

Evaluation of Business Competence of Elevator Inspectors Based on Combination-Variable Weights

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Abstract—An objective and effective assessment of elevator inspectors' professional competencies is fundamental to ensuring the operational efficiency and safety of elevators. Given the frequent elevator accidents and significant variations in inspectors' abilities, this paper proposes a general evaluation method for elevator inspectors' competencies based on combination-variable weights. It establishes a 39-indicator evaluation system across seven dimensions to objectively describe their work capabilities. By integrating AHP and the entropy weight method, it combines experiential judgments with objective data. To address varying emphasis on the competencies of different scenarios, a combination-variable weighting mechanism is introduced for comprehensive evaluation. This method not only provides a comprehensive assessment of inspectors' capabilities but also aligns with the specific demands of task scenarios. Its effectiveness is verified through comparative experiments, thereby offering theoretical and technical support for the evaluation and management of elevator inspectors' competencies.

Index Terms—Ability evaluation; AHP; Elevator inspection; Entropy power method; Portfolio-variant

I. INTRODUCTION

Elevator inspectors play a pivotal role in ensuring the safe operation of elevators, which are indispensable vertical transportation tools in modern urban life. Their professional skills and rigorous attitudes are crucial for maintaining the safety performance of elevators, thereby directly impacting public life and property safety[1]. According to statistics, by the end of 2023, the total number of elevators in China reached 10.63 million, an increase of approximately 10.2% compared with 2022[2]. However, there were 14 elevator accidents in 2023, leading to 13 fatalities, including the notable "10-18" elevator fall accident in Mile, Honghe Prefecture, Yunnan Province, which caused four deaths and

16 injuries, with direct economic losses amounting to 7.84 million yuan[3]. This incident highlights the urgency of elevator safety supervision and underscores its importance of elevator inspectors' professional competence and responsibility.

Elevator inspectors vary in their professional knowledge and skill levels due to differences in education, training experiences, and work experience. These variations hinder the resolution of human-machine conflicts and the continuous improvement of safety standards, thereby adversely affecting the healthy development of the elevator inspection industry. Therefore, a comprehensive and objective evaluation method to assess the competencies of elevator inspectors is essential for enhancing elevator safety.

Capability evaluation is widely applied in various fields. For instance, Shen established a multi-level fuzzy comprehensive evaluation model using the entropy weight method and fuzzy evaluation method to assess community emergency preparedness and response capabilities during the COVID-19 pandemic[4]. Wang developed an evaluation model for the suitability of emergency shelters in Tianjin based on AHP, considering operational effectiveness, safety, and accessibility[5]. Li constructed a flight performance evaluation index system based on traffic pattern tasks, flight training manuals, and interviews with instructors. A fuzzy comprehensive evaluation model established using the G1 method was employed to assess the flight performance of pilot trainees[6]. Yang used the fuzzy comprehensive evaluation method to evaluate the quality of simulation teaching, with nursing undergraduates from the Peking University School of Nursing in the 2015 grade as the evaluation subjects[7]. However, no method exists that provides a comprehensive and objective evaluation of the capabilities of elevator inspectors, and these methods lack flexibility in adjusting weights based on specific task scenarios.

To address these limitations, this study innovatively proposes an evaluation method for the professional competence of elevator inspectors based on combination-variable weights. This method adheres to the principles of comprehensiveness and operability, establishes a multi-dimensional indicator system, and integrates AHP with the entropy weight method by using game theory to consider both subjective and objective factors. The combination-variable weighting mechanism allows for dynamic adjustments of weights in different task scenarios, thereby providing a more precise and comprehensive

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assessment of elevator inspectors' capabilities. This method not only enhances the accuracy and comprehensiveness of elevator inspector capability evaluation but also provides scientific and efficient decision support for talent management and task allocation in the elevator inspection industry through its high flexibility and adaptability.

II. DEVELOPMENT OF AN ELEVATOR INSPECTOR CAPABILITY EVALUATION MODEL UTILIZING COMBINATORIAL-VARIABLE WEIGHTS

Addressing the limitations of existing research methods in scientifically and comprehensively evaluating elevator inspectors' capabilities, as well as their inability to flexibly adjust capability dimension weights based on different task scenarios to obtain more appropriate evaluation results, this paper proposes a combination-variable weight-based evaluation model for elevator inspectors' capabilities. The overall structure of the model is illustrated in Figure 1. The core elements of elevator inspection focus on the professional competencies and comprehensive qualities of elevator inspectors. Given this, developing a systematic evaluation model for elevator inspectors is of particular urgency and importance. At the outset of model construction, the selection of indicators must be rigorous and careful. It is not only essential to ensure the rationality and scientific validity of the indicators to accurately reflect inspectors' true capability levels, but also to consider the availability and ease of quantification of indicator data to facilitate practical operation and application.

In the selection of indicator weighting methods, this study adheres to the principles of comprehensiveness and objectivity. On one hand, it fully considers and incorporates subjective expert guidance from professionals in the field of elevator inspection. On the other hand, it also places great emphasis on the realities revealed by objective data to ensure the objectivity and fairness of the evaluation results. Additionally, considering that different task scenarios require

different capabilities, this study adopts a comprehensive weighting strategy to balance subjective experience and objective data. Through combination-variable weighting, dynamic adjustments to the weights will be made for different task scenarios, thereby enabling a more precise and comprehensive assessment of elevator inspectors' capabilities and performance. This approach lays a solid foundation for improving the overall quality of elevator inspection work.

Numerous factors influence the capabilities of elevator inspectors, making the selection of reasonable and comprehensive evaluation indicators crucial for assessing their abilities. Firstly, based on empirical research on human errors and their influencing factors in the elevator inspection process, indicators related to personnel profiles were extracted. Secondly, with reference to TSG Z8002-2022 Assessment Rules for Special Equipment Inspectors, indicators related to knowledge levels were identified. Subsequently, using TSG Z7002-2022 Approval Rules for Special Equipment Inspection Institutions as a guide, indicators related to technical achievements and training were extracted. Through the analysis of inspection data, indicators related to professional competence were derived. Based on the 14th Five-Year Plan for the Development of Special Equipment Safety and Energy Efficiency issued by the State Administration for Market Regulation and a summary of elevator accident reports over the past decade, indicators related to emergency response capabilities, such as the number of major events safeguarded, and industry exchange indicators, such as the number of international cooperation projects participated in, were also extracted. Finally, considering practicality and data collection feasibility, unreasonable indicators were optimized, resulting in 39 tertiary indicators and 19 secondary indicators, as detailed in Table 1. The data for knowledge-level indicators can be collected through examinations, while data for other indicators can be directly collected through surveys.

