A Multi-Criteria Decision-Making Approach for Equipment Evaluation Based on Cloud Model and VIKOR Method

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***Abstract*—Equipment evaluation stands as a critical task in both equipment system development and military operation planning. This task is often recognized as a complex multi-criteria decision-making (MCDM) problem. Adding to the intricacy is the uncertain nature inherent in military operations, leading to the introduction of fuzziness and randomness into the equipment evaluation problem, rendering it unsuitable for precise information. This paper addresses the uncertainty associated with equipment evaluation by proposing a novel MCDM method that combines the cloud model and the VIKOR method. To address the multifaceted nature of the equipment evaluation problem, a two-level hierarchical evaluation framework is constructed, which comprehensively considers both the capabilities and characteristics of the equipment system during the evaluation process. The cloud model is then employed to represent the uncertain evaluations provided by experts, and a similarity-based expert weight calculation approach is introduced for calculating expert weights, thereby determining the relative importance of different experts. Subsequently, the VIKOR method is extended by incorporating the cloud model to evaluate and rank various equipment systems, where the criteria weights for this evaluation are established using the analytic hierarchy process (AHP). To demonstrate the efficacy of the proposed method, a practical case study involving the evaluation of unmanned combat aerial vehicles is presented. The results obtained are validated through sensitivity analysis and comparative analysis, affirming the reliability and reasonability of the proposed method in providing equipment evaluation results. In summary, the proposed method offers a novel and effective approach for addressing equipment evaluation challenges under uncertainty.**

***Keywords*—Multi-criteria decision-making; equipment evaluation; cloud model; VIKOR**

I. Introduction

Equipment systems stand as the cornerstone of modern military endeavors, playing a pivotal role in both the platform-centric and network-centric eras of warfare [1], [2], [3]. Over the past decades, as various equipment systems have rapidly developed and expanded, the evaluation and selection of these systems in alignment with operational goals, referred to as equipment system evaluation, has garnered substantial attention from researchers [4], [5], [6]. Consequently, equipment system evaluation has become a crucial consideration for both military operation planning and equipment system development.

The equipment system evaluation problem has been recognized as a complex multi-criteria decision-making (MCDM) challenge, given the involvement of multiple factors in varying forms [7], [8], [9]. Various MCDM methods have been applied to address this problem, including the analytic hierarchy process (AHP) [10], the evidential reasoning algorithm [11], the technique for order preference by similarity to an ideal solution (TOPSIS) [12], and others [13], [14]. For instance, Bi et al. [15] combined the interval evidential reasoning algorithm with AHP to evaluate different equipment systems, considering the inherent uncertainty in the problem. Gao et al. [16] introduced the intuitionistic fuzzy weighted influence non-linear gauge system, applying this method to equipment evaluation while considering interrelationships among different equipment systems. However, the handling of uncertain information and the reliable evaluation of different equipment systems while considering various factors remain urgent issues in equipment system evaluation problem.

Addressing uncertain information is a significant challenge in MCDM problems. Conventional fuzzy set (FS) theory, while effective in representing fuzziness, often falls short when dealing with the randomness of quantitative information. To address this limitation, Li et al. [17] introduced the cloud model theory for knowledge representation, accounting for both fuzziness and randomness in human cognitive processes. The cloud model transforms qualitative judgments into quantitative representations using the forward cloud generator, effectively and accurately modeling fuzziness and randomness, which offers a more intuitive and reliable representation of human knowledge. Given the inherent fuzziness and randomness in equipment evaluation, the cloud model holds potential for precisely modeling expert evaluations in this domain.

Decision-making problems have been extensively studied, leading to the development of numerous MCDM methods, including TOPSIS [18], MULTIMOORA [19], VIKOR [20], and others [21], [22], [23]. The VIKOR method, proposed by Opricovic [24], has proven effective for discrete MCDM problems by employing compromise solutions for ranking and selection amid conflicting criteria. VIKOR excels in reaching a compromised solution closest to the ideal solution, even when criteria conflict, making it widely used in various fields. In equipment evaluation problem, as there could be some conflicting information, adopting the VIKOR method could enhance the reliability of the results.

Nevertheless, to the best of our knowledge, there has been a noticeable gap in research utilizing the cloud model for equipment system evaluation. Additionally, scant attention has

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been directed towards integrating the VIKOR method with the cloud model, thereby serving as a key motivation for this study. The primary motivations for undertaking this research can be succinctly summarized as follows:

(1) The inherently complex nature of equipment evaluation necessitates the consideration of various factors. While prior studies have proposed different evaluation index systems for equipment assessment, these may prove less suitable for handling complex situations. Therefore, there is a crucial need to construct a systemic evaluation index framework tailored for equipment evaluation.

(2) Effectively representing expert knowledge considering fuzziness and randomness poses a significant challenge when evaluating different equipment systems. The cloud model has demonstrated efficacy in modeling uncertain information, particularly under conditions of fuzziness and randomness. Thus, the adoption of cloud models in equipment evaluation holds promise for yielding reliable results.

(3) Equipment evaluation problems inherently fall under the umbrella of MCDM. To enable the evaluation and selection of different alternatives, a comprehensive analysis of each equipment system is imperative. The VIKOR method stands out for its ability to produce reliable and reasonable solutions for complex MCDM problems. Consequently, leveraging the VIKOR method for equipment evaluation is a plausible approach.

