Research on Decision-making Model for Transport Means of Equipment Based on Multi-factor Comprehensive

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Abstract. This paper systematically analyzes the influencing factors of the transport means of equipment. Based on the principles of completeness, maneuverability, rationality and comparability, this paper puts forward a multi-factor comprehensive evaluation index system covering safety index, timeliness index and economy index. Combining the multi-factor comprehensive evaluation model, the decision-making model of the transport means of equipment and the decision mode of combined transportation mode are constructed, and the construction and solution process of the combined transportation mode decision model is analyzed by assuming the case. The multi-factor comprehensive evaluation model of the transport means of equipment proposed in this paper provides a quantitative analysis method for the transport means of equipment decision-making, which lays a foundation for further evaluation of equipment transportation efficiency.

1. Introduction

The transport means of equipment used during routine training and in transit in wartime are generally classified into roads, railways, waterways, and air. Each of them has applicable conditions and advantages, and has been compared with others and analyzed by many experts and scholars. Yu Danya [1] put forward an evaluation system for advantage index of waterway transport and analyzed and commented each index. Zheng Yi [2], Zhao Ruijia [3] and Xu Junhua [4] analyzed the advantages and applicability of waterway transport and road transport from different angles. Zhao Wenjuan [5] and Zhang Xueqin [6] considered that each of them has its most favorable application scope through analyzing the technical and economic characteristics of four transport means. However, how to select one or a combination of transport means from four transport means for a specific transport task. It is not enough to decide the most favorable transport means by considering the advantages and disadvantages of one of them, it is also necessary to analyze evaluation factors of transport means comprehensively and quantitatively analyze transport means by constructing a multi-factor comprehensive evaluation model.
2. Multi-factor comprehensive evaluation index system

Due to different design characteristics of equipment for different transport means and the safety, time and cost required for different transport means used for a specific transport task are different; therefore, it is necessary to construct an evaluation index system for transport means based on various factors to determine the best transport means for the task.

2.1 Principle of index system construction

Identify and establish a systematic and reasonable evaluation index system based on certain construction principles is the premise of constructing a decision-making model of transport means of equipment. The principles [1] adhered to construct a multi-factor comprehensive evaluation index system of transport means of equipment are as follows:

2.1.1 Completeness. The evaluation index system should reflect all characteristics of a transport means as much as possible.

2.1.2 Maneuverability. The evaluation index should be quantitative if possible, to perform an intuitive comparison based on values.

2.1.3 Rationality. The evaluation index must have clear boundary and reasonable content, to clearly express the contents to be compared.

2.1.4 Comparability. The evaluation index must be comparable among different transport means.

2.2 Frame of index system

In this paper, the frame of a multi-factor efficiency evaluation index system of transport means is constructed based on the construction principles from aspects of safety, timeliness and economy. Safety includes reliability of transport means; timeliness includes transport time, on-time delivery rate, intact delivery rate; economy includes generality of equipment and transport cost [7, 8, 9].

2.2.1 Safety index. Safety index refers to the probability of a transport means to complete a task under a specific environment and transportation condition. It is represented by the reliability of transport means.

2.2.2 Timeliness index. Timeliness of a transport means are indicated by transport time, on-time delivery rate and intact delivery rate. Transport time is represented by time required for each link of transport [7] and waiting time, on-time delivery rate is represented by the ratio of on-time delivery times to total delivery times of equipment, and intact delivery rate is represented by the ratio of intact delivery times to total delivery times of equipment to the destination. Under the same conditions, when the shortest transport time is, the higher the on-time delivery rate is, and the higher the intact delivery rate is, the higher the timeliness index is.

2.2.3 Economy index. Economy index can be divided into generality of equipment and transport cost. Generality index refers to the general condition of transported resource during transport of equipment, and the transport cost refers to the expenses arising from personnel, equipment, maintenance and energy consumption in the transport of equipment. Under the same conditions, when the fewer the type and quantity of special and newly-researched equipment used is and the lower the transport cost is, the higher the economy of the transport means is.