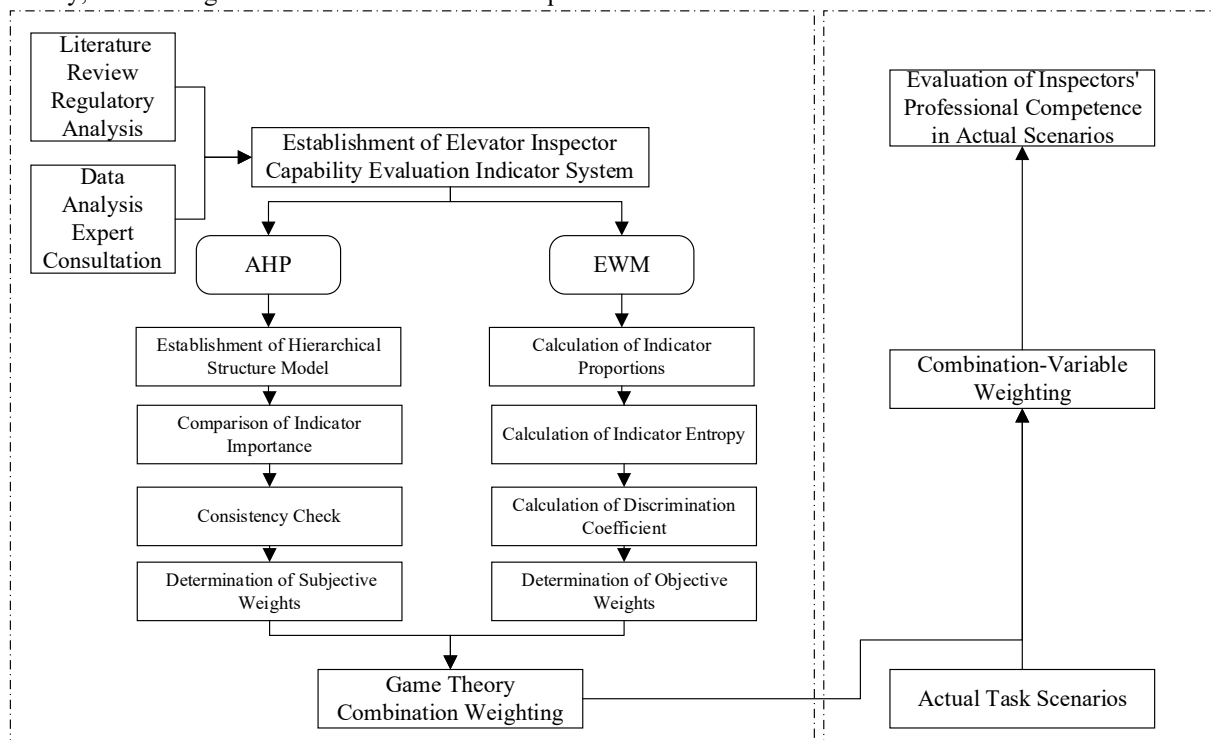


Fig. 1. Framework diagram of the competence evaluation model for elevator inspectors based on combined assignment-variable weights.

A. Determination of Evaluation Indicator Weights Based on Combination-Variable Weighting

In the process of constructing an evaluation system for elevator inspector competence, it is crucial to reasonably determine the weights of evaluation indicators. This can be achieved through subjective or objective weighting methods, each with its own limitations. The Analytic Hierarchy Process (AHP) is straightforward, easy to operate, and capable of systematically evaluating multiple objectives, but it is susceptible to personal biases of decision-makers, leading to potential errors [8]. The Entropy Weight Method, on the other hand, determines weights based on indicator variability, reflecting discriminatory power and avoiding artificial biases [9], but it may overlook the interactions between indicators, potentially leading to distorted weight assignments [10],[11].

Therefore, this study employs a combination of Game Theory, Analytic Hierarchy Process (AHP), and the Entropy Weight Method to determine the combined weights. This approach integrates subjective and objective factors, ensuring objectivity and scientific validity of the weights. It minimizes human interference and comprehensively reflects ability levels [12]. However, determining fixed weights is challenging in meeting the varying demands for changes in the composition of inspectors' abilities across different scenarios, and some extreme data may lead to weights deviating from reality. To address this issue, this study introduces a combination-variable weighting method.

The core idea of combination-variable weighting is to penalize indicators with poor performance in the current scenario by reducing their weights and to reward indicators with excellent performance by increasing their weights [13]. This approach ensures that the weight distribution of the evaluation indicator system more accurately reflects the actual situation, thereby enhancing the accuracy and effectiveness of the evaluation [14].

When elevator inspectors face emergency tasks, the weights of emergency response and professional competence are increased to emphasize their importance in the current task. When training is arranged, the weight of training-related competence is increased to encourage inspectors to prioritize training and enhance relevant skills. Across different task scenarios, decision-makers can dynamically adjust the weights of competencies that need to be emphasized for the task.

1). Determination of Subjective Weights Using AHP

The AHP is characterized by its simplicity and ease of operation, enabling the full utilization of experts' experience in the field of elevator inspection. Firstly, a hierarchical structure model for evaluating the professional competence of elevator inspectors is established. Then, using Saaty's 1-9 scale method, pairwise comparisons are conducted among the factors within each level to construct judgment matrices.

Subsequently, the judgment matrices are calculated to obtain the weights of each indicator. Finally, a consistency check is performed on each judgment matrix.

To assess consistency, a consistency index (CI) is defined:

$$CI = \frac{\lambda - n}{n - 1} \quad (1)$$

Where λ represents the maximum eigenvalue, and n is the unique non-zero eigenvalue. The closer the CI is to 0, the better the consistency. To measure the magnitude of CI, the Random Consistency Index (RI) is introduced, and the Consistency Ratio (CR) is defined:

$$CR = \frac{CI}{RI} \quad (2)$$

It is generally considered that the judgment matrix passes the consistency test if the CR is less than 0.1; otherwise, the judgment matrix needs to be adjusted and recalculated[15].

2). Determination of Objective Weights Using the Entropy Weight Method

The Entropy Weight Method can avoid the issue of weight distortion due to excessive subjectivity[16]:

(1) Eliminate the influence of dimensions by converting the original data x into a dimensionless value x' :

$$x' = \frac{x - x_{\min}}{x_{\max} - x_{\min}} \quad (3)$$

(2) Calculate the proportion of each sample's normalized data in the total sample set p_{ij} :

$$p_{ij} = \frac{x_{ij}}{\sum x_{ij}} \quad (4)$$

(3) Calculate the entropy value of each indicator based on its proportion e_j :

$$e_j = -k \sum p_{ij} \ln p_{ij} \quad (5)$$

Where k is a constant, usually taken as m , represents the number of samples.

(4) Calculate the coefficient of variation. A larger coefficient of variation indicates a greater impact of the indicator on the comprehensive evaluation:

$$g_j = 1 - e_j \quad (6)$$

(5) Calculate the weight of each indicator based on its coefficient of variation w_j :

$$w_j = \frac{g_j}{\sum g_j} \quad (7)$$

3). Determination of Combined-Variable Weights

To integrate the advantages of the AHP and Entropy Weight methods, leveraging game theory principles, we treat the AHP weights W_1 and the Entropy Weight method weights W_2 as the two players in a game, and calculate the optimal combined weights between them[17].

Denote the combined weight vector W' expressed as a linear combination of W_1 and W_2 as:

$$W' = \alpha_1 W_1 + \alpha_2 W_2 \quad (8)$$

Following game theory principles, we establish an objective function aimed at minimizing the sum of deviations between the combined weight vector W' and W_2 , seeking the optimal linear combination coefficients. The resulting

combined weight vector is the optimal combined weight W^* . The objective function and constraints are as follows:

$$\begin{aligned} \min(& \|W - W_1\|_2 + \|W - W_2\|_2) = \\ \min(& \|\alpha_1 W_1 + \alpha_2 W_2 - W_1\|_2 + \\ & \|\alpha_1 W_1 + \alpha_2 W_2 - W_2\|_2) \\ \text{s.t. } & \alpha_1 + \alpha_2 = 1, \alpha_1, \alpha_2 \geq 0 \end{aligned} \quad (9)$$

According to the principle of differentiation, the first-order derivative condition for achieving the minimum value of the formula is:

$$\begin{cases} \alpha_1 W_1 W_1^T + \alpha_2 W_1 W_2^T = W_1 W_1^T \\ \alpha_1 W_2 W_1^T + \alpha_2 W_2 W_2^T = W_2 W_2^T \end{cases} \quad (11)$$

Normalize the linear combination coefficients α_2 obtained from the equation to get the optimal linear combination coefficients α_2^* , and then calculate the optimal combined weight W^* as:

$$W^* = \alpha_1^* W_1 + \alpha_2^* W_2 \quad (12)$$

After obtaining the combined weight vector W^* , assume $W^* = [w_1, w_2, \dots, w_n]$, where w_i represents the weight of the i -th evaluation indicator. Based on the combined-variable weight function, the adjusted weight vector W'' can be expressed as:

$$W'' = [f(w_1, p_1), f(w_2, p_2), \dots, f(w_n, p_n)] \quad (13)$$

Here, $f(w_i, p_i)$ is the combined-variable weight function, and p_i represents the combined-variable weight factor for the i -th evaluation indicator. The value of p_i can be set according to actual circumstances. For example, to emphasize a certain capability, set its corresponding p_i value as an incentive factor greater than 1; to reduce the weight of a certain capability, set its corresponding value as a penalty factor less than 1.

