trucks, it is considered to establish a selection of vehicles composed of express boxcar, container flat car, luggage car, road rail vehicle and high-speed freight Electric Multiple Units (EMU) train. Now the technical parameters and operating conditions of different carrying tools are analyzed. The following Table 1 lists the technical specifications.

Table 1. Technical parameters of the vehicles.

Types	Load (t)	Unit Compartment Capacity (m³)	Inside Length (mm)	Inside Width (mm)	Speed (km*h-1)	High of Loading Door (mm)	Wide of Loading Door (mm)
P65	45	135	15462	2790	120	2537	1964
P70A	70	140	15494	2800	120	2535	7670
X1K	61	52	13800	—	120	—	—
X2K	78	104	18400	—	120	—	—
XL25T	23	160	25500	3104	160	2535	2520
QT1	98	160	49846	3330	120	—	—
EMU	85	80	25000	3360	350	2800	2350

2.2 Carrying capacity

The carrying volume of different models is affected by vehicle grouping, unit load and volume, as shown in Table 2 below. Through the analysis, it can be seen that XL25T has the fastest speed, but its load capacity is lower than other models. The load capacity of rail-highway combined transport vehicle and EMU is higher, but the total load capacity is low due to the influence of the number of marshalling. Since most of the express goods are lightweight goods, there will be no full load in the transportation process, so the actual carrying capacity of the carrier should be determined according to the actual situation.

Table 2. Carrying capacity.

Types	P65	P70A	X2K	X1K	XL25T	QT1	EMU
Load(t)	45	70	78	72	23	98	85
Unit Volume (m³)	135	140	132	66	160	160	80
Number of Groups	40	40	20	40	16~20	6	8

2.3 Loading and unloading equipment of different models

Different types of loading and unloading tools need to be equipped at the transfer node for different carrying volumes, and the loading and unloading tools also affect the selection of the transfer node. For example, bags can be loaded and unloaded at the passenger station, while flat containers need to be loaded and unloaded at the freight station or central station. Table 3 shows the loading and unloading tools suitable for different loading and unloading tools.

Table 3. Loading and unloading equipment of different models.

Types	P65	P70A	X2K	X1K	XL25T	QT1	EMU
Loading and Unloading Equipment	Forklift	Forklift	Gantry Crane	Gantry Crane	Forklift	Dedicated Tractor	Forklift

3. MODEL STUDY

In order to facilitate analysis, when calculating the volume of cargo, except for container cargo, all other express cargo uses pallets as loading tools, and the loading unit does not change during transportation. All loading and unloading equipment at the transfer station participates in the loading and unloading operations. The handover of goods between railway and other modes of transportation is carried out at the railway stop. For example, air-road-rail combined transportation is not included in the scope of the plan. The number of vehicles designed is only one column, and there will be no mixed grouping.

For the service level of the whole intermodal transport system, the lower the total transport time, the higher the service level. In order to fully consider the influence of the choice of railway carrier on the comprehensive operation of the entire intermodal transport system, as shown in Equation (1), the total transport time studied in this paper is divided into the transport time of railway trucks, the loading and unloading time of transport operation sites (such as freight station) and the transport time. Therefore, in this study, the objective function of the proposed minimum optimization model of total transportation timeliness can be interpreted as:

$$\mathrm{MinF(t)} = \sum_{k\in K} x_k (ST(1) + ST(2) + ST(3)) \quad (1)$$

Where $F(t)$ is the intermodal transportation total time limitation, $ST(1)$ is the transportation efficiency, $ST(2)$ is the loading and unloading efficiency, $ST(3)$ is the transit efficiency, and x_k is whether to use vehicle number k.