3. Decision-making Model for Single Transport Means

Single transport means refers that only one of road transport, railway transport, waterway transport and air transport is used to complete a specific task.
Definition 1: $u_i$ refers to the valuation index of transport means; $u_2$ refers to the reliability of transport means; $u_3$ refers to transport time; $u_4$ refers to on-time delivery rate; $u_5$ refers to intact delivery rate; $u_6$ refers to generality of equipment; $u_7$ refers to transport cost.

Definition 2: $t_i$ refers to the transport means of equipment; and $t_1$ refers to the road transport, $t_2$ refers to the railway transport, $t_3$ refers to the waterway transport, and $t_4$ refers to the air transport.

Definition 3: $u_i(t_j)$ refers to $i$ evaluation index of $j$ transport means, and $f_{ij}$ refers to the single factor evaluation value of this index.

The specific formula of $f_{ij}$ is as follows:

$$f_{ij} = u_i(t_j) / \sum_{i=1}^{4} u_i(t_j) \quad i=1,2,3,4$$

Definition 4: $w_i$ refers to the weighted value of importance of $i$ transp.

Based on the formula (1) and (2), the multi-factor comprehensive evaluation values of road transport ($t_1$), railway transport ($t_2$), waterway transport ($t_3$) and air transport ($t_4$) are calculated and expressed as follows:

$$F_1 = w_1f_{i1} + w_2f_{i2} + w_3f_{i3} + w_4f_{i4} + w_5f_{i5} + w_6f_{i6}$$

$$F_2 = w_1f_{21} + w_2f_{22} + w_3f_{23} + w_4f_{24} + w_5f_{25} + w_6f_{26}$$

$$F_3 = w_1f_{31} + w_2f_{32} + w_3f_{33} + w_4f_{34} + w_5f_{35} + w_6f_{36}$$

$$F_4 = w_1f_{41} + w_2f_{42} + w_3f_{43} + w_4f_{44} + w_5f_{45} + w_6f_{46}$$

Then, $t_j$ refers the best transport means selected after comprehensive comparison and evaluation for above-mentioned factors, and $F_j$ refers the integrated evaluation value for the best transport means.

4. Decision-making Model for a Combination of Transport Means

Instead of just one transport means, two or more transport means are often required for a task due to complex and changeable natural environment and battlefield situation. We select the best combination of transport means by constructing a selection model for combined transport means and considering various factors.

4.1 Steps of model construction

1) Draw a network diagram for multi-path transport of equipment with the origin and destination clearly specified;

2) Determine the integrated evaluation value of the best transport means from the node of the previous layer to the destination in turn by deducting from the destination reversely and referring to the selection model of single transport means;

3) Determine the best combination of transport means between the nodes of each layer by deducting from front to back, and then determine the corresponding transport route.

4.2 Example of model construction

The decision-making model of combination of transport means is complex, which is illustrated briefly through giving examples.

4.2.1 Problem description. In order to meet the reserve demand of materials, it is necessary to transport a batch of equipment system from A to E. Due to long distance, different levels of transit
warehouses are required during the transport, and the specific route is shown in Figure 1 below. It is assumed the distance for various transport means used are calculated with \( d_i \).

![Network Diagram for Transport of Equipment](image)

**Figure 1** Network Diagram for Transport of Equipment

4.2.2 Model construction.

4) The model is solved by the single transport means of Equation 1 - Equation 7 to obtain the integrated evaluation values \( F(D_1) \) and \( F(D_2) \) of the most reasonable transport means for \( D_1 \)-E and \( D_2 \)-E, so as to determine the most reasonable transport means for each of them respectively.

Then:

\[
F(D_1) = N_1, S(D_1) = E; F(D_2) = N_2, S(D_2) = E.
\]

Among them, \( N_i \) indicates the integrated evaluation value of the best transport means from a transfer station to a terminal at a certain level of transport, \( S(D_i) = E \) means that the transport route corresponding to the most reasonable transport means from the transfer station \( D_1 \) to \( E \) is \( (D_1 - E) \).