A simple combined-variable weight function can be defined as:

$$f(w_i, p_i) = w_i * p_i^k \quad (14)$$

TABLE II

SELECTION OF VARIABLE WEIGHT PARAMETERS FOR COMMON SCENARIOS

Scene Type	k	p
Emergency Scene (Major Event Security Tasks, etc.)	1-1.5	Emergency Capability Dimension
		Indicators 1.2- 1.5
		Professional Competence
		Dimension Indicators 1.1- 1.5
Research Scene (Research Projects, Topics, etc.)	1-1.5	Other Dimension
		Indicators 0.8-1.1
		Research Achievement
		Dimension Indicators 1.2- 1.5
Training Scene (Participation in and Organization of Training, etc.)	1-1.5	Knowledge Level Dimension
		Indicators 1.1- 1.5
		Other Dimension Indicators
		0.8-1.1

Where k is an adjustment factor used to control the intensity of penalties or incentives. When $k > 0$, $p_i > 1$ increases weight, and $p_i < 1$ decreases weight; when $k < 0$, the effect is reversed. Table 2 provides the ranges for selecting k and p values for indicators in several common scenarios.

III. EXPERIMENTS AND ANALYSIS

A. Experiment Details

To validate the effectiveness of the proposed method, various data from personnel in an elevator inspection department of a city were selected for verification. Some of the indicator data were simulated and supplemented based on actual circumstances, resulting in 30 personnel datasets in total. The raw data for typical indicators across different dimensions is presented in Table 3. Ten evaluation experts were invited to provide professional scores based on the actual performance of the inspection personnel and considering the task scenarios. Based on expert experience, two groups of personnel with high ability and two groups with low ability were selected as control groups for verification, while the remaining 14 groups were used as samples for weight calculation in the experiment.

Following the methodology introduced in this paper, the weights of each indicator were calculated using both AHP and the Entropy Weight Method, and the combined weights were determined using game theory. Initially, the comprehensive scores and dimensional scores for the two groups of personnel were calculated without considering the task scenarios and compared with their actual performance. Subsequently, the comprehensive scores and dimensional scores for the two groups under different scenarios were calculated and compared with the expert scores to validate the effectiveness of the method.

TABLE III
SELECTED ORIGINAL SAMPLE DATA

The name of the inspector	X_{111}	X_{342}	X_{411}	X_{521}	X_{611}
Inspector 1	42	5	532	4	4
Inspector 2	49	3	475	2	3
Inspector 3	47	3	466	2	3
Inspector 4	30	2	412	1	3
Inspector 5	31	2	453	1	3

1). Determination of Constant Weights

TABLE IV
CR VALUES OF JUDGMENT MATRICES OF EACH ORDER OF AHP

First-L evel Indicat or	CR	Second-Le vel Indicator	CR	Third-L evel Indicato r	CR
$X_1 - X_7$	0.0196	$X_{21} - X_{24}$	0.0071	$X_{221} - X_{225}$	0.0139
		$X_{31} - X_{35}$	0.0139	$X_{241} - X_{243}$	0.0032

According to Saaty's 1-9 scale method, the judgment matrix A for each level is constructed. Consistency checks are performed using Equations (1) and (2) to obtain the CR values for each level, as shown in Table 4.

All second-level matrices are inherently consistent. The result of the consistency checks for the matrices at other levels is presented in Table 4, and all have passed the consistency test.

2). Calculation of Objective Weights Using the Entropy Weight Method

TABLE V
CODING OF INDICATORS

Indicator Name	Corresponding Code			
X_{111}	40-49 years old 1	Under 29 years old 2	30-39 years old 3	Over 50 years old 4
X_{112}	Below a bachelor's degree 1	Bachelor's degree 2	Master's degree 3	Doctorate degree 4
X_{121}	Junior level 1	Intermediate level 2	Associate senior level 3	Senior level 4
X_{122}	Less than 5 years 1	11-20 years 2	6-10 years 3	Over 21 years 4
$X_{211}-X_{243}$	Below 50 points 1	51-70 points 2	71-90 points 3	91-100 points 4
$X_{311}-X_{332}$	0 papers 1	1-3 papers 2	4-5 papers 3	Over 6 papers 4
X_{341}	0 projects 1	1 project 2	2 projects 3	Over 3 projects 4
X_{342}	0 projects 1	1-3 projects 2	4-5 projects 3	Over 6 projects 4
X_{351}	0 awards 1	1 award 2	2 awards 3	Over 3 awards 4
X_{352}	0 awards 1	1-3 awards 2	4-5 awards 3	Over 6 awards 4
X_{411}	Less than 100 units 1	101-300 units 2	301-500 units 3	Over 501 units 4
X_{412}	Less than 5 units 1	6-10 units 2	11-30 units 3	Over 31 units 4
X_{421}	Less than 3 times 1	2 times 2	1 times 3	0 times 4
$X_{511}-X_{611}$	0 times 1	1 times 2	2-3 times 3	Over 4 times 4
X_{612}	Less than 12 hours 1	13-24 hours 2	25-48 hours 3	Over 49 hours 4
X_{621}	0 times 1	1 times 2	2 times 3	Over 3 times 4
X_{622}	Less than 12 hours 1	13-24 hours 2	25-48 hours 3	Over 49 hours 4
$X_{711}-X_{721}$	0 times 1	1 times 2	2 times 3	Over 3 times 4
X_{722}	0 times 1	1-3 times 2	4-5 times 3	Over 6 times 4

Considering that some data are categorical and that higher values do not always indicate better performance, the data were segmented and encoded based on an analysis of their distribution and with reference to relevant regulations and standards, as shown in Table 5.

Firstly, the data were normalized using Equation (3). Then, the proportion of each indicator in the sample was calculated using Equation (4). Subsequently, the entropy value and difference coefficient for each indicator were computed using Equations (5) and (6), respectively. Finally, the weights of each indicator were obtained using Equation (7).

3). Calculation of Combined Weights Using Game Theory

TABLE VI
COMBINED WEIGHTS OF INDICATORS

First-level Indicator	Weight	Second-level Indicator	Weight	Third-level Indicator	Weight
X_1	0.0688	X_{11}	0.0453	X_{111}	0.0148
				X_{112}	0.0404
		X_{12}	0.0235	X_{121}	0.0150
				X_{122}	0.0126
X_2	0.0954	X_{21}	0.0144	X_{211}	0.0030
				X_{212}	0.0043
				X_{213}	0.0043
				X_{214}	0.0030
		X_{22}	0.0174	X_{215}	0.0030
				X_{221}	0.0039
				X_{222}	0.0022
				X_{223}	0.0045
				X_{224}	0.0048
				X_{225}	0.0056
		X_{23}	0.0207	X_{231}	0.0094
				X_{232}	0.0153
X_3	0.17	X_{24}	0.0429	X_{241}	0.0060
				X_{242}	0.0187
				X_{243}	0.0268
				X_{31}	0.0083
		X_{33}	0.0329	X_{311}	0.0099
				X_{321}	0.0141
				X_{331}	0.0228
				X_{332}	0.0170
X_4	0.1952	X_{34}	0.0503	X_{341}	0.0458
				X_{342}	0.0162
				X_{351}	0.0671
				X_{352}	0.0147
X_5	0.2586	X_{41}	0.0553	X_{411}	0.0236
				X_{412}	0.0429
				X_{42}	0.1399
				X_{421}	0.0870
X_6	0.0843	X_{51}	0.09	X_{511}	0.0770
				X_{521}	0.1309
				X_{52}	0.1686
				X_{61}	0.0252
X_7	0.1277	X_{62}	0.0591	X_{611}	0.0166
				X_{612}	0.0123
				X_{621}	0.0309
				X_{622}	0.0377
X_7	0.1277	X_{71}	0.0286	X_{711}	0.0314
				X_{721}	0.0437
				X_{722}	0.0606

The weight calculation results for the sample data were obtained through the above computations. As shown in Figure 2, the overall distribution pattern of the combined weights determined using the cooperative game approach is

clearly observable and exhibits significant similarity to the respective distribution patterns of the three independent methods. Compared to simple coefficient weighting methods, employing cooperative game theory to determine weights demonstrates a more comprehensive global consideration and thoroughly accounts for the complexity of interactions among various weighting methods, thereby effectively enhancing the rationality and accuracy of the evaluation results.