Building on the aforementioned motivations, this study introduces a novel equipment evaluation method that integrates the cloud model, the AHP (AHP), and the VIKOR method. In this proposed approach, the cloud model serves as a tool to represent evaluation information, while the VIKOR method is employed to assess and rank various equipment systems. The determination of criteria weights is facilitated by the AHP. To showcase the effectiveness of the proposed method, a practical case involving the evaluation of unmanned combat aerial vehicles is presented, and the results are compared with those obtained through alternative methods. The key novelties of the proposed method include:

(1) This study establishes a two-level hierarchical evaluation structure for equipment evaluation. By considering both the capabilities and characteristics of equipment systems, the proposed evaluation structure enhances the reliability and comprehensiveness of equipment evaluation.

(2) The cloud model is employed as a tool for equipment evaluation. Through the construction of cloud models based on expert knowledge, the proposed method offers more reliable and reasonable results for equipment evaluation, particularly in the presence of fuzziness and randomness.

(3) The study proposes an integrated MCDM method that combines the cloud model and the VIKOR method. Through the calculation of group utility, individual regret, and aggregating index to determine the evaluation of different equipment systems, the proposed method ensures the attainment of an optimal solution.

The rest of this paper is organized as follows. Section II reviews several previous literature related to this study. Section III briefly revisits several basic concepts about cloud model. The proposed method is described in Section IV. Section V presents a case study of equipment system evaluation, and the results are analyzed in Section VI. Finally, Section VII provides some concluding remarks.

II. Related Works

A. Cloud Model

Proposed by Li et al. [17], the cloud model could work as an effective tool to convert qualitative judgments and quantitative representation through forward cloud generator, thus providing a flexible tool for human knowledge representation. Due to its advantages, the cloud model has been used in various fields. For instance, Xie et al. [25] introduced cloud-analytic hierarchy process and group cloud decision-making method for risk evaluation of fire and explosion accidents in oil depots, where the cloud model is utilized to model the probability data under uncertainty and ambiguity. Lin et al. [26] integrated the variable weight theory and cloud model theory for evaluating the risk of construction of karst tunnels. Gao [27] proposed an integrated risk analysis method based on cloud model and DEMATEL for tanker cargo handling operation, which utilizes the cloud model for uncertain knowledge representation and adopts the DEMATEL method to rank different risk factors. Wu et al. [28] integrated the cloud model with the improved criteria importance through intercriteria correlation (CRITIC) method, and applied the proposed method to urban rail transit operation safety evaluation.

B. VIKOR Method

The VIKOR method is a useful MCDM method that considers both the group utility and individual regret of the alternative when evaluating and ranking different alternatives, and it has been applied to various fields. For example, Gao et al. [29] extended the VIKOR method with Fermatean fuzzy sets, proposing a novel Fermatean fuzzy decision-making approach for health care waste treatment technology selection. Abdul et al. [30] introduced an integrated decision-making approach based on AHP and the VIKOR method for prioritizing renewable energy sources. Bakioglu and Atahan [31] proposed a hybrid MCDM method based on AHP, TOPSIS, and VIKOR under the Pythagorean fuzzy environment for prioritizing risks in self-driving vehicles. Li et al. [32] integrated the later defuzzification VIKOR method with fuzzy DEMATEL and entropy weighting, presenting a hybrid MCDM method for machine tool selection, where the later defuzzification VIKOR method is used to rank different alternatives.

III. Preliminaries

The cloud model, serving as the foundation for cloud-based reasoning, computing, and control, provides an uncertain transformation model for handling both qualitative concepts and quantitative descriptions. This model adeptly captures the transition from qualitative concepts to quantitative representation through the forward cloud generator, and conversely, from quantitative representation to qualitative concept through the reverse cloud generator.

Definition 1. Consider a qualitative domain U and the corresponding qualitative concept C on U. Let x be a random number following a normal distribution with $x \in U$. The membership degree $\mu(x)$ of x for C is a random number exhibiting stable inclination, satisfying $\mu(x) \in [0, 1]$. Here, x and its distribution on U are termed cloud droplets and clouds, respectively.

In the cloud model, the uncertainty of the data x is expressed through three key values:

1) The expected value Ex, reflecting the qualitative concept in the argument domain space.
2) The entropy En, representing the desirable range of assessment results and the degree of cloud droplet clustering.
3) The hyper entropy He, reflecting the dispersion degree of the cloud droplets.

The characteristics of the cloud model are denoted as $C = (Ex, En, He)$, and they can be calculated using Eq. (1)-(3):

$$Ex = \frac{1}{n}\sum_{i=1}^{n} X_i \tag{1}$$

$$En = \sqrt{\frac{\pi}{2}} \times \frac{1}{n}\sum_{i=1}^{n} |X_i - Ex| \tag{2}$$

$$He = \sqrt{\left|\frac{1}{n-1}\sum_{i=1}^{n}(X_i - Ex)^2 - En^2\right|} \tag{3}$$

where X_i $(i = 1, 2, \ldots, n)$ represents the ith data from the distribution, and n is the number of data in the distribution.

