Forest Chemicals Review
www.forestchemicalsreview.com
ISSN: 1520-0191
May-June 2022 Page No. 1055-1062
Article History: Received: 24 February 2022, Revised: 05 April 2022, Accepted: 08 May 2022, Publication: 30 June 2022

Research on Civil Aviation Safety Supervision Capability Evaluation Model Based on Entropy Weight TOPSIS

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Abstract:

Taking the safety concept proposed by ICAO and the classical SHEL model in the field of aviation safety as the theoretical basis, in combination with the characteristics of civil aviation safety supervision, the evaluation index system of civil aviation safety supervision capability is constructed from the perspective of finding the safety problems of administrative counterparts in civil aviation safety supervision, including 12 evaluation indicators in 4 dimensions: "issues of institutional responsibilities", "issues related to people", "issues related to equipment and facilities environment" and "issues related to system procedures". The entropy weight method was used to calculate the weight of each evaluation index, and then the TOPSIS method was used to comprehensively rank the safety supervision capability of the civil aviation regional administrations. The study shows that the entropy TOPSIS method, as a mathematical modeling method based on data itself, can reduce the subjectivity of experts' assignments and can provide a scientific basis for the evaluation of civil aviation safety supervision capability.

Keywords*: Civil aviation administrative authorities, Capacity evaluation; entropy method, TOPSIS method, SHEL model.*

I. INTRODUCTION

Safety is the lifeline of civil aviation industry. According to statistics, by the end of 2021, China's civil aviation has achieved a new record of "120+16" months, 98.76 million hours of continuous safe flight for transport aviation, and 235 months of air defense safety, and will soon cross the 100 million hours mark for safe flight for transport aviation. The good development of the industry has been accompanied by a complicated regulatory environment for civil aviation safety. The number of administrative counterparts is increasing, the scale is growing, and more complex forms of business chains are being formed, which puts forward higher requirements and standards for the safety supervision capability of civil aviation administrative authorities.

The level of safety supervision capability of civil aviation administrative authorities is a key factor affecting the overall safety level of the industry, and the evaluation of their safety supervision capability helps civil aviation regulatory units understand the level of regional safety supervision, identify safety risks and take control measures. At present, the domestic literature has carried out studies on the evaluation of

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safety supervision capacity mainly in the fields of food safety[1-2], drug safety[3-4], and financial safety[5]. The research paths of the existing literature mostly revolve around the safety supervision input and output elements, as well as the industry safety supervision procedures to construct safety supervision evaluation indexes, which have disadvantages such as index settings are easily influenced by subjective factors and evaluation criteria are not easily defined; while the Delphi Method, the analytic hierarchy process (AHP), the Fuzzy Comprehension Evaluation Method and other expert empowerment methods also have a certain degree of subjective factors.

This paper uses the safety concept proposed by ICAO and the classical SHEL model in the field of aviation safety as the theoretical basis to construct a more universal and practical evaluation index system of safety supervision capacity of civil aviation. The entropy weight TOPSIS method is used to construct the evaluation model of safety supervision capability of civil aviation administrative authorities, which is based on the original data of safety supervision to calculate the index weights, which is conducive to overcoming the influence of subjective factors of expert assignment method and improving the accuracy of evaluation results[6-7].