B. Evaluation of Inspection Personnel's Competence Without Considering Scenarios

Without considering task scenarios and setting the capability p-values for all dimensions to 1, with k set to 1.2, the comprehensive competence scores for four inspection personnel were obtained by combining real and partially simulated data, as shown in Table 7.

TABLE VII
COMPARISON OF COMPOSITE SCORES FOR DIFFERENT PERSONNEL

<i>Inspectors</i>	<i>Scores</i>
Inspector A	76
Inspector B	76
Inspector C	56
Inspector D	56

The scores of the four inspection personnel across various dimensions are shown in Figure 3.

Inspector A has a high overall score, performing strongly in the dimension of professional competence but weakly in the dimension of scientific research achievements, and moderately in other dimensions.

Inspector B also has a high overall score, performing strongly in the dimensions of knowledge level and training status, but weakly in the dimensions of industry communication and scientific research achievements, and moderately in other dimensions.

Inspector C has a lower overall score, performing strongly in the dimension of professional competence but weakly in the dimensions of industry communication and scientific research achievements, and moderately in other dimensions.

Inspector D also has a lower overall score, performing strongly in the dimensions of professional competence and knowledge level but weakly in the dimensions of scientific research achievements and emergency response capability, and moderately in other dimensions.

In reality, Inspector A and Inspector B are elevator inspectors, while Inspector C and Inspector D are elevator inspection technicians. Therefore, the evaluation results of the overall scores align with reality.

C. Evaluation of Inspectors' Competencies in Different Scenarios

To verify the effectiveness of the method in different scenarios, the scores of two groups of personnel in emergency and research scenarios were selected for comparison with expert scores.

1). Evaluation of Inspection Personnel's Competence in Emergency Scenarios

Based on two sets of data from inspection personnel with similar capabilities, the task scenario involves dispatching elevator inspection personnel for safety inspections. With the emergency capability p-value set to 1.4 and the professional competence p-value set to 1.2, and k set to 1.2, the comprehensive scores and scores for each dimension were calculated for both groups using a combination of real and partially simulated data. These scores were then compared with expert ratings, as shown in Table 8.

TABLE VIII
COMPARISON OF COMPOSITE SCORES FOR DIFFERENT PERSONNEL

<i>Inspectors</i>	<i>Combination-variable weights</i>	<i>Scoring by Expert</i>
Inspector A	77	80
Inspector B	75	78
Inspector C	58	60
Inspector D	57	55

The scores for each dimension are shown in Figure 4 and Figure 5.

From the perspective of the overall score, Inspector A's score is higher than that of Inspector B.

In terms of the scores for each dimension, Inspector A scores higher than Inspector B in personnel profile, professional competence, and industry communication, while scoring lower in knowledge level and training status. The scores for emergency response capability and scientific research achievements are equal between the two inspectors.

Without considering the scenario, the overall scores of Inspector A and Inspector B are the same, and their scores in the emergency response capability dimension, which directly reflects emergency capabilities, are also the same. It is not possible to directly select a suitable candidate for the safety inspection based on these scores. However, after applying the combination-variable weighting method, Inspector A's overall score is higher than that of Inspector B, and this aligns with the expert ratings. Therefore, Inspector A is more suitable for this safety inspection task.

From the perspective of the overall score, Inspector C's score is higher than that of Inspector D. In terms of the scores for each dimension, Inspector C scores higher than Inspector D in personnel profile, professional competence, and emergency response capability, while scoring lower in knowledge level, scientific research achievements, training status, and industry communication. These results align with the expert ratings, indicating that Inspector C is more suitable for this safety inspection task.

2). Evaluation of Inspection Personnel's Competence in Research Scenarios

Based on two sets of data from inspection personnel with similar capabilities, the task scenario involves dispatching elevator inspection personnel to participate in research projects. With the scientific research achievements p-value set to 1.4 and the knowledge level p-value set to 1.2, and k set to 1.2, the comprehensive scores and scores for each

dimension were calculated for Inspector A, Inspector B, and Inspector D using a combination of real and partially simulated data. These scores were then compared with expert ratings, as shown in Table 9.

TABLE IX
COMPARISON OF COMPOSITE SCORES OF DIFFERENT EVALUATION
METHODS UNDER EMERGENCY RESPONSE TASKS

<i>Inspectors</i>	<i>Combination-variable weights</i>	<i>Scoring by Expert</i>
Inspector A	75	72
Inspector B	76	73
Inspector C	57	60
Inspector D	59	61

The scores for each dimension are shown in Figure 6 and Figure 7.

From the perspective of the overall score, Inspector B's score is higher than that of Inspector A. In terms of the scores for each dimension, Inspector A scores higher than Inspector B in personnel profile, professional competence, and industry communication, while scoring lower in knowledge level and training status. The scores for emergency response capability and scientific research achievements are equal between Inspector A and Inspector B.

Without considering the scenario, the overall scores of Inspector A and Inspector B are the same, and their scores in the scientific research achievements dimension, which directly reflect their research capabilities, are also identical. It is not possible to directly select a suitable candidate for the research project based on these scores. However, after applying the combination-variable weighting method, Inspector B's overall score is higher than that of Inspector A, and this aligns with the expert ratings. Therefore, Inspector B is more suitable for this research task.

From the overall score perspective, Inspector D's score is higher than that of Inspector C. In terms of the scores for each dimension, Inspector C scores higher than Inspector D in personnel profile, professional competence, and emergency response capability, while scoring lower in knowledge level, scientific research achievements, training status, and industry communication. These results align with the expert ratings, indicating that Inspector D is more suitable for this research task.

Therefore, in both emergency tasks and research tasks, regardless of whether the specific required abilities are similar or significantly different, the combination-variable weighting method can select the most appropriate personnel for the task.

D. Comparative Analysis of Evaluation Methods

To validate the effectiveness of the Combination-Variable Weights (CVW) method in evaluating the competencies of elevator inspectors, a cross-scenario comparative experiment was conducted. Three traditional methods, the Entropy Weight Method, the Analytic Hierarchy Process, and the Fuzzy Comprehensive Evaluation (FCE), were selected as baselines. The experiment utilized total competency scores (derived from a 39-indicator system across seven dimensions)

as the evaluation metric. Data from 30 inspectors under Emergency and Research scenarios were analyzed. Non-parametric Mann-Whitney U tests were employed for group comparisons, and Cohen's d was calculated to quantify effect sizes. Statistical significance was set at $\alpha = 0.05$.

Key findings from the cross-scenario analysis are summarized in Table X.

(1) Superiority of CVW Method:

In Emergency scenarios, CVW demonstrated a large effect size compared to EWM ($d = 0.72$, $p = 0.0335$) and a medium effect size compared to AHP ($d = 0.62$, $p = 0.0467$). Against FCE, it showed a small - to - medium effect size ($d = 0.33$, $p = 0.0496$).

In Research scenarios, the advantage of CVW over EWM remained large ($d = 0.79$, $p = 0.0311$), its superiority over AHP persisted with a medium effect size ($d = 0.66$, $p = 0.0458$), and over FCE, it had a small - to - medium effect size ($d = 0.41$, $p = 0.0481$).

(2) Comparative Performance of Other Methods:

EWM showed significant differences from CVW in both scenarios with relatively large effect sizes, indicating that CVW has notable advantages over it. AHP also differed significantly from CVW in both scenarios, with medium-sized effect differences. FCE, although also having a significant difference from CVW, had relatively smaller effect sizes compared to EWM and AHP, suggesting that while it differs from CVW, the gap is not as large as that of the other two baseline methods.