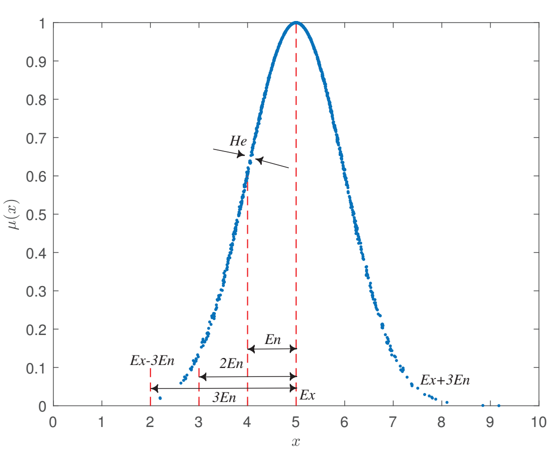

Fig. 1. Demonstration of the cloud model.

Utilizing the forward cloud generator, which is based on the characteristics obtained from the cloud model, a positive random number $x \sim N(Ex, En^2)$ can be generated, as illustrated in Fig. 1. A cloud droplet is defined as $(x, \mu(x))$, where the cloud droplet membership degree $\mu(x)$ is calculated by using Eq. (4) as:

$$\mu(x) = e^{\frac{-(x-Ex)^2}{2En^2}} \tag{4}$$

Definition 2. Let $C_1 = (Ex_1, En_1, He_1)$ and $C_2 = (Ex_2, En_2, He_2)$ be two clouds, the operations among C_1 and C_2 is defined as:

1) $C_1 + C_2 = (Ex_1 + Ex_2, \sqrt{En_1^2 + En_2^2}, \sqrt{He_1^2 + He_2^2})$
2) $C_1 - C_2 = (Ex_1 - Ex_2, \sqrt{En_1^2 + En_2^2}, \sqrt{He_1^2 + He_2^2})$
3) $C_1 \times C_2 = (Ex_1 \times Ex_2, \sqrt{(En_1 Ex_2)^2 + (En_2 Ex_1)^2}, \sqrt{(He_1 Ex_2)^2 + (He_2 Ex_1)^2})$
4) $\lambda C_1 = (\lambda Ex_1, \sqrt{\lambda} En_1, \sqrt{\lambda} He_1)$

Definition 3. Let $C_1 = (Ex_1, En_1, He_1)$ and $C_2 = (Ex_2, En_2, He_2)$ be two clouds, then the distance between C_1 and C_2 is defined using Eq. (5):

$$d(C_1, C_2) = \sqrt{\frac{1}{2}(d_1 + d_2)} \tag{5}$$

where

$$d_1 = \left(\left(1 - \frac{3\sqrt{En_1^2 + He_1^2}}{Ex_1}\right) Ex_1 - \left(1 - \frac{3\sqrt{En_2^2 + He_2^2}}{Ex_2}\right) Ex_2\right)^2$$
$$d_2 = \left(\left(1 + \frac{3\sqrt{En_1^2 + He_1^2}}{Ex_1}\right) Ex_1 - \left(1 + \frac{3\sqrt{En_2^2 + He_2^2}}{Ex_2}\right) Ex_2\right)^2 \tag{6}$$

Definition 4. Let $C_i = (Ex_i, En_i, He_i)$ $(i = 1, 2, \ldots, n)$ be a set of clouds in the domain U, the cloud weighted average (CWA) operator is defined by Eq. (7) as:

$$\begin{aligned} CWA(C_1, C_2, \ldots, C_n) &= \sum_{i=1}^{n} w_i C_i \\ &= \left(\sum_{i=1}^{n} w_i Ex_i, \sqrt{\sum_{i=1}^{n} w_i (En_i)^2}, \sqrt{\sum_{i=1}^{n} w_i (He_i)^2}\right) \end{aligned} \tag{7}$$

where $(w_1, w_2, \ldots, w_n)$ is the weight vector with $0 \le w_i \le 1$ and $\sum_{i=1}^{n} w_i = 1$.

In cloud model-based assessments, the $3En$ principle is commonly employed to analyze the assessment results. This is because the cloud droplets in the cloud diagram are predominantly concentrated in the $[Ex - 3En, Ex + 3En]$ interval, as depicted in Fig. 1. It is noteworthy that varying distribution locations of the cloud droplets signify different qualitative assessments, which can be broadly categorized into three parts:

1) The main part $(Ex - En, Ex + En)$, characterized by the highest membership degree.
2) The secondary part $(Ex - 2En, Ex - En) \cup (Ex + En, Ex + 2En)$.
3) The minor part $(Ex - 3En, Ex - 2En) \cup (Ex + 2En, Ex + 3En)$.

Cloud droplets beyond this interval are typically not utilized as the basis for qualitative descriptions of the assessment.

IV. Proposed Method

In this section, a novel decision-making approach for equipment evaluation based on the cloud model, the DEMATEL method, and the VIKOR method is described in detail. The proposed method consists of four phases, as demonstrated in Fig. 2. Firstly, the equipment system evaluation problem is defined in detail. Secondly, the linguistic judgments of different experts are converted into cloud models and aggregated while considering the weights of the experts. Thirdly, a hybrid criteria weight calculation method that takes into account both the subjective weights and objective weights is introduced to determine the weights of the criteria. Fourthly, the VIKOR method is extended with cloud model to evaluate and rank different equipment systems. The detailed steps of the proposed method are described as follows.