In the intermodal railway subsystem, the transportation time includes the transportation time of the carrier and the stopping time of the carrier at the stations along the way. The transportation time is also affected by the train organization mode. If it is a direct train, the stopping time is 0. As explained by in Equation (2) and Equation (3). Transport time is expressed by transport time and possibility.

$$ST(1) = \left(\frac{\sum_{(i,j)\in G} L(i,j)}{v_k}\right)(1 - P_k) \quad (2)$$

Where G is a collection of freight stations along a railway route, $\mathrm{L(i,j)}$ is the transportation distance between adjacent stations i and j, the unit is km, v_k is the speed of vehicle k, the unit is km/h, and P_k is the possibility that vehicle k can carry out inter-site transport.

$$T(1) = \left(\frac{\sum_{(i,j)\in G} L(i,j)}{v_k}\right) \quad (3)$$

Where $T(1)$ is transportation time, the unit is h.

Equation (4) and Equation (5) explain that the loading and unloading efficiency is affected by the amount of loading and unloading equipment and the degree of convenience of loading and unloading. Meanwhile, different loading and unloading equipment corresponds to different loading and unloading equipment, and the different loading and unloading equipment will also affect the loading and unloading time.

$$\mathrm{ST(2)} = [\mathrm{Q}/\ (\mathrm{n_z} * \mathrm{q_z})\ ](l_\mathrm{d}/l_\mathrm{kw})(q_k/q_e) \quad (4)$$

Where Q is the total loading and unloading capacity of the transshipment station, the unit is t, $\mathrm{n_z}$ is the quantity of equipment used for loading and unloading between vehicle k and other transport, $\mathrm{q_z}$ is the amount of equipment per unit time used for loading and unloading between vehicle k and other transport, the unit is t, l_d is the pallet width or container width of loading cell, the unit is mm, l_kw is K vehicle carriage width or flat car width, the unit is mm, q_k is the total carrying capacity of unit vehicle k, the unit is t, and q_e is other transport unit carrying vehicle volume.

$$\mathrm{T(2)} = \mathrm{Q}/\ (\mathrm{n_z} * \mathrm{q_z}) \quad (5)$$

Where $\mathrm{T(2)}$ is the loading and unloading time, the unit is h.

Transfer efficiency is the evaluation of the intermodal transport system cohesion level of important factors that influence the transit time is influenced by the specific mode of transportation, because the highway, railway, air and shipping four units on the mode of transportation vehicles traffic difference is bigger, the set time, the implementation of each are not identical, to the specific mode of transportation of transshipments time have explained in Equation (6).

$$\mathrm{ST}(3) = \mathrm{T}(3) = t_e \quad (6)$$

Where $\mathrm{T}(3)$ is the transfer time, the unit is h, and t_e is the average waiting time for other modes of transportation and rail transshipment, the unit is h.

For the system, the lower the total cost, the better the "economics" of intermodal transport. As explained by Equation (7), the total cost of intermodal transportation consists of the cost of vehicle and the cost of loading and unloading.

$$\mathrm{MinF(c)} = \sum_{k\in K} x_k \big(C(1) + C(2)\big) \quad (7)$$

where $\mathrm{F(c)}$ is the total cost of intermodal transportation, the unit is yuan, $\mathrm{C}(1)$ is the cost of vehicle, the unit is yuan, and $\mathrm{C}(2)$ is the cost of loading and unloading, the unit is yuan.

Vehicle cost refers to the cost of vehicle after use. Equation (8) is expressed in terms of annual depreciation cost, annual maintenance cost and annual inspection of maintenance costs.

$$\mathrm{C}(1) = c_{kz} + c_{kw} + c_{kj} \quad (8)$$

where c_{kz} is the annual depreciation cost of type k vehicle, the unit is yuan, c_{kw} is the annual maintenance cost of type k vehicle, the unit is yuan, and c_{kj} is the annual inspection of maintenance costs, the unit is yuan.

Different vehicles use different handling equipment and incur different costs, as shown in Equation (9).

$$\mathrm{C}(2) = c_{kz} * n_s \quad (9)$$

Where c_{kz} is the unit loading and unloading equipment cost in z years, the unit is yuan, and n_s is the loading and unloading equipment quantity.