TABLE X
CROSS-SCENARIO COMPARISON OF EVALUATION METHODS

<i>Comparison</i>	<i>Emergency Scenario</i>		<i>Research Scenario</i>	
	<i>p-value</i>	<i>Cohen's d</i>	<i>p-value</i>	<i>Cohen's d</i>
EWM vs. CVW	0.0335	0.72	0.0311	0.79
AHP vs. CVW	0.0467	0.62	0.0458	0.66
FCE vs. CVW	0.0496	0.33	0.0481	0.41

Practical Significance of CVW:

The large effect sizes ($d > 0.7$) between CVW and EWM, as well as the medium effect sizes with AHP, highlight the efficacy of the dynamic weight adjustment mechanism. For instance, in emergency scenarios, CVW prioritizes emergency response capability by increasing its weight (reward factor $p = 1.4$), aligning with practical safety demands. Similarly, in research scenarios, boosting the weight of scientific achievements ($p = 1.2$) enhances scenario adaptability. Against FCE, the smaller but significant effect sizes suggest that CVW can also distinguish itself in performance, albeit to a lesser extent compared to EWM and AHP.

Statistical Power and Limitations:

The p-values being less than the conventional significance threshold ($\alpha = 0.05$) in all comparisons with CVW confirm the statistical significance of the differences. The medium-to-large effect sizes ($d = 0.33\text{--}0.79$) suggest meaningful practical improvements. A post-hoc power analysis (G*Power, effect size = 0.8, $\alpha = 0.05$) indicates that a sample size of 50–60 inspectors per group would achieve 80% statistical power. Current limitations include:

Sample size constraints ($n = 30$) may still limit the full exploration of more nuanced differences.

Lack of direct linkage between scores and real-world performance metrics (e.g., accident resolution time).

IV. CONCLUSION

This study systematically established a comprehensive evaluation system for the professional competence of elevator inspectors, encompassing seven dimensions: personnel profile, knowledge level, technical achievements, professional competence, emergency response capability, training participation, and industry exchange. Through rigorous literature review and data analysis, this system effectively and comprehensively reflects the overall capability characteristics of elevator inspectors.

For the evaluation methodology, this study considered the combined effects of subjective and objective factors, utilizing game theory to integrate the Analytic Hierarchy Process and Entropy Weight Method for indicator weighting, thereby enhancing the accuracy of evaluation results. Furthermore, the introduction of the combination-variable weighting approach enables dynamic weight adjustments based on scenario-specific capability requirements.

In comparative experiments, two representative groups of elevator inspectors (higher and lower capability levels) were selected. Initial evaluations (without scenario considerations) yielded results aligned with real-world performance, while subsequent scenario-based evaluations (using combination-variable weighting) successfully identified task-suitable inspectors.

From a practical perspective, the proposed evaluation system provides a scientific, comprehensive assessment tool for the elevator inspection industry. It supports human resource decisions (recruitment, training, promotion) and offers robust decision-making for resource allocation/task assignment by safety management agencies. Critically, it highlights scenario-specific key capabilities, laying a foundation for elevating inspection standards and ensuring elevator safety.