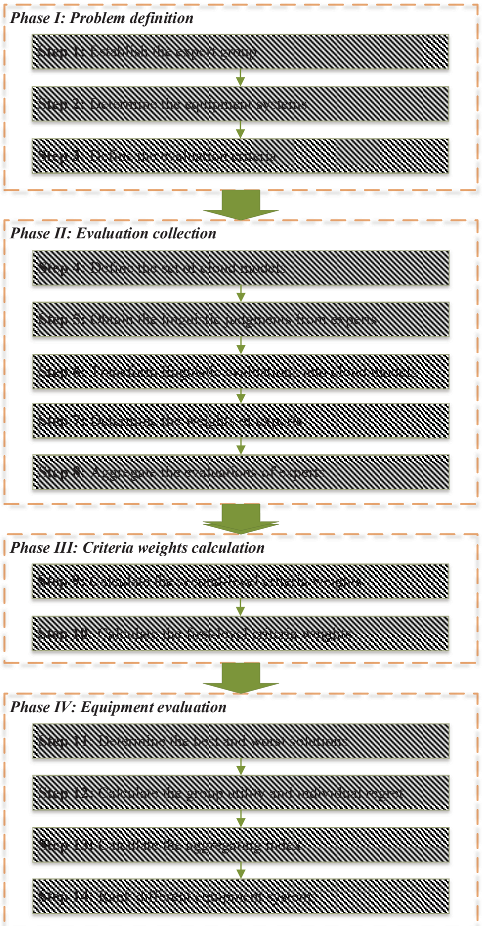

Fig. 2. Framework of the proposed method.

A. Phase I: Problem Definition

Step 1: Establish the expert group

Firstly, given the uncertainty inherent in the equipment evaluation problem and the limited information available, it becomes imperative to rely on a group of experts to enhance the reliability and effectiveness of the results. The selection of these experts is conducted considering the following aspects:

1) Expertise of the experts: To ensure the reliability and effectiveness of expert judgments, members of the expert group must possess more than five years of experience in the field of equipment design, production, application, or scientific research.

2) Number of the experts: To ensure the comprehensiveness and rationality of the results, the number of experts should not be too small. After analyzing the problem and consulting previous literature, it is determined that a group of 3-10 experts will be selected for evaluation based on their knowledge.

3) Diversity of the experts: To construct a reliable expert group, diversity among the experts is crucial to avoid excessive convergence of opinions. Therefore, experts with different positions, expertise, and experiences are invited, enhancing the objectivity and comprehensiveness of the evaluations.

Step 2: Determine the equipment systems

The primary objective of equipment evaluation is to assess and rank various equipment systems based on their performance. In this step, the expert group collaboratively determines the specific equipment systems that will serve as the foundation for the evaluation process, and the equipment systems are denoted as $A = \{A_1, A_2, \ldots, A_m\}$.

Step 3: Define the evaluation criteria

In the equipment evaluation problem, each equipment system undergoes assessment, taking into account its multifaceted performance. Given the diverse aspects influencing the performance of equipment systems, considering both the capabilities and characteristics becomes crucial for enhancing the reliability and rationality of the results. In this study, a two-level hierarchical evaluation structure is adopted for equipment evaluation, illustrated using the example of an unmanned combat aerial vehicle (UCAV) in Fig. 3.

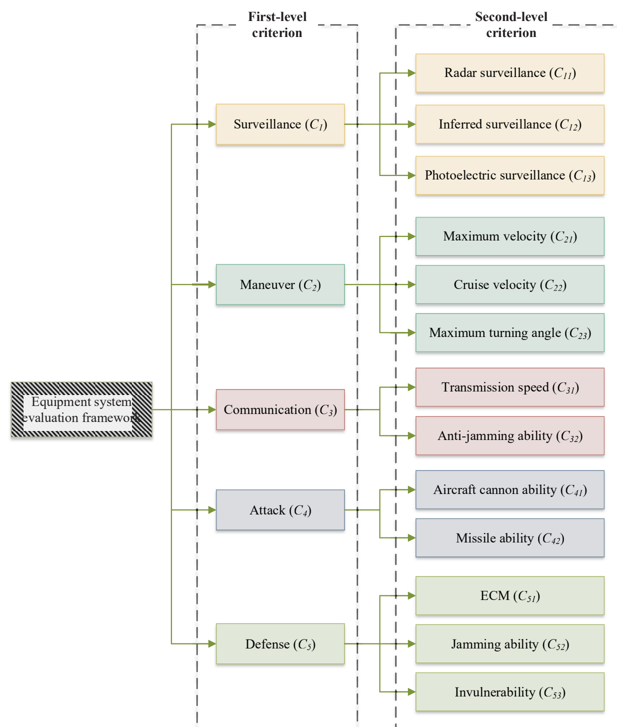

Fig. 3. Two-level hierarchical evaluation structure for unmanned combat aerial vehicle.

