Modeling and evaluation for effectiveness of dangerous chemicals transport vehicle based on ADC model

Kan Zhou¹*, Ge Huang¹, Hongbo Wang¹ and Huang Huang¹

¹Institute of Chemical, Beijing, China

*E-mail:517525860@qq.com

Abstract. Based on the ADC model proposed by WSEIAC, this paper establishes the effectiveness evaluation index system of the dangerous chemicals transport vehicle. Then the analytic hierarchy process (AHP) and fuzzy comprehensive evaluation method are combined to distribute the index weight reasonably, and the ability value is quantified to establish the ADC effectiveness evaluation model of the system. Finally, an example is given to verify the evaluation model. The results show that the effectiveness evaluation model has the feasibility and reference value of engineering application.

1. Introduction
The transportation of hazardous chemicals is related to the safety of people's lives and property. Once an accident occurs, it is easy to cause a significant negative impact on the society [1]. According to the nature of hazardous chemicals and the demand for safe transportation, the dangerous chemical transportation vehicle shall have concurrently explosion-proof and chemical defense two functions, be able to resist the shock wave generated by the explosion of the transported hazardous chemicals, be able to monitor and prevent the leakage and diffusion of hazardous chemicals in various situations, especially after the explosion, and have the corresponding emergency decompression and disinfection disposal capability to maximize the Reduce transport risk. Therefore, the effectiveness evaluation of dangerous chemicals transport vehicle is very important in the transportation decision of dangerous chemicals, but there is no reasonable and effective efficiency evaluation model for a long time.

2. ADC effectiveness evaluation model
Effectiveness is an important index of system, and has been studied in many industries [2-5]. The effectiveness of a system, in short, refers to the system’s actual ability to complete an intended mission [6]. Proposed by Weapons System Effectiveness Industry Advisory Committee (WSEIAC) [7] in the middle of 1960s, The ADC model has been the classic effectiveness evaluation model, and it is the most widely applied effectiveness model by far. Through the definition and analysis of the three indexes of system availability A, dependability D and capability C, the effectiveness evaluation method is integrated into a single effectiveness measure to describe the system effectiveness. Availability is a measure of the system state at the beginning of task execution. Dependability is a measure of the system state at one or more moments in the process of task execution under the condition that the system is known to be in the state at the beginning of task execution. Inherent capability is a measure of the system's ability to achieve the task goal under the condition that the system is known to be in the state at the beginning of task execution.
The expression for this model is

\[ E = ADC \]  

(1)

where: the matrix \( A \) represents the availability vector of the system to be evaluated, which is a measure of the degree to which the system is in a working state or can undertake tasks when it starts to execute tasks. \( A = \{a_1, a_2, a_3, \ldots, a_n\} \), \( n \) is the number of states when the system starts executing tasks.

Among them, \( \sum a_i = 1 \).

Matrix \( D \) is the dependability index of the system. It is the expression of the system state transition index when the system starts to perform tasks in one state and ends in another state. It reflects the dependability of the system. Matrix \( D \) is the dependability matrix of \( N \times N \).

Matrix \( C \) is the inherent capability index of the system, which is a measure of the capability of the system to complete tasks under various conditions. If only one performance of the system is evaluated, then \( C \) is only a vector, if several (e.g. \( m \)) capabilities of the system are evaluated, then \( C \) is the capability matrix of \( N \times M \).

\( C_j \) represents the probability of completing the task when the system is in state \( j \), and \( C_{ij} \) represents the probability of completing the sub task \( j \) when the system is in state \( i \). The calculation of \( C_{ij} \) can be realized by self-defined measurement method or operation model.

The matrix \( E \) represents the comprehensive efficiency index of the system to be evaluated, which is a comprehensive measure of the system's ability to complete tasks. It is usually expressed by the probability value.

3. ADC effectiveness evaluation model of dangerous chemicals transport vehicle

3.1. Determination of effectiveness evaluation index system

The availability matrix \( A \) of dangerous chemicals transport vehicles is mainly determined by the reliability, maintainability and maintenance management level of the system, specifically by the failure rate \( \lambda \) and repair rate \( \mu \) of the system. Dependability matrix \( D \) directly depends on the reliability of the system and the repairability in the process of use, as well as the quality of personnel. Capability matrix \( C \) represents the inherent capability of the system, which is determined by the design and manufacturing of the system. It mainly includes work capability, carry out ability, man-machine-environment, etc. The main indexes of work capability include loading capability, anti-explosion capability and sealability. Carry out ability includes maneuverability, emergency capability, decontamination ability. Man-machine-environment includes human-computer interface and labor intensity. Considering the above factors comprehensively, a performance evaluation index system for dangerous chemicals transport vehicle was constructed, as shown in figure 1.