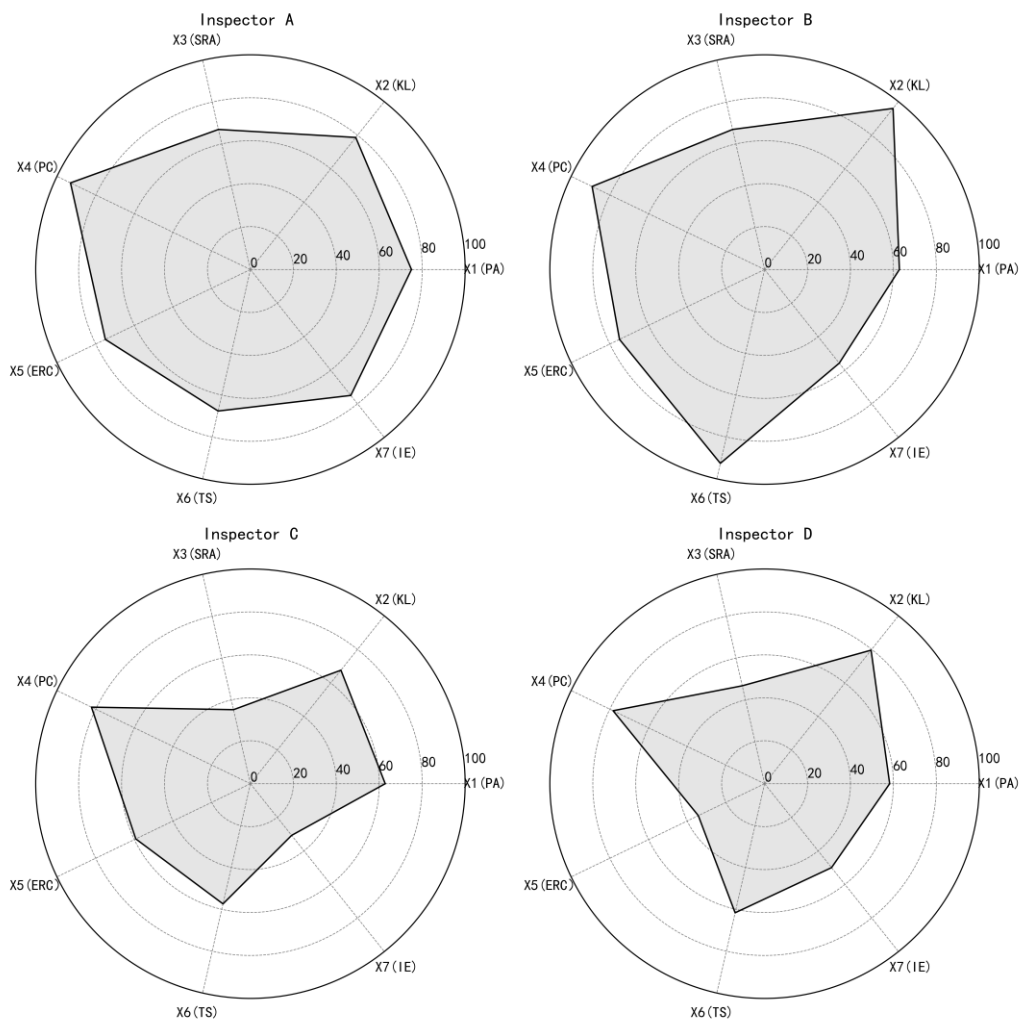


Fig. 3. Comparison of the scores of the four inspectors on each dimension

TABLE I
ELEVATOR INSPECTOR COMPETENCY INDICATOR SYSTEM

<i>First-level Indicator</i>	<i>Variable Notation</i>	<i>Second-level Indicator</i>	<i>Variable Notation</i>	<i>Third-level Indicator</i>	<i>Variable Notation</i>
Personnel Overview	X_1	Basic Information	X_{11}	Age	X_{111}
				Educational Background	X_{112}
		Professional Qualifications	X_{12}	Title	X_{121}
				Years of Work Experience	X_{122}
Knowledge Level	X_2	Basic Knowledge	X_{21}	Materials Mechanics Knowledge	X_{211}
				Mechanical-related Knowledge	X_{212}
				Hydraulic-related Knowledge	X_{213}
				Electrical Component Knowledge	X_{214}
				Quality Management Knowledge	X_{215}
		Professional Knowledge	X_{22}	Elevator Types, Varieties, Licensed Items, and Levels	X_{221}
				Elevator Terminology and Parameters	X_{222}
				Elevator Main Components, Electrical Components, Hydraulic Components	X_{223}
				Elevator Safety Protection Devices	X_{224}
				Elevator Hydraulic Systems	X_{225}
		Inspection Knowledge	X_{23}	Periodic and Supervisory Inspection, Elevator Inspection Procedures, Contents, Requirements, and Methods	X_{231}
				Safety Protection	X_{232}
		Regulations and Standards	X_{24}	Composition and Relationships of the Special Equipment Laws and Regulations System	X_{241}
				Relevant Provisions of Laws, Regulations, and Standards Related to Elevator Periodic and Supervisory Inspection and Testing	X_{242}
				Safety Technical Specifications for Elevator Periodic and Supervisory Inspection and Testing	X_{243}
Scientific Research Achievements	X_3	Papers	X_{31}	Number of Papers Published in the Past Five Years	X_{311}
		Patents	X_{32}	Number of Patents Published in the Past Five Years	X_{321}
		Regulations and Standards	X_{33}	Number of Regulations Participated in Writing in the Past Five Years	X_{331}
				Number of Standards Participated in Writing in the Past Five Years	X_{332}
		Projects (Topics)	X_{34}	Number of National Projects (Topics) Participated in the Past Five Years	X_{341}
				Number of Provincial (Ministerial) Projects (Topics) Participated in the Past Five Years	X_{342}
		Awards	X_{35}	Number of National Awards Received in the Past Five Years	X_{351}
Professional Competence	X_4	Workload	X_{41}	Average Annual Number of Inspected Equipment	X_{411}
				Average Annual Number of Identified Hazards and Issues	X_{412}
		External Feedback	X_{42}	Number of Complaints Received	X_{421}
Emergency Response Capability	X_5	Accidents	X_{51}	Number of Accident Investigations Participated in the Past Five Years	X_{511}
		Major Events	X_{52}	Number of Major Event Safeguards Participated in the Past Five Years	X_{521}
Training Situation	X_6	Participation in Training	X_{61}	Average Annual Number of Training Sessions Participated	X_{611}
				Average Annual Duration of Training Sessions Participated	X_{612}
		Organization of Training	X_{62}	Average Annual Number of Training Sessions Organized	X_{621}
				Average Annual Duration of Training Sessions Organized	X_{622}
Industry Exchange	X_7	Domestic Exchange	X_{71}	Number of Domestic Seminars Participated	X_{711}
		International Exchange	X_{72}	Number of International Seminars Participated	X_{721}
				Number of International Cooperation Projects Participated	X_{722}

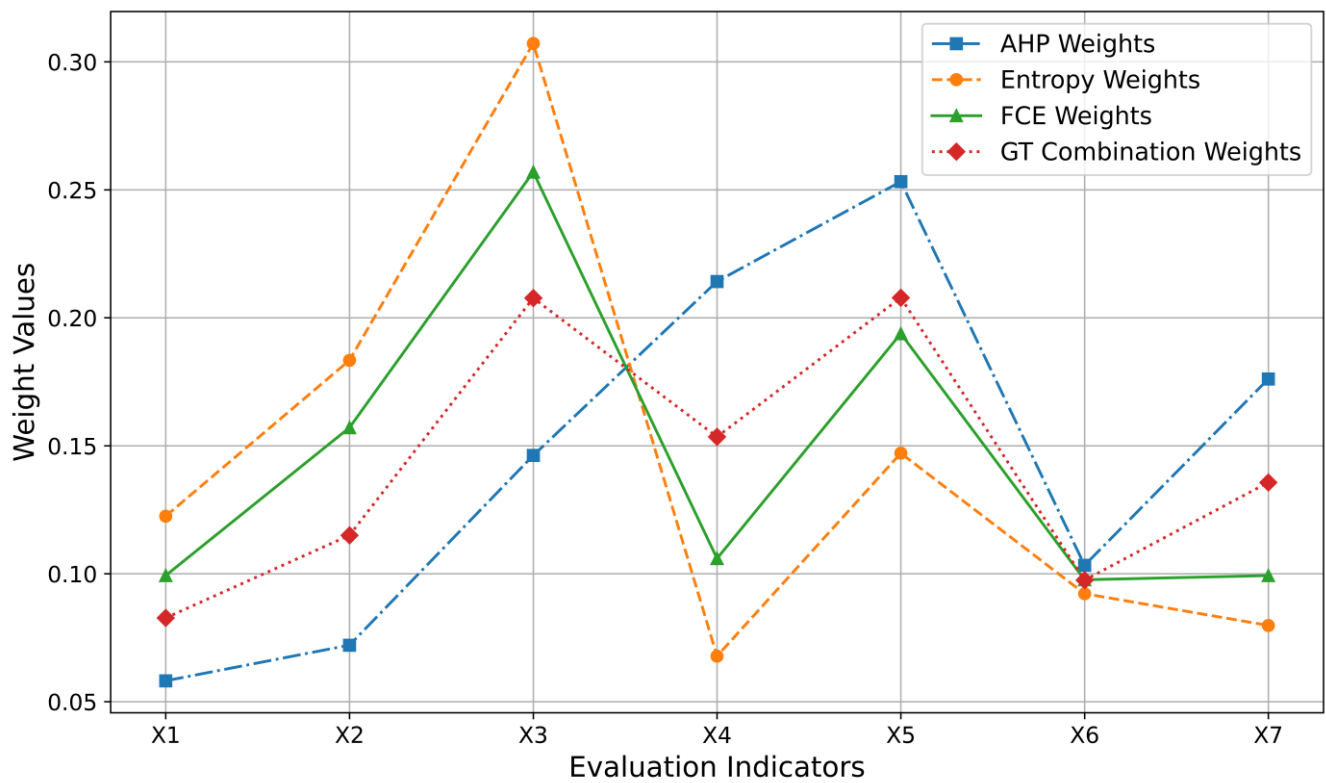


Fig. 2. Individual weights of the four weighting methods

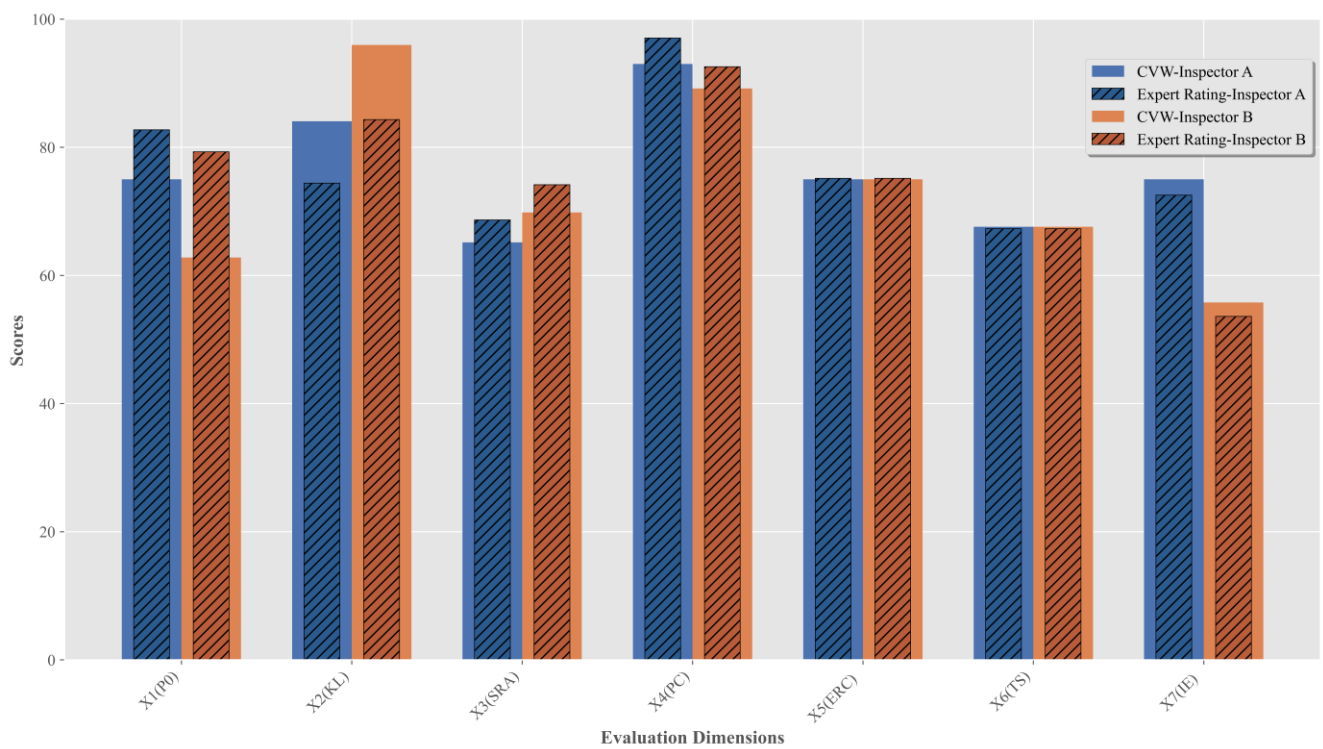


Fig. 4. Comparison of dimension scores between inspector A and inspector B in emergency scenarios