In this two-level hierarchical framework, capabilities constitute the first-level criteria, encompassing surveillance (C_1), maneuver (C_2), communication (C_3), attack (C_4), and defense (C_5). Subsequently, ten second-level criteria, representing specific characteristics of the equipment, are defined. For instance, the capability surveillance is subdivided into three sub-criteria: radar surveillance (C_{11}), inferred surveillance (C_{12}), and photoelectric surveillance (C_{13}). The capability maneuver entails the UCAV's ability to execute various maneuvers, further divided into three sub-criteria: maximum velocity (C_{21}), cruise velocity (C_{22}), and maximum turning angle (C_{23}). Communication capability comprises two sub-criteria: transmission speed (C_{31}) and anti-jamming ability (C_{32}). The attack capability is delineated by two sub-criteria: aircraft cannon ability (C_{41}) and missile ability (C_{42}). The defense capability encompasses three sub-criteria: ECM (C_{51}), jamming ability (C_{52}), and invulnerability (C_{53}). This hierarchical framework ensures a comprehensive evaluation of the equipment systems.

B. Phase II: Evaluation Collection

Step 4: Define the set of cloud models.

In this step, a set of cloud models is constructed to represent the evaluations, utilizing five evaluation grades within the domain $[0.05, 0.95]$. The linguistic terms employed are $S = \{$"Very low (VL)", "Low (L)", "Medium (M)", "High (H)", "Very High (VH)"$\}$. The transformation between the cloud models and the linguistic terms is detailed in Table I.

TABLE I. TRANSFORMATION AMONG LINGUISTIC TERMS AND CLOUD MODELS

Linguistic terms	Cloud models
Very low (VL)	(0.05,0.033,0.012)
Low (L)	(0.309,0.021,0.008)
Medium (M)	(0.5,0.013,0.005)
High (H)	(0.691,0.021,0.008)
Very high (VH)	(0.95,0.033,0.012)

Step 5: Obtain the linguistic judgments from experts.

In the context of equipment evaluation, multiple experts contribute their judgments in the form of linguistic terms to enrich the comprehensiveness and rationality of the results. Each expert within the expert group is tasked with evaluating each equipment system across the evaluation criteria.

For the equipment evaluation problem, assuming there are m equipment systems, each characterized by n second-level criteria, and involving the perspectives of k experts. Let z_{ij}^t represent the evaluation of the tth expert for the ith equipment system concerning the jth criterion, with $i = 1, 2, \ldots, m$, $j = 1, 2, \ldots, n$, and $t = 1, 2, \ldots, k$. It is important to note that z_{ij}^t denotes the linguistic term from the linguistic term set S and can be converted into corresponding cloud models. The linguistic decision matrix Z^t for the tth expert is derived by synthesizing their linguistic evaluations as Eq. (8):

$$Z^t = \begin{bmatrix} z_{11}^t & z_{12}^t & \cdots & z_{1n}^t \\ z_{21}^t & z_{22}^t & \cdots & z_{2n}^t \\ \vdots & \vdots & \ddots & \vdots \\ z_{m1}^t & z_{m2}^t & \cdots & z_{mn}^t \end{bmatrix} \tag{8}$$

Step 6: Transform linguistic evaluations into cloud models.

For the subsequent evaluation, the acquired linguistic evaluations need to be transformed into cloud models to effectively manage fuzziness and randomness. In this study, cloud models are defined in consideration of linguistic terms. Each linguistic evaluation z_{ij}^t can be equivalently transformed into a cloud model $\tilde{z}_{ij}^t$ using Table I. The cloud decision matrix $\tilde{Z}^t$ is obtained using Eq. (9):

$$\tilde{Z}^t = \begin{bmatrix} \tilde{z}_{11}^t & \tilde{z}_{12}^t & \cdots & \tilde{z}_{1n}^t \\ \tilde{z}_{21}^t & \tilde{z}_{22}^t & \cdots & \tilde{z}_{2n}^t \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{z}_{m1}^t & \tilde{z}_{m2}^t & \cdots & \tilde{z}_{mn}^t \end{bmatrix} \tag{9}$$

Step 7: Determine the weights of experts.

Given the involvement of multiple experts in the evaluation, each with diverse experiences and backgrounds, it is reasonable to acknowledge that they may carry different levels of importance and credibility in their evaluations. Hence, determining the weights of different experts becomes crucial to ensure the reliability of the results. In this study, considering the evaluations provided by the experts, a similarity-based expert weight calculation method is introduced. The process is as follows:

Firstly, the distance between the cloud evaluations of any two pair of experts is calculated using the distance measure in Eq. (10) as:

$$d_{i,j}^{k,l} = d(\tilde{z}_{ij}^k, \tilde{z}_{ij}^l) \tag{10}$$

Then, the similarity between the cloud evaluations of each pair of experts are obtained using Eq. (11):

$$sim_{i,j}^{k,l} = 1 - d_{i,j}^{k,l} \tag{11}$$

and the similarity matrix is constructed as:

$$SMM = \begin{bmatrix} S_{11} & S_{12} & \cdots & S_{1t} \\ S_{21} & S_{22} & \cdots & S_{2t} \\ \vdots & \vdots & \ddots & \vdots \\ S_{t1} & S_{t2} & \cdots & S_{tt} \end{bmatrix} \tag{12}$$

where $S_{kl} = \sum_{i=1}^{m} \sum_{j=1}^{n} sim_{i,j}^{k,l}$.

