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Comparative Study on the Economic of Railway Piggyback Transportation Distance

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Abstract: The paper calculates the freight of road transportation, container multimodal transportation and piggyback transportation. Then the paper establishes a modal with the goal of minimizing the direct and indirect transport costs. Finally, the paper uses lingo software for implicit enumeration calculations. The result indicates that under the mode of charging according to the actual weight, the road transportation cost is the highest, the cargo reloading time of the container multimodal transport is long, and the piggyback transportation wastes more transportation capacity due to the deadweight and load of semitrailer. The actual case analysis shows that the direct cost advantage of piggyback transportation is not great, but the advantage of transportation time is more prominent, especially between 500km and 900km.

Keywords: Railway freight; multimodal transportation; piggyback transportation; cost.

1. Introduction

Piggyback transportation by rail is a combined mode of transportation by road and railway. Special vehicles for self-driving on the Railway at the starting subway station, When a highway truck or semi-trailer loads the goods. After completing long-distance transportation by rail to the destination railway station, The car pulls itself off the special railway vehicle and drives to its final destination [1]. Piggyback transportation was first adopted by North American countries, and then applied in France, Germany, Japan and other countries. In recent years, with the development of multimodal transport, piggyback transport has gradually developed in China.

Through data collection, the U.S. Department of Energy proposed a study on fuel consumption, The results show that the fuel efficiency ratio of the piggyback transportation line to the fuel consumption of the truck is about 2:1[2]. Piggyback transportation in Europe began in the late 1960s, At that time, the European railway transport enterprises saw that the vigorous development of American carry on back transport brought good economic benefits [3]. In the 1980s, Germany increased the speed of traditional freight trains to 90km/h, the speed of European freight trains on German railways is higher than 100 km/h, The running speed of piggyback transportation and container train reaches 120 km/h [4]. France, Japan and other countries have also carried out a lot of research on the direction of production and development of new vehicles in view of the characteristics of piggyback transportation. Since 1957, France has manufactured a number of piggyback flatcars with lower floor surface than ordinary flatcars, Japan designed a low-floor flat car for piggyback transportation with floor gauge and rail height of 450mm in 1983 [5-6].

In China although multimodal transport started early, but the research on piggyback transport is relatively late. In October 2014, the State Council issued "The Long-term Plan for Logistics Industry Development (2014-2020) ". It proposes to accelerate the development of multimodal transport and explore the construction of multimodal transport systems such as piggyback transport, water Ro-Ro transport and so on. Piggyback transportation has the advantages of economy, convenience, energy saving, environmental protection, safety and reliability. It is a kind of "door-to-door" transport mode, which has good social and economic benefits. Therefore, China actively carries out research on piggyback transportation in terms of equipment development, railway station yard renovation and cargo attraction [8-10]. But piggyback transport is a new type of multimodal transport, and its competitiveness and acceptance are obviously insufficient. The corresponding laws and regulations and the necessary facilities and equipment need to be matched and improved urgently. At the same time, the economy of piggyback transportation depends largely on the existing railways. However, the surplus capacity of the existing railway network is not balanced, and the characteristics of piggyback transportation determine the inevitable waste of transport capacity. How to rationally organize transportation and allocate resources to give full play to the capacity and economic advantages of piggyback transportation remains to be studied in depth.

2. Problem Description and Parameter Design

According to the relevant documents and regulations of China Railway Corporation on transport prices, the mode of charging for piggyback transportation is mainly determined by transport facilities and equipment. But in fact, other factors that are not easy to quantify, such as the time cost of in-transit transportation and the interference to the line, should also be taken into account.

(1) Highway freight cars and special railway vehicles. The current piggyback transportation is loaded by trucks or semi-trailers. Its load is shown in Table 1. The bottom of container-specific vehicles is mostly used in railways. Down as G_c , G_h , The self-weight of highway semi-trailer and the actual weight of goods are expressed respectively, H_r , H_t Separately Express the maximum allowable loading capacity of road and railway loaders.

Tab.1 Maximum Permissible Total Mass of Vehicles

Vehicle type		Maximum permissible total mass(t)
vans	Semi-trailer tractor	26
	vans	32
trailers	semitrailer	40
	Other trailers	20

(2) Line capacity. With the improvement of the time limit of railway transportation and the release of transport capacity, the surplus capacity on the section line is one of the basic conditions for carrying out piggyback transportation. The sum of the original traffic volume of the section must not exceed the passing capacity of the section, which is recorded as N_{ij} .

(3) Transportation mileage. When carrying on piggyback transportation, the freight rate of the whole truck or semi-trailer should be calculated because of the loading of the whole truck or semi-trailer. According to the tariff table, when the whole vehicle is composed of goods with multiple tariffs, the tariff is calculated according to the highest tariff, down as $p(p_k)$, p_k means Price Rate Level k , p_r is the unit freight rate of highway transportation.

(4) Transportation time. As the value of modern transport goods is getting higher and higher, the cost of time-efficiency of goods in transit is also increasing. It not only reduces the loading and unloading time t_z , but also reduces the transportation time and cost on the way, v_r , v_t recorded as transportation speed.