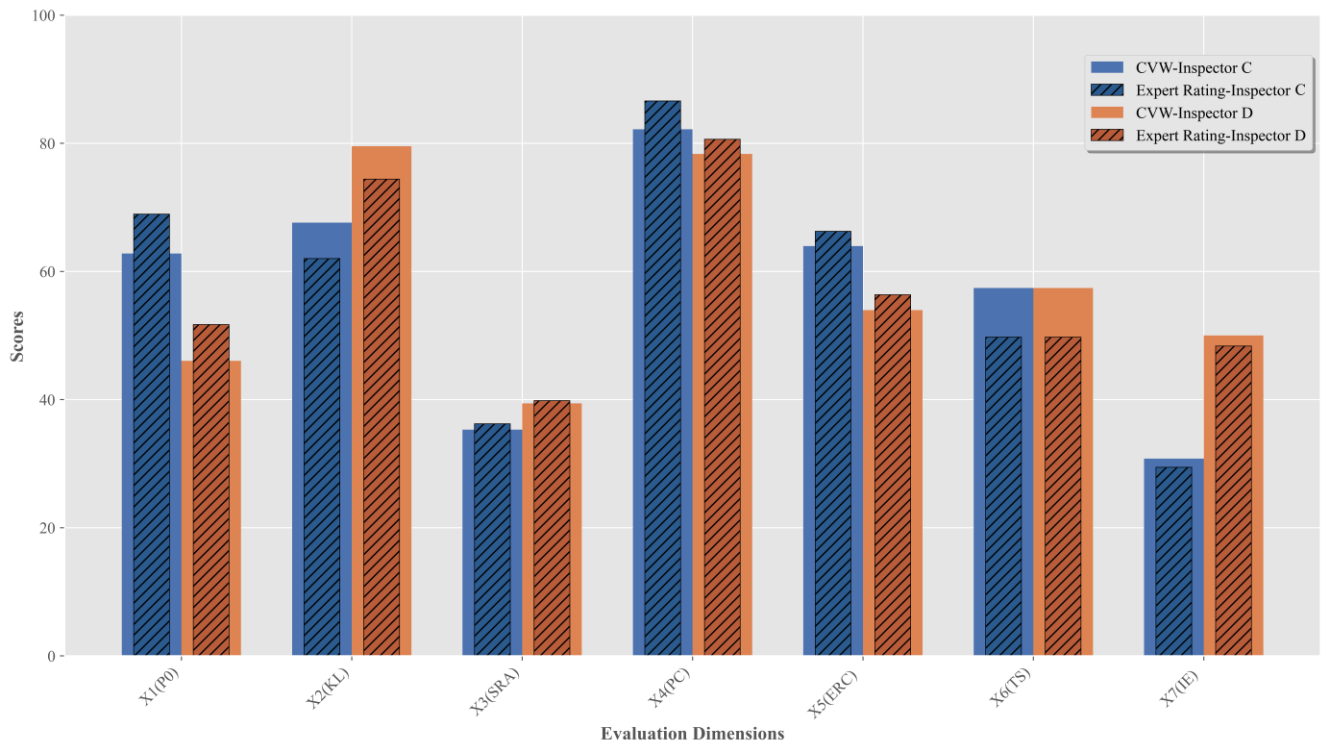


Fig.5. Comparison of dimension scores between inspector C and inspector D in emergency scenarios.

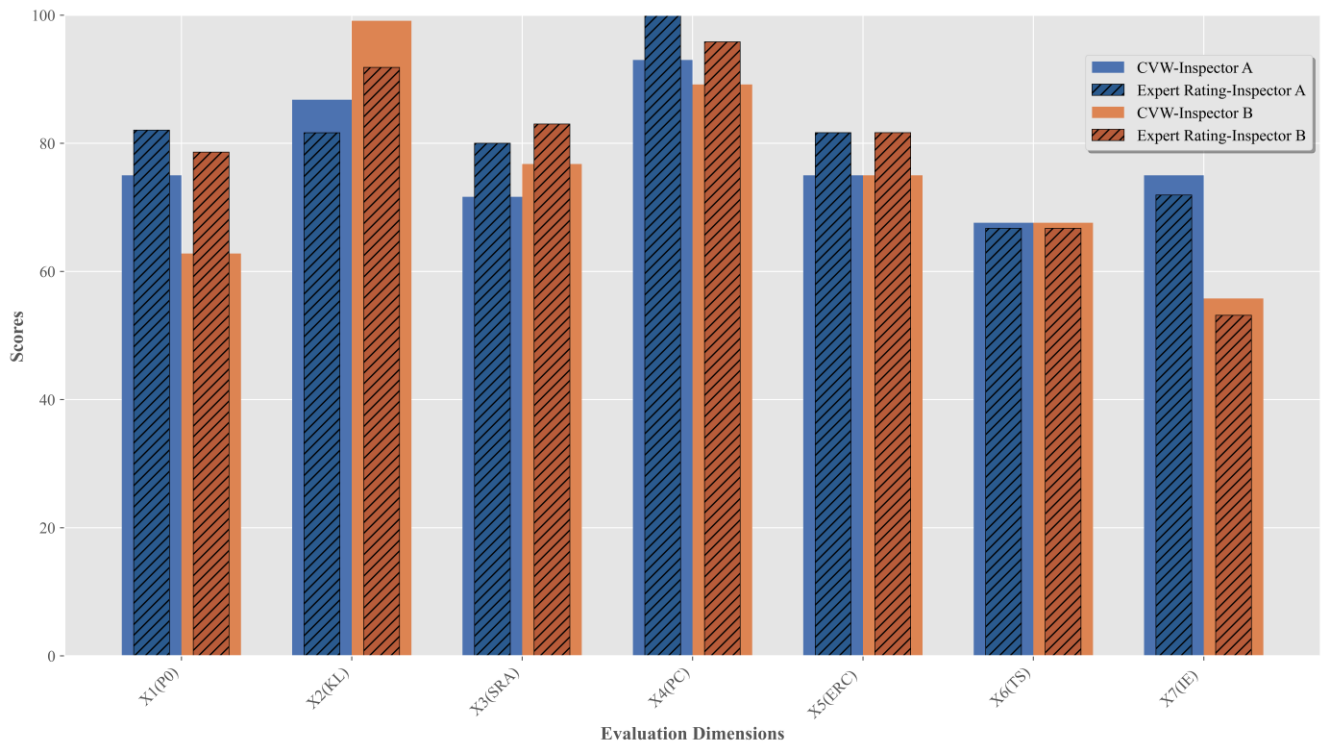


Fig. 6. Comparison of dimension scores in research scenarios for inspector A and inspector B.

