A Study to Compare Transportation Loading Schemes by Cost Consideration

Hao CHEN

National United Engineering Laboratory of Integrated and Intelligent Transportation, College of Traffic and Transportation, Southwest Jiaotong University, Chengdu, Sichuan 610031, China

Abstract — With the development of transportation technology and the improvement demand for transportation safety, speed, and efficiency, the railway freight loading and securing issue is one of the most important transportation safety technology that has attracted great attention. However, it is extremely difficult to evaluate and estimate a loading reinforcement plan and scheme, which can be regarded as a multi-attribute comprehensive evaluation problem, for we have to consider and assess not only the direct factors such as cost, safety, vehicle, policy, loading and unloading, etc, but also the indirect factors, e.g. station place, hoisting machinery, vehicle deformation, etc. Therefore, the paper proposes a method of Grey relation analysis and evaluation in order to estimate accurately the relevant factors to effectively appraise the plan and scheme.

Keywords - Railway Freight Loading and Securing; Loading Reinforcement Plan and Scheme; Reliability; Grey Relation Analysis and Evaluation

I. INTRODUCTION

With the development of railway transportation, the weight, length, volume of out-of-gauge goods undertook by railway sector has been improved seriously. For some of the out-of-gauge goods, there are more and more loading reinforcement and transport method can be selected. But in the previous studies, most of the influence factors of loading reinforcement scheme are only concern with the out-off-gauge level, height of loaded wagon and deflection of gravity center. [1-3]. The methods and indexes just aim at security elements [2-4]. Or introduce improved evaluating method to enhance the accuracy. [5] Rare study analyzes the security and economy at the same time. Because of the enormous difference in method and unit caused by accuracy and economy indexes, this article uses the correlation decision-making method in view of the different target scheme selections, which contains of the maximum correlation method, the minimum correlation method as well as comprehensive correlation method and so on. Depending on the target, choose appropriate correlation degree, will produce certain effect to the accuracy of the results [6].

II. QUANTITATIVE INDICATORS OF CARGO LOADING REINFORCEMENT SCHEME

Modern cargo transport, more the target on the safe, efficient, economic, and environmental, safety and economy have been the focus of concern to the transport of goods, in order to consider the safety and economy of transportation at the same time. The transportation of the transport safety class target is defined as the safety benefits, the cost of transportation is defined as the economic cost of the target class, by two kinds of target under the various indexes of dimensionless. Finally it is concluded that a collection of all kinds of quantitative indicators of the loading reinforcement scheme. Here, according to the target layer important degree, chose the out-off-gauge level, height of loaded wagon, deflection of gravity center and concentration of weight to set as a security; Truck load factors, the used of special vehicle, loading reinforcement materials used as a quantitative indicator of economic cost.

A. Quantification of safe benefit decision goal

Quantification of safe benefit decision goal include out-off-gauge level, height of gravity center of loaded wagon and deflection of gravity center.

1) Out-off-gauge level

After loading the goods, According to gauge level is divided into first out-off-gauge, second out-off-gauge and super out-off-gauge. When the goods exceed level, will not only increased by 50%, 100%, 150% of transportation costs, and also security of the scheme and transport speed is restricted, at the same time transport organization lines will be affected. Reference to various factors, quantify the goods out-off-gauge level:

\[
\begin{align*}
  u_{11} &= \begin{cases} 0, & \text{Not out-off-gauge} \\ (0,0.3), & \text{First out-off-gauge} \\ (0.3,0.6), & \text{Second out-off-gauge} \\ (0.6,1), & \text{Super out-off-gauge} \end{cases} 
\end{align*}
\]

2) Height of gravity center of loaded wagon

Height of gravity center of loaded wagon is an important indicator of freight loading reinforcement scheme, the higher the height of gravity center, the load vehicle stability during operation of the worse, more accidents Will be happen. According to “The Railway Cargo Loading Reinforcement Rules”, the calculation method of heavy vehicle high center of gravity is: When one car load:

\[
H = \frac{Q_c \cdot h_c + Q_1 \cdot h_1 + Q_2 \cdot h_2 + \ldots + Q_n \cdot h_n}{Q_c + Q_1 + Q_2 + \ldots + Q_n}
\]

In the formula,

- \(Q_c\): Freight weight, ton;
\( Q_1, Q_2, \ldots, Q_n \): Weight of each goods, ton; 
\( h_c \): The height of the empty weight calculate (since the rail surface), millimeter; 
\( h_1, h_2, \ldots, h_k \): The height of the each goods weight calculate (since rail surface) after loading, millimeter.