3. Comparisons of Transportation Costs

For a transportation process with $L = L_A + L_1 + \cdots + L_n + L_B$ section, L_A and L_B can only choose road transportation, other sections L_i can be transported by road or rail. The alternative modes of transport organization are:

①Full road transportation.

②Highway-Railway Container Multimodal Transport. Highway transportation between

L_A and L_i sections, sections L_{i+1} to L_j by railway transportation, sections L_{j+1} to L_B by highway transportation.

③ Piggyback transportation with the same replacement scheme as ②.

For the three modes, the generalized transportation cost is calculated according to the following parts.

(1) Direct Transport Cost. In the transport organization scheme, the cost of freight transportation is complex, whether it is road or railway. In order to simplify the calculation, referring to previous studies, it can be roughly considered that the railway transportation cost is p_k yuan/ton km. The transportation cost of the road is p_k yuan/ton km. The direct costs of the three types of transport organization models are:

① $F_1 = p_r \cdot \left(\sum l_i\right) \cdot G_h$;② $F_2 = p_r \cdot \left(\sum_A^i l_i + \sum_{j+1}^B l_i\right) \cdot G_h + \max\{p_k\} \cdot \left(\sum_{i+1}^j l_i\right) \cdot G_h$;

③ $F_3 = p_r \cdot \left(\sum_A^i l_i + \sum_{j+1}^B l_i\right) \cdot G_h + \max\{p_k\} \cdot \left(\sum_{i+1}^j l_i\right) \cdot \left(G_h + G_c\right)$. Where l_i is the distance of the road segment L_i, and assuming that any road segment i, the transportation distance between the road and the railway is the same.

(2) Indirect transportation costs: due to the time value of the goods themselves during transportation. In particular, some key projects have high time and cost per day, so delivery of these transportation products as soon as possible is also a manifestation of transportation costs. The time costs of the three types of transport organization models are:① $F_1' = \sum l_i / v_r$;② $F_2' = \left(\sum_A^i l_i + \sum_{j+1}^B l_i\right) / v_r + \sum_{i+1}^j l_i / v_t + 2t_z$;

③ $F_3' = \left(\sum_A^i l_i + \sum_{j+1}^B l_i\right) / v_r + \sum_{i+1}^j l_i / v_t + 2t_p$.

3.1 Objective function

Shipping costs are minimal. That is, the sum of direct costs and indirect costs, but because the units of direct and indirect costs are not uniform, and the multimodal transport station can select more points, it is difficult to calculate directly, and the summation is processed after dimensionless normalization.

$$\min\left(X\right) = f_\alpha + f_\alpha' \tag{1}$$

$$f_\alpha = \frac{F_\alpha - F_{\min}}{F_{\max} - F_{\min}}, \quad f_\alpha' = \frac{F_\alpha' - F_{\min}'}{F_{\max}' - F_{\min}'} \tag{2}$$

Where $F_{\max}$ and $F_{\min}$ are the highest and lowest of the direct costs in all scenarios;

$F'_{\max}$ and $F'_{\min}$ are the highest and lowest of the indirect costs in all scenarios.

3.2 Constraint

(1) Piggyback shipping weight constraints. The weight of the cargo does not exceed the maximum allowable load of the road truck or trailer. The total weight of the cargo and semi-trailer does not exceed the maximum allowable load of the railway carrier.

$$G_h \leq H_r ; G_h + G_c \leq H_t \qquad (3)$$

(2) The section of the rail transport section is subject to capacity constraints. The railway transportation section itself has the limit of maximum transportation capacity. After the transportation of the piggyback, the transportation capacity of the section cannot exceed the maximum carrying capacity.

$$\text{ent}\left[f_{ij} / K + 1 \right] + n_{ij} < N_{ij} \qquad (4)$$

In the formula: $\text{ent}[\ ]$ is the value rounded up, K is the average number of trains for the train, N_{ij} is the ability to pass the road $i \to j$, n_{ij} is the number of trains in the road $i \to j$.

4. Algorithm design

Considering the actual situation, multimodal transport generally only takes one road to rail and one rail to highway. This making the model smaller, although the objective function is more complicated, the constraints are simpler. Therefore, the implicit enumeration algorithm can be used for calculation. Specific steps are as follows:

Step 1: Design the solution set $S = (A, 1, 2, \cdots, i, \cdots, n, B)$, $A, 1, 2, \cdots, n, B$ are 0-1 variables. 1 means that the site is reloaded, 0 means not changing at this point, and adding constraints: $\sum_A^B i = 0 or 2$.

Step 2: There is a solution set S^0, Satisfy $A, 1, 2, \cdots, n, B$ are 0, means full road transport, not changing the railway, At this point the target function value is written as X^0. Check if the solution set S^0 satisfies the constraint, Check this solution set satisfies the constraint. Split this question into two sub-questions: One is S^0, and the another is $S^1 = (1, 0, \cdots, 0, 1)$. Find the value of the objective function, and check whether the value of the solution set S^1 satisfies the constraint condition, and decide whether to continue the branch according to the following principles:

(1) When the solution set S^k of the branch is a feasible solution, then the branch retains the branch with the smallest target value among all feasible solutions. Remove the big branch of the feasible solution X^k.