Next, the support degree of the kth experts is obtained by using Eq. (13) as:

$$Sup_k = \sum_{l=1, l \neq k}^{t} S_{kl} \tag{13}$$

Finally, the weight of each expert is calculated based on the credibility degree, as shown in Eq. (14):

$$w_k = \frac{Sup_k}{\sum_{k=1}^{t} Sup_k} \tag{14}$$

Step 8: Aggregate the evaluations of experts.

In this step, the evaluations of different experts on the equipment system A_i concerning the criterion C_j are aggregated using the CWA operator, resulting in the formation of the aggregated decision matrix in Eq. (16):

$$\tilde{Z} = \begin{bmatrix} \tilde{z}_{11} & \tilde{z}_{12} & \cdots & \tilde{z}_{m1} \\ \tilde{z}_{21} & \tilde{z}_{22} & \cdots & \tilde{z}_{m2} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{z}_{m1} & \tilde{z}_{m2} & \cdots & \tilde{z}_{mn} \end{bmatrix} \tag{15}$$

where $\tilde{z}_{ij}$ denotes the aggregated evaluation of the ith equipment system regarding the jth criterion, and is obtained by using Eq. (16) as:

$$\tilde{z}_{ij} = CWA(z_{ij}^1, z_{ij}^2, \ldots, z_{ij}^t) \tag{16}$$

C. Phase III: Criteria Weights Calculation

Step 9: Calculate the second-level criteria weights.

In this step, the AHP is employed to determine the weights of the second-level criteria in relation to the first-level criteria. It is essential to note that for the second-level criteria, the calculated weights represent their relative importance within the context of the first-level criteria. In other words, for the five first-level criteria, five sets of sub-criteria weights are calculated and obtained using the AHP.

Step 10: Calculate the first-level criteria weights.

For the first-level criteria, the AHP is employed in this step to determine their weights based on the judgments of experts. The weights assigned to the criteria represent their relative importance in the evaluation process, where a larger criteria weight indicates higher importance.

D. Phase IV: Equipment Evaluation

Step 11: Determine the best and worst solutions.

In this step, the best and worst solutions for each criterion are determined based on their characteristics and aggregated evaluations. It is important to note that the determination of the best and worst solutions may vary depending on whether the criteria are benefit-oriented or cost-oriented, as both types could be involved.

The best solution is obtained as:

$$\rho_j^* = \begin{cases} \max_{i=1,\ldots,m} \tilde{z}_{ij} & C_j \in C_B \\ \min_{i=1,\ldots,m} \tilde{z}_{ij} & C_j \in C_C \end{cases} \tag{17}$$

The worst solution is obtained as:

$$\rho_j^- = \begin{cases} \min_{i=1,\ldots,m} \tilde{z}_{ij} & C_j \in C_B \\ \max_{i=1,\ldots,m} \tilde{z}_{ij} & C_j \in C_C \end{cases} \tag{18}$$

where C_B and C_C denotes the set of benefit criteria and cost criteria, respectively.

Step 12: Calculate the group utility and individual regret.

Using the distance measure, the group utility S_i and the individual regret R_i of the ith equipment system can be obtained by calculating the distance from the ith equipment system to the best solution using Eq. (19) as:

$$\begin{gathered} S_i = \sum_{j=1}^{n} \omega_j \frac{d(\rho^*, \tilde{z}_{ij})}{d(\rho^*, \rho^-)} \\ R_i = \max_j \omega_j \frac{d(\rho^*, \tilde{z}_{ij})}{d(\rho^*, \rho^-)} \end{gathered} \tag{19}$$

where ω_j denotes the weights of the jth criterion.

Step 13: Calculate the aggregating index.

The aggregating index of each equipment system is computed by combining the group utility and the individual regret using Eq. (20) as:

$$Q_i = \gamma \frac{S_i - S^-}{S^* - S^-} + (1-\gamma) \frac{R_i - R^-}{R^* - R^-} \tag{20}$$

where $S^* = \max_i S_i$, $S^- = \min_i S_i$, $R^* = \max_i R_i$, $R^- = \min_i R_i$, and γ is the decision coefficient. When $\gamma > 0.5$, it is the strategy of maximum group utility, whereas $\gamma < 0.5$ indicates the strategy of with veto.

Step 14: Rank different equipment systems.

Based on the values of S_i, R_i, and Q_i, the equipment systems can be ranked in descending order, with a higher value indicating better preference. Additionally, to identify the optimal solution, it should satisfy the following condition:

Condition 1: The difference between the first equipment system and the second equipment systems should satisfy Eq. (21):

$$Q(A_{(2)}) - Q(A_{(1)}) \geq \frac{1}{m-1} \tag{21}$$

Condition 2: The optimal equipment system $A_{(1)}$ must be the best one according to S and/or R.

If one of these two conditions is not satisfied, the obtained results are a set of compromised solutions that:

(1) $A_{(1)}$ and $A_{(2)}$ are compromised solutions if Condition 2 is not satisfied.