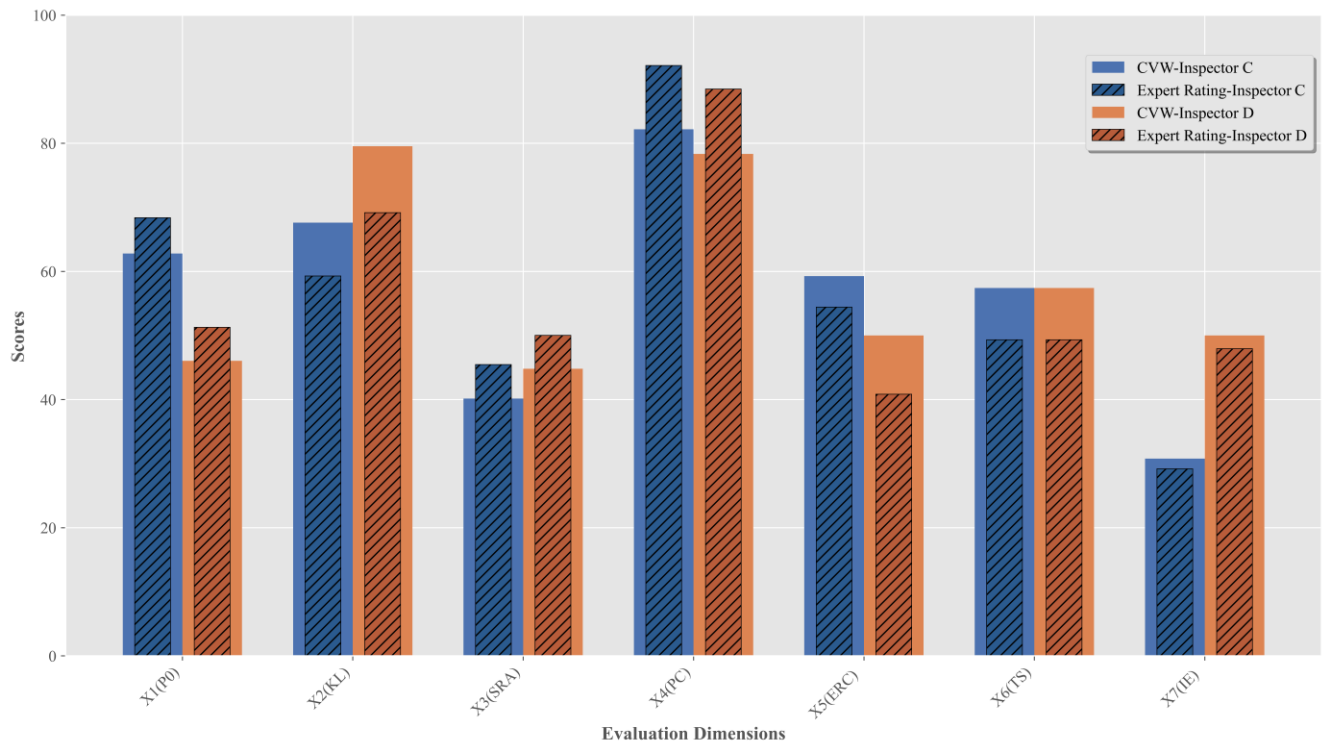


Fig. 7. Comparison of dimension scores in research scenarios for inspector C and inspector D.

REFERENCES

- [1] H. Huang, X. Xie, and L. Zhou, "Detection and alarm of e-bike intrusion in elevator scene," *Engineering Letters*, vol. 29, no. 3, pp. 1194-1200, 2021.
- [2] State Admin. for Market Regulation, "Notice of the State Administration for Market Regulation on the safety status of special equipment in the country in 2023," (Online). [Online]. Available: https://www.samr.gov.cn/zw/zfxgk/fdzdgknr/tzsb/art/2024/art_aea38293416e4af382c0136d2e73f8a2.html. [Accessed Apr. 1, 2024].
- [3] Yunnan Admin. for Market Regulation, "Investigation Report on the '10-18' Large Elevator Fall Accident in Mile City, Honghe Prefecture, Yunnan Province," (Online). [Online]. Available: <https://amr.yn.gov.cn/info/1030/39287.htm>. [Accessed October 1, 2024].
- [4] N. Z. Shen, X. Y. Guo, J. W. Cui, and Z. Q. Wu, "Assessment of Urban Community Emergency Preparedness and Response Capacity Using Entropy Weight Method and Multilayer Fuzzy Comprehensive Model," *Tehnički Vjesnik*, vol. 31, no. 3, pp. 843-850, 2024.
- [5] X. F. Wang, "Research on the Suitability of the Emergency Shelter in Tianjin," in *5th Annual International Conference on Social Science and Contemporary Humanity Development (SSCHD)*, Wuhan, People's Republic of China, Nov. 15-16, 2019, Atlantis Press, Advances in Social Science Education and Humanities Research, vol. 376, pp. 121-126, 2019.
- [6] G. Li, H. B. Wang, T. Pan, H. B. Liu, and H. Q. Si, "Fuzzy Comprehensive Evaluation of Pilot Cadets' Flight Performance Based on G1 Method," *Applied Sciences-Basel*, vol. 13, no. 21, pp. 16, 2023.
- [7] J. Yang, L. Q. Shen, X. Y. Jin, L. Y. Hou, S. M. Shang, and Y. Zhang, "Evaluating the quality of simulation teaching in Fundamental Nursing Curriculum: AHP-Fuzzy comprehensive evaluation," *Nurse Education Today*, vol. 77, pp. 77-82, 2019.
- [8] Y. Li and X. Y. Wang, "Risk assessment for public-private partnership projects: using a fuzzy analytic hierarchical process method and expert opinion in China," *Journal of Risk Research*, vol. 21, no. 8, pp. 952-973, 2018.
- [9] Y. Y. Gao, H. Qian, W. H. Ren, H. K. Wang, F. X. Liu, and F. X. Yang, "Hydrogeochemical characterization and quality assessment of groundwater based on integrated-weight water quality index in a concentrated urban area," *Journal of Cleaner Production*, vol. 260, pp. 15, 2020.
- [10] X. Deng, F. Geng, and J. Yang, "A Novel Portfolio Based on Interval-Valued Intuitionistic Fuzzy AHP with Improved Combination Weight Method and New Score Function," *Engineering Letters*, vol. 31, no. 4, pp. 1442-1456, 2023.
- [11] G. P. Zhao and D. Wang, "Comprehensive Evaluation of AC/DC Hybrid Microgrid Planning Based on Analytic Hierarchy Process and Entropy Weight Method," *Applied Sciences-Basel*, vol. 9, no. 18, pp. 19, 2019.
- [12] W. Na and Z. C. Zhao, "The comprehensive evaluation method of low-carbon campus based on analytic hierarchy process and weights of entropy," *Environmental Development and Sustainability*, vol. 23, no. 6, pp. 9308-9319, 2021.
- [13] H. Xian and J. Che, "A Variable Weight Combined Model Based on Time Similarity and Particle Swarm Optimization for Short-term Power Load Forecasting," *IAENG International Journal of Computer Science*, vol. 48, no. 4, pp. 915-924, 2021.
- [14] Z. L. Peng, Y. Zhang, F. Tan, J. H. Lv, and L. H. Li, "Variable-Weight Suitability Evaluation of Underground Space Development Considering Socioeconomic Factors," *Sustainability*, vol. 15, no. 4, pp. 20, 2023.
- [15] S. Khurana, A. Haleem, S. Luthra, and B. Mannan, "Evaluating critical factors to implement sustainable oriented innovation practices: An analysis of micro, small, and medium manufacturing enterprises," *Journal of Cleaner Production*, vol. 285, Art. 125377, pp. 16, 2021.
- [16] Z. Y. Xue, W. J. Zhang, J. C. Yin, "Security Evaluation Model of Precautionary Area Based on Improved Entropy Weight TOPSIS," in *32nd Chinese Control and Decision Conference (CCDC)*, Hefei, People's Republic of China, Aug. 22-24, 2020, IEEE, Chinese Control and Decision Conference, pp. 3553-3559, 2020.
- [17] B. Yang, C. G. Lai, X. H. Chen, X. Q. Wu, and Y. H. He, "Surface Water Quality Evaluation Based on a Game Theory-Based Cloud Model," *Water*, vol. 10, no. 4, pp. 15, 2018.