II. ESTABLISHMENT OF CIVIL AVIATION SAFETY SUPERVISION CAPACITY EVALUATION INDEX SYSTEM

2.1 Construction of Evaluation Index System

ICAO defines safety in the fourth edition of the Safety Management Manual (Doc 9859) as "a state in which the risks of aviation activities associated with or directly supporting the operation of an aircraft are reduced and controlled to an acceptable level", and administrative counterparts such as airlines, air traffic control units, and maintenance units, as the object of safety supervision by civil aviation administrative authorities, their safety assessment is mainly to evaluate the performance of the severity and number of unsafe events and accident signs triggered in aviation activities. Through continuous hazard identification and risk management, civil aviation administrative authorities reduce and maintain the risk of human injury or property damage to an acceptable level or below, which is also the main objective of their safety supervision. Based on the above two points, this paper takes the classical model of aviation safety - SHEL model as the theoretical basis, analyzes civil aviation safety supervision work from four aspects: Software, Hardware, Environment and Liveware, combines the safety concept of ICAO and the analysis framework of supervision problems established by Chinese civil aviation to build evaluation index system, and evaluates the safety supervision capability of civil aviation administrative authorities from the perspective of the type and number of problems found by administrative inspection of administrative counterparts. The evaluation index system of civil aviation safety supervision capability is shown in Table I.

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TABLE I. Civil aviation administrative authority's safety supervision capacity evaluation index system

Level I index	Level II index	Interpretation of indicators
A Issues of institutional responsibilities	A1. Inadequate organization/position	The number of problems found in the administrative inspection that the administrative counterpart's "organizational structure/position setting does not meet the regulatory requirements or operational requirements", a positive indicator.
	A2. Unclear responsibilities	The number of problems found in the administrative inspection of the administrative counterparts "fail to clearly defined responsibilities for the relevant work or unclear division of responsibilities", a positive indicator.
B. Issues related to people	B1. Work ability	The number of problems found in the administrative inspection that the administrative counterparts "front-line personnel fails to master their own duties, do not master their own work procedures and requirements, etc." is a positive indicator.
	B2. Work style	The number of problems of "intentional violation, negligence and blind confidence of front-line personnel" found in administrative inspection, a positive indicator.
	B3. Staffing	The number of problems found in the administrative inspection of the administrative counterparts "the number of staff equipped does not meet the requirements of the regulations and the actual work needs, and the duty time exceeds the limit, etc.", a positive indicator.
	B4. Personnel qualification	The number of problems found in the administrative inspection of administrative counterparts "arranging unqualified personnel to perform the relevant work", a positive indicator.
C. Issues related to equipment and facilities environment	C1. Environmental completeness of equipment and facilities	The number of problems found in the administrative inspection of the administrative counterpart "equipped with the number of equipment and facilities, functions, etc. do not meet the regulatory requirements or operational requirements", a positive indicators.
	C2. Environmental integrity of equipment and facilities	The number of problems found in the administrative inspection of the administrative counterpart "direct defects such as equipment and facilities failure", a positive indicator.
D. Issues related to system procedures	D1. Program defects	The number of problems found in the administrative inspection of the administrative counterpart "problems in the content and communication of systems/procedures/standards", a positive indicator.
	D2. Program not executed	The number of problems of "non-implementation of regulations and procedures at the organizational level" of administrative counterparts found during administrative

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		inspections, a positive indicator.
	D3. Inadequate implementation of procedures	The number of problems found in the administrative inspection of the administrative counterpart "inadequate implementation of regulations and procedures at the organizational level", a positive indicator.
	D4. No procedure	The number of problems found in the administrative inspection of the administrative counterpart "does not have the required system/procedure/standard", a positive indicator.

2.2 Indicator Evaluation Criteria

China's civil aviation safety supervision implements the basic model of "administrative inspection finds problems - administrative counterparts carry out problem rectification and feedback", the greater the number of problems found by civil aviation administrative authorities in administrative inspections, the greater the room for administrative counterparts to carry out problem rectification, and the easier it is to identify sources of danger and reduce safety risks. In the administrative inspection, the number of problems found by civil aviation administrative authorities that may induce unsafe events or accident signs is the most direct and objective manifestation of their safety supervision ability. The indicator provides a visual quantitative picture of the level of safety supervision, while the data itself reduces the influence of subjective judgments and provides ease of data collection. Therefore, this paper uses the number of different types of problems found by the administrative inspection of civil aviation administrative authorities as an evaluation index to establish a safety supervision capacity assessment model.