On the basis of discussing the impact of timeliness and cost, the matching degree of vehicle and goods should also be considered, as mentioned in Equation (10).

$$\mathrm{MinF(p)} = \sum_{k\in K} x_k * P(1) * P(k) \quad (10)$$

where $\mathrm{F(p)}$ is the vehicle cargo matching, $\mathrm{P}(1)$ is the load unit matching, and $\mathrm{P(k)}$ is whether vehicle k can carry out cold chain transportation.

There are various types of express cargo, with different sizes and volumes. Equation (11) explains that whether it is suitable for a carrier depends first on whether the cargo could be loaded into the carrier through loading and unloading activities.

$$\mathrm{P}(1) = l_{\mathrm{d}}/l_{\mathrm{kmw}} \quad (11)$$

where l_{kmw} is the door width of vehicle k.

Constrained by the research problem itself, the number of railway vehicle types selected is fixed, as explained by Equation (12).

$$\sum_{k\in K} x_k = 1 \quad (12)$$

The carrying capacity of different models is different. From the perspective of transportation feasibility, the carrying capacity of a freight train is higher than the total amount of goods collected by other transportation in the previous stage, as explained in Equation (13).

$$q_k \le (q_e * n_e) \quad (13)$$

Different cargo sizes are different, and the conditions for loading and unloading are also different. Whether a type of cargo is suitable for a type of carrier also needs to determine the ratio of the width of the cargo loading unit to the width of the carrier door. Equation (14) explains the constraints of the loading tools.

$$l_{\mathrm{d}}/l_{\mathrm{kmw}} \le 1 \quad (14)$$

Express cargo itself has the characteristics of high timeliness, usually customers will put forward certain requirements on the delivery time, so the whole intermodal transport time should conform to the time limit given by the cargo owner. Equation (15) shows the time limit.

$$T(1) + T(2) + T(3) \ll T \tag{15}$$

Where T is the delivery time.

4. ALGORITHM DESIGN

Under normal circumstances, different targets with multiple objectives may restrict and contradict each other. Under the influence of constraints, other targets may not be optimal when one target gets the optimal value. Therefore, the ultimate optimal solution of multi-objective function is the optimal solution for the whole system. In this paper, the linear weighting method is adopted to convert multiple objective functions into single objective functions. The three objective functions are normalized for dimensionless processing, and the evaluation value *wi* is obtained as the weight for solving. The details in each step of the whole optimization procedure are as follows:

Step 1: Use range normalization to convert multiple objective functions into a single objective function, and the result is assigned to w_i;

Step 2: Set up the corresponding set of decision variables and vehicle types

Step 3: Let $k=1$;

Step 4: Substitute x_k data into the model and determine whether constraint conditions are met;

Step 5: If the conditions are met, compare with the value of the existing objective function, otherwise, set $k=k+1$ and go to Step 4;

Step 6: If it is better than the existing target value function, set $x_k=1$ and the rest values to 0, otherwise, set $k=k+1$ and go to Step 4;

Step 7: When $k=7$, the algorithm stops and the optimal selection is output.

5. CONCLUSIONS

This research presents a new multi-objective vehicle selection model, which could provide a suitable choice for intermodal transport. It improves the matching degree of vehicle and cargo, the speed of rapid change and transfer between the railway and other different means of transport through the adaptation scheme. High degree of match improves the intermodal transport efficiency, and reduce the cost of railway in the process of intermodal transport. This is of great significance to the application of intermodal transport in China.

In the study of this paper, the mixed situation of different vehicle types is not taken into account. In order to be more realistic, this situation should be taken into account in the future study. Meanwhile, the transportation situation of different loading units should also be taken into account, so that cargo types can be classified in more detail to improve the matching degree of vehicle and cargo. Vehicle marshalling and vehicle and cargo matching are two key contents to be optimized next.

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