5) The optimal transport means and corresponding transport route algorithm of the two transfer stations on the layer C are as follows:

\[
F(C_1) = \max \left\{ \frac{d_{10}F(C_1 - D_1)}{d_{10} + d_{14}}, \frac{d_{14}F(D_2)}{d_{14} + d_{15}} \right\}
\]

\[
F(C_2) = \max \left\{ \frac{d_{12}F(C_2 - D_1)}{d_{12} + d_{14}}, \frac{d_{14}F(D_1)}{d_{14} + d_{15}} \right\}
\]

Make:

\[
\frac{d_{10}F(C_1 - D_1)}{d_{10} + d_{14}} = N_3, \quad \frac{d_{14}F(C_1 - D_2)}{d_{14} + d_{15}} = N_4, \quad N_3 > N_4;
\]

\[
\frac{d_{12}F(C_2 - D_1)}{d_{12} + d_{14}} = N_5, \quad \frac{d_{14}F(D_1)}{d_{14} + d_{15}} = N_6, \quad N_5 > N_6.
\]

Then you can get,

\( S(C_1) = D_1 \), that is, the transport route corresponding to the optimal transport means of the transfer station \( C_1 \) to \( D \) is: \( C_1-D_1 \);

\( S(C_2) = D_1 \), that is, the transport route corresponding to the optimal transport means of the transfer station \( C_1 \) to \( D \) is: \( C_1-D_1 \).

6) The optimal transport means and corresponding transport route algorithm of the three transfer stations on the layer B are as follows:
Determine the combination of transport means.

Because of $S(A) = B_1$, the transport route from A to B is: $A - B_1$.

Because of $S(B_1) = C_1$, the transport route from B to C is: $B_1 - C_1$.

Because of $S(C_1) = D_1$, the transport route from C to D is: $C_1 - D_1$.

Because of $S(D_1) = E$, the transport route from D to E is: $D_1 - E$. 

7) Same as above, the optimal transport means of the transfer station A and the corresponding transport route algorithm are as follows:

$$F(A) = \max \left\{ \begin{array}{l}
\frac{d_1 F(A - B_1)}{d_1 + d_4 + d_{10} + d_{14}} + \frac{(d_4 + d_{10} + d_{14}) F(B_1)}{d_4 + d_{10} + d_{14}} \\
\frac{d_2 F(A - B_2)}{d_2 + d_6 + d_{10} + d_{14}} + \frac{(d_6 + d_{10} + d_{14}) F(B_2)}{d_6 + d_{10} + d_{14}} \\
\frac{d_3 F(A - B_3)}{d_3 + d_8 + d_{10} + d_{14}} + \frac{(d_8 + d_{10} + d_{14}) F(B_3)}{d_8 + d_{10} + d_{14}}
\end{array} \right\}$$

Make:

$$\frac{d_4 F(B_2 - C_1)}{d_4 + d_{10} + d_{14} + (d_{10} + d_{14}) F(C_1)} = N_7,$$
$$\frac{d_5 F(B_2 - C_2)}{d_5 + d_{12} + d_{14} + (d_{12} + d_{14}) F(C_2)} = N_8,$$
$$\frac{d_6 F(B_2 - C_3)}{d_6 + d_{10} + d_{14} + (d_{10} + d_{14}) F(C_3)} = N_9,$$
$$\frac{d_7 F(B_2 - C_4)}{d_7 + d_{12} + d_{14} + (d_{12} + d_{14}) F(C_4)} = N_{10},$$
$$\frac{d_8 F(B_2 - C_5)}{d_8 + d_{10} + d_{14} + (d_{10} + d_{14}) F(C_5)} = N_{11},$$
$$\frac{d_9 F(B_2 - C_6)}{d_9 + d_{12} + d_{14} + (d_{12} + d_{14}) F(C_6)} = N_{12},$$
$$\frac{d_10 F(B_2 - C_7)}{d_{10} + d_{12} + d_{14} + (d_{12} + d_{14}) F(C_7)} = N_{13},$$
$$\frac{d_11 F(B_2 - C_8)}{d_{11} + d_{12} + d_{14} + (d_{12} + d_{14}) F(C_8)} = N_{14},$$
$$\frac{d_12 F(B_2 - C_9)}{d_{12} + d_{12} + d_{14} + (d_{12} + d_{14}) F(C_9)} = N_{15}.$$ 