III. CIVIL AVIATION SAFETY SUPERVISION CAPABILITY EVALUATION MODEL BASED ON ENTROPY WEIGHT TOPSIS METHOD

3.1 Standardization of Raw Data

As the governmental supervisory authority of civil aviation in China, the civil aviation regional administration undertakes the function of civil aviation safety supervision and inspection according to the law. Let the original data matrix of q civil aviation regional administrations to be evaluated for p capability evaluation indicators are:

$$X = (x_{ij})_{p \times q} \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1q} \\ x_{21} & x_{22} & \cdots & x_{2q} \\ \cdots & \cdots & \cdots & \cdots \\ x_{p1} & x_{p2} & \cdots & x_{pq} \end{bmatrix}$$

The capability evaluation index established in this paper is of the larger the better type, so it is standardized by equation (1):

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$$y_{ij} = \frac{x_{ij} - \min x_{ij}}{\max x_{ij} - \min x_{ij}} (1 \le i \le p; 1 \le j \le q) \quad (1)$$

3.2 Calculation of Index Weights Using Entropy Weight Method

Firstly, the weight w_{ij} of the ith CAA under the jth evaluation indicator is calculated by equation (2):

$$w_{ij} = \frac{y_{ij}}{\sum_{i=1}^{p} y_{ij}} (1 \le i \le p; 1 \le j \le q) \quad (2)$$

Secondly, the entropy value e_j of the qth indicator is calculated by equation (3):

$$e_j = -m \sum_{i=1}^{p} w_{ij} \cdot \ln w_{ij} (1 \le i \le p; 1 \le j \le q), m = \frac{1}{\ln p} \quad (3)$$

Then, the coefficient of variation of the indicator u_j is calculated by equation (4):

$$u_j = 1 - e_j (1 \le j \le q) \quad (4)$$

Finally, the entropy weight v_j of each indicator is calculated by equation (5):

$$v_j = \frac{u_j}{\sum_{j=1}^{q} u_j} (1 \le j \le q) \quad (5)$$

3.3 Use TOPSIS Method to Comprehensively Evaluate the Safety Supervision Capability of Civil Aviation Administrative Authorities

Firstly, the weighted normalization matrix is constructed by equation (6):

$$Y = (p_{ij})_{m \times n} = (v_{jwij})_{m \times n} \quad (6)$$

Secondly, the positive ideal solution S^+ and the negative ideal solution S^- are calculated by equation (7) and equation (8), respectively:

$$S^+ = \left\{ p_j^+ \middle| j = 1,2,....q \right\} = \left\{ \max_i p_{ij} \middle| j = 1,2,....q \right\} \quad (7)$$

$$S^- = \left\{ p_j^- \middle| j = 1,2,....q \right\} = \left\{ \min_i p_{ij} \middle| j = 1,2,....q \right\} \quad (8)$$

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Then, the Euclidean spatial distances d_i^+, d_i^- of each evaluation value vector to the positive and negative ideal solutions of the safety supervision capability of the civil aviation regional administration are calculated by equations (9) and (10):

$$d_i^+ = \left[\sum_{j=1}^{q} (p_{ij} - p_j^+)^2 \right]^{\frac{1}{2}} (1 \le i \le p) \tag{9}$$

$$d_i^- = \left[\sum_{j=1}^{q} (p_{ij} - p_j^-)^2 \right]^{\frac{1}{2}} (1 \le i \le p) \tag{10}$$

Finally, the relative proximity Ci of the evaluated object to the ideal solution is calculated by equation (11). The larger Ci is, the stronger the safety supervision capability of the evaluated civil aviation regional authority.

$$C_i = \frac{d_i^-}{d_i^+ + d_i^-} \times 100 (1 \le i \le P) \tag{11}$$

IV. CIVIL AVIATION REGIONAL ADMINISTRATION SAFETY SUPERVISION CAPABILITY EVALUATION MODEL EMPIRICAL EVIDENCE

China's civil aviation has established 7 civil aviation regional administrations in North China, Northeast China, East China, South Central China, Southwest China, Northwest China and Xinjiang, respectively, and each administration is responsible for supervising and inspecting the safe operation of air transport enterprises, airports and other civil aviation enterprises and institutions within its jurisdiction as authorized by the CAAC. The data on the problems found by the civil aviation regional administrations in administrative inspections in January 2022 were classified and organized by relevant experts to obtain the data on the problems found by the civil aviation supervision. For the consideration of data security, this paper desensitizes the regional administrations.