(2) $A_{(1)}, A_{(2)}, \ldots, A_{(m)}$ are compromised solutions if Condition 1 is not satisfied, where the closeness of $A_{(m)}$ is determined by Eq. (22):

$$Q(A_{(m)}) - Q(A_{(1)}) < \frac{1}{m-1} \tag{22}$$

V. Case Study

In this section, a practical case of unmanned combat aerial vehicle (UCAV) evaluation is presented to illustrate the process and effectiveness of the proposed method.

In recent years, with the rapid development of automation and control technologies, unmanned aerial vehicles (UAVs) have found widespread applications in various fields. Notably, UAVs have become integral in military operations, undertaking missions such as surveillance and combat. With the rise in military UAV applications, UCAVs, specifically designed for combat missions, have garnered attention from researchers and practitioners alike. Given their ability to effectively execute missions like surveillance, search, and assault, UCAVs have become focal points in military operations. Consequently, the evaluation and selection of suitable UCAVs have emerged as crucial concerns. In this study, with a focus on the evaluation and selection of UCAVs for military operations, the proposed method is applied to assess different UCAVs.

Step 1: In this study, the evaluation of various UCAV alternatives is conducted. A panel of three experts from Northwestern Polytechnical University and AVIC is assembled to form the expert group. The experts provide their judgments in the form of linguistic terms, assessing different UCAV alternatives based on their extensive understanding and knowledge. The selected experts, denoted as $E = \{E_1, E_2, E_3\}$, possess significant expertise and experience in the design and operation of UCAVs.

Step 2: Based on the analysis of potential alternatives, seven UCAV alternatives are identified by the experts, denoted as $A = \{A_1, A_2, A_3, A_4, A_5, A_6, A_7\}$.

Step 3: In this study, the two-level evaluation hierarchical framework in Fig 3 is adopted to evaluate the UCAV alternatives.

Step 4: Due to the complexity and uncertainty inherent in the UCAV evaluation problem, experts may not be able to provide precise numerical evaluations. To accommodate this uncertainty and ensure flexibility and reliability in the evaluations, this study employs a linguistic term set with five terms $S = \{VL, L, M, H, VH\}$ to represent expert assessments. The transformation between linguistic evaluations and cloud models is detailed in Table I.

Step 5: Each expert generates a linguistic evaluation based on their understanding of a specific UCAV alternative in relation to a specific criterion. The linguistic evaluations provided by the experts are presented in Table II.

Step 6: Using Table I, the cloud models of the experts judgments can be derived from their linguistic evaluations. Subsequently, the cloud decision matrix for each expert is constructed. Table III provides a summary of the cloud models representing the experts evaluations.

Step 7: In this study, the weights of the experts are determined based on the similarity among them. Firstly, by using Eq. (10)-(13), the similarity matrix of the experts is constructed as:

$$SMM = \begin{bmatrix} 91 & 57.7355 & 54.6704 \\ 57.7355 & 91 & 60.0740 \\ 54.6704 & 60.0740 & 91 \end{bmatrix}$$

Then, based on the similarity matrix, the support degree of each expert could be obtained as:

$$Sup_1 = 112.4058,\ Sup_2 = 117.8095,\ Sup_3 = 114.7444$$

Hence, the weights of the experts are calculated as:

$$w_1 = 0.3259,\ w_2 = 0.2415,\ w_3 = 0.3326$$

Step 8: Utilizing the CWA operator, the aggregated evaluation can be obtained based on the expert weights and the individual decision matrices. The resulting aggregated decision matrix is presented in Table IV.

Step 9: To determine the weights of the sub-criteria, AHP is employed. Pairwise comparison matrices are constructed for different sub-criteria. For instance, the pairwise comparison matrix for sub-criteria under the surveillance capability is constructed as:

$$\begin{bmatrix} 1 & \frac{1}{5} & \frac{1}{3} \\ 5 & 1 & 3 \\ 3 & \frac{1}{3} & 1 \end{bmatrix}$$

Then, by using the AHP, the local weights of the sub-criteria are calculated as:

$$\omega_{11} = 0.6370,\ \omega_{12} = 0.1047,\ \omega_{13} = 0.2583$$

Similarly, by using the AHP, the local weights of the sub-criteria could be obtained, as listed in Table V.

Step 10: Similarly, by using the AHP, the weights of the first-level criteria could be obtained as:

$$\omega_1 = 0.1290,\ \omega_2 = 0.0634,\ \omega_3 = 0.0333,$$
$$\omega_4 = 0.5128,\ \omega_5 = 0.2615$$

Thus, the global weights of different second-level criteria could be obtained, as shown in Table V.

Step 11: Upon analyzing the criteria, it is observed that all criteria are benefit criteria. Hence, the best and worst solutions for each criterion can be obtained using Eq. (18) and (19). The results are listed in Table VI.

Step 12: By using the distance measure, the group utility and the individual regret of each equipment system could be obtained, and the results are listed in Table VII.

Step 13: By combining the results of the group utility and the individual regret, the aggregating index of each equipment system can be computed. In this case, the decision coefficient γ is set to 0.5, and the results are shown in Table VIII.