![Figure 1](image-url)
3.2. Determination of availability matrix
It is assumed that the dangerous chemical transport vehicle has only two states, namely normal working state and fault state. In this case, the availability matrix has only two components \( a_1 \) and \( a_2 \), namely

\[
A = \begin{bmatrix} a_1 & a_2 \end{bmatrix}
\]  

(2)

\[
a_1 = \frac{MTBF}{MTBF + MTTR}
\]  

(3)

\[
a_2 = \frac{MTTR}{MTBF + MTTR} = 1 - a_1
\]  

(4)

where: \( a_1 \) and \( a_2 \) respectively represent the probability that the system is in a working state and a fault state at any time. MTBF is the Mean Time Between Failures of system, and MTTR is the Mean Time To Repair of system.

3.3. Determination of dependability matrix
Since the system only has two availability states of work and fault when it starts to work or performs tasks, its dependability matrix is composed of four elements, namely

\[
D = \begin{bmatrix} d_{11} & d_{12} \\ d_{21} & d_{22} \end{bmatrix}
\]  

(5)

where, \( d_{11} \) is the probability that the system is in state \( a_1 \) at the beginning of the task execution and still in state \( a_1 \) at the completion of the task; \( d_{12} \) is the probability that the system is in state \( a_1 \) at the beginning of the task execution and in state \( a_2 \) at the completion of the task; \( d_{21} \) is the probability that the system is in state \( a_2 \) at the beginning of the task execution and in state \( a_1 \) at the completion of the task. \( d_{22} \) is the probability that the system is in state \( a_2 \) at the beginning of the execution of the task and still in state \( a_2 \) at the completion of the task. For a repairable system, when both MTBF and MTTR obey exponential distribution, failure rate \( \lambda \) and repair rate \( \mu \) are constant, and \( T \) is the duration of the task, then

\[
d_{11} = \frac{\mu}{\lambda + \mu} + \frac{\lambda}{\lambda + \mu} e^{-(\lambda+\mu)T}
\]  

(6)

\[
d_{12} = \frac{\lambda}{\lambda + \mu} \left[ 1 - e^{-(\lambda+\mu)T} \right]
\]  

(7)

\[
d_{21} = \frac{\mu}{\lambda + \mu} \left[ 1 - e^{-(\lambda+\mu)T} \right]
\]  

(8)

\[
d_{22} = \frac{\lambda}{\lambda + \mu} + \frac{\mu}{\lambda + \mu} e^{-(\lambda+\mu)T}
\]  

(9)

3.4. Determination of capability matrix
The capability matrix of dangerous chemicals transport vehicle is

\[
C = \begin{bmatrix} c_1 & c_2 \end{bmatrix}
\]  

(10)

where, \( c_1 \) is the probability of completing the transportation task when the system is normal, and \( c_2 \) is the probability of completing the transportation task when the system is failure. In general, \( c_2 = 0 \).

In this paper, the analytic hierarchy process (AHP) and fuzzy comprehensive evaluation method are used to quantify \( c_1 \). Determine the comment set \( V = \{ v_1, v_2, v_3, v_4 \} = \{ \text{excellent, good, medium, poor} \} = \{ 0.9, 0.8, 0.7, 0.5 \} \).

\[
c_1 = B \cdot V = \begin{bmatrix} b_1, b_2, b_3, b_4 \end{bmatrix} \cdot \begin{bmatrix} v_1 & v_2 & v_3 & v_4 \end{bmatrix}^T
\]  

(11)
In the formula, \( v_1, v_2, v_3 \) and \( v_4 \) respectively correspond to the comment set: excellent, good, medium and poor. \( B \) is the fuzzy evaluation set, and \( b_1, b_2, b_3 \) and \( b_4 \) respectively correspond to the fuzzy evaluation values of excellent, good, medium and poor.

\[
B = W \circ R = \left( w_1, w_2, \cdots, w_i \right) \circ \left[ \begin{array}{cccc}
 r_{11} & r_{12} & r_{13} & r_{14} \\
 r_{21} & r_{22} & r_{23} & r_{24} \\
 \vdots & \vdots & \vdots & \vdots \\
 r_{41} & r_{42} & r_{43} & r_{44}
\end{array} \right] = \left( b_1, b_2, b_3, b_4 \right)
\]

In the formula, \( w_i \) is the weight of index \( i \), and the weight value is determined by simple table method or Delphi expert consultation method. \( r_{ij} \) is the membership degree of item \( i \) corresponding to the comment that is good, similarly \( r_{ij} \) is the membership degree of item \( i \) corresponding to the comment that is medium, \( r_{ij} \) is the membership degree of item \( i \) corresponding to the comment that is poor. In this paper, the synthetic operator \( \circ \) is taken as the \( M(\cdot,+) \) operator. If \( \Sigma B \) is not equal to 1, normalization is performed.

3.5. Calculation of performance evaluation value

The availability matrix \( A \), dependability matrix \( D \) and capability matrix \( C \) obtained by the above calculation were used to calculate the effectiveness evaluation value \( E \) of dangerous chemicals transport vehicle.