4.1 Calculation of Index Weights Using Entropy Weight Method

As the original data contained numbers that were 0, this paper first performs a non-negative translation process, with the translation in units of 0.01. After standardizing the original data, the entropy weight method was used to calculate the weight value of each evaluation index item, and then the data were weighted with the weight value, and the calculation results are shown in Table II below.

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TABLE II. Entropy value method to calculate the weight results

Level I index	Level II index	Information entropy value	Information utility value	Weight coefficient
A Issues of institutional responsibilities	A1. Inadequate organization/position	0.1626	0.8374	23.02%
	A2. Unclear responsibilities	0.6375	0.3625	9.97%
B. Issues related to people	B1. Work ability	0.7872	0.2128	5.85%
	B2. Work style	0.5528	0.4472	12.30%
	B3. Staffing	0.8682	0.1318	3.62%
	B4. Personnel qualification	0.6905	0.3095	8.51%
C. Issues related to equipment and facilities environment	C1. Environmental completeness of equipment and facilities	0.8169	0.1831	5.04%
	C2. Environmental integrity of equipment and facilities	0.6943	0.3057	8.41%
D. Issues related to system procedures	D1. Program defects	0.6882	0.3118	8.57%
	D2. Program not executed	0.8088	0.1912	5.26%
	D3. Inadequate implementation of procedures	0.8204	0.1796	4.94%
	D4. No procedure	0.8355	0.1645	4.52%

4.2 Comprehensive Evaluation Using TOPSIS Method

Firstly, the positive and negative ideal solution values (S+ and S-) of the evaluation index are found out, and then the distance values (di+ and di-) of each evaluation object from the positive and negative ideal solutions are calculated, respectively. Based on the di+ and di- values, the proximity of each evaluation object to the optimal solution (Ci value) is calculated. According to the Ci value to the civil aviation regional administration's safety supervision ability ranking, the calculation results are shown in Table III below.

TABLE III. TOPSIS comprehensive evaluation results

Civil aviation regional administration	Positive ideal solution distance di+	Negative ideal solution distance di-	Relative proximity Ci	Safety supervision capability ranking
A	0.234	0.231	0.496	2
B	0.336	0.01	0.028	7
C	0.206	0.243	0.541	1
D	0.283	0.118	0.294	4

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E	0.278	0.129	0.317	3
F	0.325	0.037	0.103	6
G	0.322	0.07	0.178	5

V. CONCLUSION

This paper focuses on the characteristics of civil aviation safety supervision, constructs evaluation index system of safety supervision capability of the Civil Aviation Regional Administration from the administrative inspection to find the administrative counterpart in four aspects: "issues of institutional responsibilities", "issues related to people", "issues related to equipment and facilities environment" and "issues related to system procedures". The evaluation model of the constructed civil aviation safety supervision system was established by using the entropy weight TOPSIS method, and the ranking of safety supervision capability of domestic regional safety bureaus was calculated.

The study shows that the entropy weight TOPSIS method is conducive to overcoming the subjective error of expert scoring assignment, and can obtain more objective and realistic evaluation results, improve the accuracy of evaluation results, and have better model applicability.

ACKNOWLEDGEMENTS

Fund Project: 1. CAAC safety capability project: research on theoretical system of civil aviation supervision with Chinese characteristics; 2. CAAC educational talent project: (Project No.:MHJY2022018) construction of competency model and assessment scale development for senior civil aviation inspectors; 3. Special fund project of Central Universities basic scientific research business (Project No.: j2021-115): Competency model construction and evaluation scale development of civil aviation health emergency management cadres.

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