When two vehicles straddle: 
\[
H = \frac{Q_1 \cdot h_1 + Q_2 \cdot h_2 + Q \cdot h}{Q_1 + Q_2 + Q}
\]

In the formula, 
\( Q_1, Q_2 \): Weight of the load car, ton; 
\( h_1, h_2 \): The height of the center of gravity of the two empty vehicle (since rail surface), millimeter; 
\( Q \): Weight of the goods, ton; 
\( h \): The height of the center of gravity of goods (since rail surface), millimeter.

According to “The Railway Cargo Loading Reinforcement Rules”, load vehicle high center of gravity is generally not more than 2000 millimeter, if more than 2000 millimeter, if the conditions allow, take weight reduce heavy generally not more than 2000 millimeter, if more than 2000 surface), millimeter.

Program in this case is not feasible.

The longitudinal deflection of gravity center of goods, millimeter.

For the longitudinal deflection of gravity center of goods, bear the weight of each bogie is normally not allowed to load of freight cars more than half, and two bogies to bear weight difference shall not be greater than 10 tons. So the longitudinal deflection of gravity center of goods for the goods to the following quantitative target.

\[
u_{\alpha} = \begin{cases}
0, & H \leq 2000 \\
(H - 2000)/1000, & 2000 < H \leq 3000 \\
\infty, & 3000 < H
\end{cases}
\]  

In the formula, 
\( H \): Height of gravity center of loaded wagon, millimeter; 
\( \infty \): The maximum (When calculating take 10), means program in this case is not feasible.

The economic costs of quantitative decision goal

1) The utilization rate of vehicle load

Vehicles load utilization is the actual cargo weight than the total marked load weight. On the premise of not exceed the permitted load, load more cargo, higher utilization rate of its load, the higher the efficiency of freight trains used. Efforts to increase the rate of vehicle load can reduce the economic cost of unit of the goods. The quantitative target for utilization rate of vehicle load:

\[
u_{\alpha} = \begin{cases}
1, & Q / Q_S, Q \leq Q_S \\
\infty, & Q > Q_S
\end{cases}
\]

In the formula, 
\( Q \): The goods weight, ton; 
\( Q_S \): The vehicle marked load capacity, ton.

2) The use of special vehicle

When using a special vehicle, will charge high fees and the sent back fee. At the same time, because of the special vehicle deployment problem, will seriously affect the speed of transport of goods. The use of special vehicle for quantitative target:

\[
u_{\alpha} = \begin{cases}
0, & m < 3000 \\
(0, 0.3), & 3000 \leq m < 6000 \\
(0.3, 0.6), & 6000 \leq m < 10000 \\
(0.6, 1), & m \geq 10000
\end{cases}
\]

In the formula, 
\( m \): Special vehicle increase cost value.

3) Number of reinforcement material

In the process of loading reinforcement, the use quantity of reinforcement material is an important indicator of measuring scheme, the lack of reinforcement materials used, may cause potential safety hazard, use too much, will increase operating cost. On the premise of meet the security, we hope reinforcement materials used as little as possible.

Due to the variety of load reinforcement materials, different nature, different models, makes calculation of the reinforcement materials are too complex. Here, on the basis of the permissible strain of material, the numbers of various materials uniform conversion become 7.7 millimeters diameter wire rope to the root of the number.
III. LOAD THE RELIABILITY MODEL OF REINFORCEMENT SCHEME

A. The construction of a Grey Decision Method

In loading reinforcement scheme, such as high center of gravity and deflection of gravity center of goods, the number of reinforcement strength data can be clear, but such as freight, material using this type of decision-making information is often grey number, access to information is expressed by interval grey numbers. In grey decision-making theory system, grey correlation decision is a kind of at a gray system in the actual effect and the link between the optimal effect size for the standard, used to evaluate the methods, advantages and disadvantages of various practical schemes of the grey correlation degree, the optimal. In dealing with this kind of grey incidence decision with grey numbers in the actual scheme decision-making information, has the advantages of simple, practical and operability is strong, is one of the most commonly used decision method.