(2) Regardless of whether it is a feasible solution, as long as the boundary value of the branch is greater than the retained X^k value, the branch stops branching.
(3) When there is a constraint in the branch that is not satisfied, the branch stops, otherwise the branch continues until all branches except the reserved branch have been removed. The feasible solution value at this time is the optimal solution of the objective function.

5. Example analysis

A total of 240t of cargo is transported through the Beijing-Shanghai Railway. The stations at both ends of the railway transport are Beijing East and Shanghai Minhang. The main intermediate stations are Tianjin North, Jinan East and Nanjing West station. The distance between cities is: Beijing East station-Tianjin North station has 160km, Tianjin North station-Jinan East station has 335km, Jinan East station-Nanjing West station has 659km, Nanjing West station-Shanghai Minhang station has 308km, a total of 1462km. The distance from the door to the station is 20km.
The railway transportation cost is calculated based on the actual vehicle weight of the 6-level freight rate. Due to the complicated calculation, it is roughly estimated as $p_t \approx 0.22$ yuan/ton km by experience, and $p_r \approx 0.29$ yuan/ton km. The speed of road transportation on this line is about 70km/h, and the speed of railway transportation is about 85km/h, Each change time is t_z=1.5h, t_p=0.5h. The maximum allowable load $H_r = 40t$ for semi-trailers, the allowable load $H_t = 60t$ for railway carriers, and the 10t for semi-trailers [9,11]. By calculation, the results of selecting the shortest and longest branches in each transport organization are shown in Table 2.

Tab.2 Cost of various organization methods

Organization	Road transport		Container multimodal transport		Piggyback transport	
	Direct cost (yuan)	overhead costs (h)	Direct cost (yuan)	overhead costs (h)	Direct cost (yuan)	overhead costs (h)
(0,0,0,0,0)	104539	21.5	-	-	-	-
(1,0,0,0,1)			79978 (min)	20.8	99276	18.8(min)
(1,1,0,0,0)			101851	24.1(max)	107522(max)	22.1

Obtained by Equation 1, when $S^1 = (1,0,0,0,1)$, The direct cost of container multimodal transport is 79,978 yuan, and the transportation time is 20.8 hours. The conversion objective function is $\left(X^{1}\right)=0.37$ .The direct cost of Piggyback transportation is 99,276 yuan, and the transportation time is 18.8 hours. The conversion objective function is $\left(X^{2}\right)=0.70$. The direct cost of road transportation is 104,539 yuan, and the transportation time is 21.5 hours. The conversion objective function is $\left(X^{3}\right)=1.39$.

It can be seen that no matter which type of multimodal transport is carried out, it is changed at both ends, and the transportation cost is lower. Adjust the distance of the middle rail transport part, that is the value of $\sum_{i=1}^{n} l_i$. The results are shown in Table 3.

Tab.3 Cost value for different shipping distances

Transportation distance (km)	Road transport		Container multimodal transport		Piggyback transport	
	Direct cost (yuan)	overhead costs (h)	Direct cost (yuan)	overhead costs (h)	Direct cost (yuan)	overhead costs (h)
1502	104539	21.5	79978	20.8	99276	18.8
1040	72384	14.9	55584	15.3	68784	13.3
840	58464	12.0	45024	13.0	55584	11.0
640	44544	9.1	34464	10.6	42384	8.6
440	30624	6.3	23904	8.3	29184	6.3
240	16704	3.4	13344	5.9	15984	3.9

From Table 3, the most advantageous road transport under 240 km, 240km to 440km of road transport and piggyback transport are not much different, between 640km and 1040km, container multimodal transport and piggyback transport show advantages, after more than 1 500km, the advantages of piggyback transport and container multimodal transport are more obvious.

6. Conclusion

Based on the study of the transportation costs of the three transportation organization modes, this paper establishes the model of the direct transportation cost and the indirect cost of multiple loading points. Use Matlab software to solve the problem while adjusting the transport distance and the position of the station. Through the calculation of the model and the comparison of the results, the generalized cost of different transport organization modes under different transport distances is analyzed, and the following conclusions are drawn: (1) Whether it is container multimodal transport or piggyback transport, as much as possible on the railway, the final cost will be lower. (2) Highway transportation costs are the highest. Container interchange has a long time to change. Piggyback transportation wastes more capacity, due to the weight and load of the semi-trailer used. Therefore, the most appropriate organization method can be selected according to the transportation distance to achieve the lowest cost target. (3) The calculation of transportation costs is actually very complicated. In order to simplify the calculation, the unit costs are directly calculated, and the results obtained are biased. The actual model should be further optimized. (4) The attributes of the goods themselves, such as high time cost, large damage rate, and complicated loading and unloading process, will also affect the model results.

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