4. A case study

4.1. The calculation of availability matrix

It is assumed that the transportation vehicle only has two states during the transportation of dangerous chemicals, namely normal working state and failure state, and MTBF=200h and MTTR=2h. Get: \( a_1 = 0.9901, a_2 = 0.0099, A = [a_1, a_2] = [0.9901, 0.0099] \).

4.2. The calculation of dependability matrix

For the repairable system, when the MTBF and MTTR both obey exponential distribution, the failure rate \( \lambda \) and repair rate \( \mu \) are constant, \( T \) is the duration time of the task, assuming that \( T = 30h \) for one transportation operation, then \( \lambda = 0.005, \mu = 0.5 \).

\[
D = \left[ \begin{array}{cc}
 d_{11} & d_{12} \\
 d_{21} & d_{22}
\end{array} \right] = \left[ \begin{array}{cc}
 0.9901 & 0.0099 \\
 0.9901 & 0.0099
\end{array} \right]
\]

4.3. The calculation of capability matrix

Through expert scoring, AHP is used to construct judgment matrix and carry out consistency inspection, the index weight of each layer of the capability matrix of a certain type of dangerous chemicals transport vehicle is calculated, and membership scoring is carried out for the evaluation set of excellent, good, medium and poor, as shown in Table 1.

| Table 1. Each layer index weight of capability matrix. |
|----------------|----------------|----------------|----------------|----------------|
| First layer index | Weight | Second layer index | Weight | Comment set |
| Work capability | 0.7147 | Loading capability | 0.1112 | excellent | 0.7 | good | 0.2 | medium | 0.1 | poor | 0 |
| Work capability | 0.7147 | Anti-explosion capability | 0.4444 | excellent | 0.9 | good | 0.1 | medium | 0 | poor | 0 |
| Work capability | 0.7147 | Sealability | 0.4444 | excellent | 0.9 | good | 0.1 | medium | 0 | poor | 0 |
| Work capability | 0.7147 | Maneuverability | 0.1219 | excellent | 0.1 | good | 0.7 | medium | 0.2 | poor | 0 |
By using the principle of fuzzy relation synthesis, the capacity value can be obtained. Then
\[ B_1 = (0.8778, 0.1111, 0.0111, 0), \quad B_2 = (0.7706, 0.1731, 0.0563, 0), \]
\[ B_3 = (0.7667, 0.2000, 0.0333, 0), \quad B = (0.8470, 0.1306, 0.0224, 0) \]

The capacity value of this type of dangerous chemicals transport vehicle in normal operation is
\[ c_1 = 0.8824 \]

4.4. The calculation of performance evaluation value

The effectiveness evaluation value of this type of dangerous chemicals transport vehicle is
\[ E = ADC = \begin{bmatrix} 0.9901 & 0.0099 \\ 0.9901 & 0.0099 \end{bmatrix} \begin{bmatrix} 0.8824 \\ 0 \end{bmatrix} = 0.8737 \]

5. Conclusions

Based on the characteristics of dangerous chemicals transport vehicle and the ADC model proposed by WSEIAC, this paper analyses the main factors that affect the effectiveness, establishes the effectiveness evaluation index system of dangerous chemicals transport vehicle. The use of AHP and fuzzy comprehensive evaluation method considers the relationship between the evaluation indexes. The weight distribution of the indexes is reasonable and the evaluation method is in line with the actual situation. The case analysis shows that the effectiveness evaluation method proposed in this paper has the feasibility and reference value of engineering application.

References

[1] K. Zhou, G. Huang, Q. Z. Zhao, S. Wang, Performance Evaluation of Dangerous Goods Transport Vehicle Based on Analytic Network Process(ANP). CA. 4th International Conference on Intelligent Transportation Engineering. 232-236 (2019)
[2] W. H. Guo, X. F. Shao, Detection Effectiveness of Ship-borne Radar under Interference Environment Based on ADC Model. J. Command Control & Simulation. 3, 47-49 (2014)
[3] X. Y. Zheng, J. S. Yao, A Method to Evaluate the Effectiveness of a Radar Based on FAHP. J. Modern Radar. 24, 7-9 (2002)
[4] P. Zhang, S. G. Li, N. Xiao, Effectiveness Evaluation for Armored Ambulance Combat Capability Based on Index Method. J. Journal of Ordnance Equipment Engineering. 37, 171-175 (2016)
[5] Y. Li, W. Liu, Research on Efficiency Evaluation Model of Electric Power Information System. J. Advanced Materials Research. 1044, 1446-1451 (2014)
[6] Q. S. Guo, Introduction to Equipment Effectiveness Evaluation. National Defense Industry Press. (2005)
[7] W. F. Stevens, Weapon System Effectiveness Industry Advisory Committee. J. Systems Engineering. (1964)