Build the collection of situation: Within the scope of cargo loading reinforcing scheme research, all of the loading reinforcement alternatives set collection for decision making. \[ A = \{ A_1, A_2, ..., A_n \} \]

Loading reinforcement scheme of the decision factors. \[ S = \{ S_1, S_2, ..., S_n \} \]. Plan \( A_i \) in the target \( S_j \) value for a nonnegative interval grey numbers \( u_{ij} \).

\[ u_{ij} \in [l_{ij}, u_{ij}] \quad (0 \leq l_{ij} < u_{ij} < 1, i=1,2,...,n, j=1,2,...,7) \]

In order to eliminate dimension and increases the comparability of various decision-making goals, using gray range transformation type of security benefit target and economic target cost type transformation as follows:

The target of secure benefits:

\[ S_x = (u_{ij} - l_{ij}) / (u_{ij} - l_{ij}), S_x = (u_{ij} - l_{ij}) / (u_{ij} - l_{ij}) \]

Among them, \( u_{ij} \) means the maximum value of upper limit of all \( u_{ij} \), which is \( l_{ij} = \min \{ l_{ij} \} \); \( u_{ij} \) means the minimum value of lower limit of all \( u_{ij} \), which is \( u_{ij} = \max \{ u_{ij} \} \).

The target of economic cost:

\[ S_y = u_{ij} / (u_{ij} - l_{ij}), \quad \bar{S}_y = u_{ij} / (u_{ij} - l_{ij}) \]

Among them, \( u_{ij} \) means the maximum value of upper limit of all \( u_{ij} \), which is \( u_{ij} = \max \{ u_{ij} \} \); \( l_{ij} \) means the minimum value of lower limit of all \( u_{ij} \), which is \( l_{ij} = \min \{ l_{ij} \} \).

B. The objective function setting and correlation calculation

In the decision-making of the grey correlation optimal loading reinforcement scheme should meet the following criteria: (1) the goods not out-off-gauge; (2) the height of gravity center of loaded wagon is less than 2000 millimeter; (3) horizontal deflection of gravity center of goods tend to 0; (4) longitudinal deflection of gravity center of goods tend to 0; (5) the goods distribution uniformity, there is no centralized phenomenon; (6) vehicle load utilization rate is 100%; (7) all landowners unused special car, traveling block; (8) the goods safety, do not need to use the loading reinforcement material. The optimal effect obviously, this is impossible to achieve, in reality it is just a set of virtual concluded from the decision goal theory is optimization scheme, the existence of cargo loading reinforcing scheme in theory, with the ideal effect vector group said:

\[ x_0 = (x_0^{(1)}, x_0^{(2)}, x_0^{(3)}, x_0^{(4)}, x_0^{(5)}, x_0^{(6)}, x_0^{(7)}) = (0,0,0,0,0,0,0) \]

By comparing the relationship between the effect of each scheme and ideal vector, can see intuitive solution and inferiority.

Computing solutions through the various decision objectives, that is between the solution \( x_0^{(i)} \) and the optimal effect \( x_0^{(i)} \) of ideal vector grey correlation coefficient \( \gamma(x_0^{(j)}, x_0^{(i)}) \) as follows:

\[ \gamma(x_0^{(j)}, x_0^{(i)}) = \frac{1}{2} \left[ \min_{\sigma \in \sigma(x_0^{(j)}, x_0^{(i)}, w, \lambda)} \left| x_0^{(j)} - x_0^{(i)} \right| + \lambda \max_{\sigma \in \sigma(x_0^{(j)}, x_0^{(i)}, w, \lambda)} \left| x_0^{(j)} - x_0^{(i)} \right| \right] \]

(8)

Among them, \( x_0^{(j)} = \max \{ x_0^{(j)} \} \); \( \bar{x}_0^{(i)} = \max \{ \bar{x}_0^{(i)} \} \). \( \lambda \in [0,1] \) is distinguish coefficient or environmental control factors, in general, \( \lambda \) value of 0.5.

At this time, the target given weight vector for 7 decisions \( w = (w_1, w_2, ..., w_7) \), then has the plan of grey correlation degree \( \sigma(x_0, x) \) is:

\[ \sigma(x_0, x) = \sum_{j=1}^{7} w_j \gamma(x_0^{(j)}, x) \]

Finally, the gray correlation degree of the effect of the various options to get the best effect of the vector and the vector can be a more direct comparison to see a program is good or bad. Take the minimum degree of correlation in this approach, scilicet the gray correlation degree is smaller, the more excellent of the program; the better the correlation, the program is not ideal.

IV. CASE STUDIES

Suppose there is a certain type of machinery, its weight is 40 tons, the overall dimensions in 7700mm×3860mm×2700mm, the bearing surface size is 5500mm×3000mm. Its gravity height is 1800mm high, and the distance from the left edge is 1750mm. The cross section as shown in Fig.1:
For each possible project, the corresponding indicators date will be calculated as following:

Scheme 1: The geometric center of the goods falls on the center of the $N_{12}$-type flat train without overloading. The gravity height is 2214mm, and the horizontal offset is 70mm. The train is ordinary, but is reinforced by 6 steel wires (17mm diameter). The capacity utilization rate is 0.66.