Then you can get,

- $S(B_1) = C_1$, that is, the transport route corresponding to the optimal transport means of the transfer station B1 to C is: B1-C1;
- $S(B_2) = C_1$, that is, the transport route corresponding to the optimal transport means of the transfer station B2 to C is: B2-C1;
- $S(B_3) = C_1$, that is, the transport route corresponding to the optimal transport means of the transfer station B3 to C is: B3-C1.

8) Determine the combination of transport means.

Because of $S(A) = B_1$, the transport route from A to B is: $A - B_1$.

Because of $S(B_1) = C_1$, the transport route from B to C is: $B_1 - C_1$.

Because of $S(C_1) = D_1$, the transport route from C to D is: $C_1 - D_1$.

Because of $S(D_1) = E$, the transport route from D to E is: $D_1 - E$. 

Then you can get,

- $S(A) = B_1$, that is, the transport route corresponding to the best transport means of transfer stations A to B is: $A - B_1$.
Therefore, the transport route under the best combination of transport means is: A−B₁−C₁−D₁−E.

In summary, the most reasonable combination of transport means is:
The transport means corresponding to F(A−B₁) is adopted for A-B₁ road section;
The transport means corresponding to F(B₁−C₁) is adopted for B₁-C₁ road section;
The transport means corresponding to F(C₁−D₁) is adopted for C₁-D₁ road section;
The transport means corresponding to F(D₁) is adopted for D₁-E road section.

5. Conclusion

The decision making of equipment transport means is a difficult point in equipment transport research. In recent years, China has recognized the importance of equipment transport, carried out research on equipment transport and obtained some research results, but it is still in the development stage. There is still a certain gap compared with foreign countries. From the aspects of safety, timeliness and economy, this paper comprehensively analyzes the influencing factors of equipment transport means, and builds a decision-making model of equipment transport means based on multi-factor integrated evaluation, which solves the decision making of transport means of equipment transport problem to some extent. The paper is hoped to provide reference for relevant scholars to carry out research on equipment transport related content.

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References

[1] Yu Danya. Research on the Evaluation Index System of Comparative Advantages of Waterway Transport [J]. Journal of Transport Research, 2018, 4(2): 1-6.
[2] Zheng Yi. Advantages of Economic Development of Waterway Transport under Low Carbon Economy [J]. Economic and Trade Practice, 2017(17): 57.
[3] Zhao Ruijia, Xie Xinlian, Wei Zhaokun. Quantitative Analysis and Comparison of Energy Saving and Emission Reduction for Highway and Waterway Transport [J]. Journal of Energy Conservation and Environmental Protection, 2017, 13(3): 46-50.
[4] Xu Junhua. Analysis of Economic Development Advantages of Waterway Transport under Low Carbon Economy [J]. Modern Business, 2018(8): 11-12.
[5] Zhao Wenjuan. Comparison of Technical and Economic Characteristics of Various Transport Means [J]. Cooperative Economy and Technology, 2017(3): 38-39.
[6] Zhang Xueqin, Cao Lixin. Comparative Analysis of Technical and Economic Characteristics of Various Transport Means [J]. Journal of Transport and Transport (Academic Edition), 2013(3): 170-172.
[7] Qian Wu, Xiaowei Lu, Shuang Wang and Dong Zheng. Analysis of Influencing Factors on the Transportation of Equipment [C]. ICSSD 2018, 2018: 364-374.
[8] Qian Wu, Ma Lin, Chaowei Wang. Study on Evaluation Index System of Equipment System Transportability [C], WCEAM2013, 2015: 1539-1547.
[9] Wu Qian. Research on the Transport Analysis Method of UAV System [D]. Beijing: Beihang University, 2014.