Scheme 2: The geometric center of the goods falls on the center of the $N_{12}$-type flat train with first-degree overloading. The gravity height is 2214mm, and the horizontal offset is 70mm. The train is ordinary, but is reinforced by 8 steel wires (17mm diameter). The capacity utilization rate is 0.66.

Scheme 3: The geometric center of the goods falls on the center of the $D_{1}$-type special train which is longer and bigger with first-degree overloading. The gravity height is 2049mm, and the horizontal offset is 70mm. The train is special, and is reinforced by 6 steel wires (17mm diameter). The capacity utilization rate is 0.66.

There is no longitudinal line offset in any of the above-mentioned schemes. This indicator will be ignored in the calculation process.

The parameters of the train are shown as following:

1)The dead weight and the load weight of $N_{12}$-type train is 20.5t and 60t. The length and width of the floor is 12500 and 3070mm, and its height is 1180mm. The gravity height of the empty train is 70mm.

2)The dead weight and the load weight of $D_{1}$-type train is 31t and 60t. The length and width of the floor is 16800 and 2890mm, and its height is 1294mm. The gravity height of the empty train is 70mm.

From the above, the quantitative evaluation of value for each scheme are shown as in Tab.1.

<table>
<thead>
<tr>
<th>Scheme</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>S6</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>0</td>
<td>0.214</td>
<td>0.7</td>
<td>0.37</td>
<td>[0.0]</td>
<td>6</td>
</tr>
<tr>
<td>A2</td>
<td>(0,0.3)</td>
<td>0.214</td>
<td>0</td>
<td>0.37</td>
<td>[0.0]</td>
<td>8</td>
</tr>
<tr>
<td>A3</td>
<td>(0,0.3)</td>
<td>0.049</td>
<td>0.7</td>
<td>0.37</td>
<td>[0.3,0.6]</td>
<td>6</td>
</tr>
</tbody>
</table>

The standardized evaluation of the value which is calculated by the grey range transformation formula for each scheme as shown in Tab.2.

Using the vector in the formula (3) which evaluates the effects of the ideal scheme, the weighted associated coefficients in the formula (4) will be calculated and the result need to be putted in the weight vector $w = (w_1,w_2,\ldots,w_k)$ in the formula (5). For the simple calculation, the weight of the designed security benefits targets is assumed as $w_1 = w_2 = w_3 = 0.6$, and the weight of the economic cost targets is assumed as $w_4 = w_5 = w_6 = 0.4$.

The grey interval associated coefficients between the each assumed scheme and the ideal scheme is shown as following:

\[
\sigma_1(x_{0i},x_i) = 0.40476 \\
\sigma_2(x_{0i},x_i) = 0.45238 \\
\sigma_3(x_{0i},x_i) = 0.45238 \\
\]

According to the calculation results, the scheme 1 is the best.

The instance of the scheme is relatively simple, but through the results of the association decision of the above three kinds of loading reinforcement, the conclusion are believable. Although the height of the gravity and the overload level is still in a relatively important position, but by introduced of cost factors which evaluates the pros and cons of the loading reinforcement scheme, the cost changes by using the special train and reinforcement material will also have a greater impact on the final result. The actual decision results is consistent with the artificial judgment.

V. CONCLUSION AND WEAKNESSES

In the loading reinforcement scheme comparison, we need to consider the safety and economic benefit of transportation. So the grey ratio incidence degree coefficient formula and grey interval relative incidence coefficient formula should be induced to compare each scheme to the ideal scheme. The overload level, the height of the center of the gravity, the offset of center of gravity, the capacity utilization rate, the using of the special train, the number of reinforcement materials are all need to be handled dimensionless to make the result of grey relational decision consistent with the actual situation. When we use the minimum correlation method to make a decision, the deviation in the similar degree between the mother factors sequence and the sub factors sequence will make the decision-making results more close to the actual results. But since there is no a large amount of data for the empirical study, it need a further research in the future.
ACKNOWLEDGEMENTS

This work was financially supported by the key project of the Ministry(2014S14022).

REFERENCES


[4] Zhang Li,Gai Yuxian.(2006). Evaluation on the loading plan of exceptional dimension Freight with Improved AHP. Railway transport and economy. 6 (28) :70-72