Step 14: Based on the aggregating index of the UCAVs, the UCAVs can be ranked in descending order, and the results are listed in Table VIII. It is noteworthy that both Conditions 1 and 2 are satisfied. Therefore, the obtained results constitute the optimal solution, and the ranking of the UCAVs can be determined as $A_6 \succ A_7 \succ A_5 \succ A_3 \succ A_2 \succ A_4 \succ A_1$, where A_6 is identified as the best UCAV alternative.

VI. Results and Discussions

In this study, a novel MCDM approach based on cloud model and VIKOR method is proposed for equipment evaluation, and the proposed method is validated through a practical case of UCAV evaluation. In this section, in order to further validate the proposed method, the results are further analyzed and discussed.

A. Sensitivity Analysis

In the proposed method, the decision coefficient γ is used to determine the preference of the final results, where $\gamma > 0.5$ indicates "maximum group utility" and $\gamma < 0.5$ indicates "with veto". To better analyze the effects of the decision coefficient on the final results, a sensitivity analysis is conducted in this section.

In this analysis, the value of γ varies from 0 to 1, and the proposed method is utilized to evaluate the same set of UCAV alternatives. The results are illustrated in Fig. 4.

From Fig. 4, it can be observed that as the decision coefficient changes from 0 to 1, there are variations in the ranking of the alternatives. Specifically, the optimal alternative would vary from A_6 to A_7, and this variation is caused by the fact that A_6 outperforms A_7 in individual regret, while it

TABLE II. LINGUISTIC EVALUATIONS OF EXPERTS

Alternative	Expert	C_{11}	C_{12}	C_{13}	C_{21}	C_{22}	C_{23}	C_{31}	C_{32}	C_{41}	C_{42}	C_{51}	C_{52}	C_{53}
	E_1	VH	VH	VL	VH	H	VL	L	M	VH	VH	VL	VH	VH
A_1	E_2	M	VH	VL	M	VH	H	VH	H	VL	VH	VH	H	H
	E_3	H	L	H	VL	H	VL	L	VL	VL	VH	H	L	VH
	E_1	VL	M	L	H	H	VL	M	M	H	H	H	L	H
A_2	E_2	H	VL	VL	M	VH	L	M	L	H	L	M	H	VH
	E_3	VH	M	VL	VL	L	VH	L	VH	L	VH	L	VL	L
	E_1	H	M	L	VH	M	M	VH	L	H	H	L	M	VL
A_3	E_2	VL	M	H	VH	VL	M	M	VL	L	VL	H	L	M
	E_3	VL	H	L	H	H	H	M	VL	L	VH	VL	VH	M
	E_1	VH	VL	M	VL	VH	VL	H	VH	VH	VL	L	L	VH
A_4	E_2	M	VH	VL	L	VL	VL	VH	M	M	VL	VH	H	L
	E_3	M	M	VL	L	VL	VL	L	M	VL	VH	VH	M	M
	E_1	L	VH	L	VL	H	L	L	M	VL	VL	VH	VH	M
A_5	E_2	VL	L	L	VH	VL	VL	VL	H	H	H	M	M	L
	E_3	H	VL	H	VL	L	H	H	VL	VH	H	M	M	M
	E_1	L	M	M	VH	H	H	L	VH	M	L	VH	VH	M
A_6	E_2	H	M	L	L	M	L	VH	VL	L	VL	L	M	L
	E_3	VH	M	VL	VH	VH	M	VL	L	M	M	L	H	H
	E_1	L	VL	L	L	M	M	VL	L	VH	VL	VH	H	M
A_7	E_2	M	L	M	VH	M	M	L	M	H	H	L	L	VH
	E_3	VL	VH	VH	H	VL	L	L	H	VL	H	VL	H	M

TABLE III. CLOUD EVALUATIONS OF EXPERTS

Alternative	Expert	C_{11}	C_{12}	C_{13}	C_{21}	C_{22}	C_{23}	C_{31}	C_{32}	C_{41}	C_{42}	C_{51}	C_{52}	C_{53}
	E_1	$(0.950, 0.033, 0.012)$	$(0.950, 0.033, 0.012)$	$(0.050, 0.033, 0.012)$	$(0.950, 0.033, 0.012)$	$(0.691, 0.021, 0.008)$	$(0.050, 0.033, 0.012)$	$(0.309, 0.021, 0.008)$	$(0.500, 0.013, 0.005)$	$(0.950, 0.033, 0.012)$	$(0.950, 0.033, 0.012)$	$(0.050, 0.033, 0.012)$	$(0.950, 0.033, 0.012)$	$(0.950, 0.033, 0.012)$
A_1	E_2	$(0.500, 0.013, 0.005)$	$(0.950, 0.033, 0.012)$	$(0.050, 0.033, 0.012)$	$(0.500, 0.013, 0.005)$	$(0.950, 0.033, 0.012)$	$(0.691, 0.021, 0.008)$	$(0.950, 0.033, 0.012)$	$(0.691, 0.021, 0.008)$	$(0.050, 0.033, 0.012)$	$(0.950, 0.033, 0.012)$	$(0.950, 0.033, 0.012)$	$(0.691, 0.021, 0.008)$	$(0.691, 0.021, 0.008)$
	E_3	$(0.691, 0.021, 0.008)$	$(0.309, 0.021, 0.008)$	$(0.691, 0.021, 0.008)$	$(0.050, 0.033, 0.012)$	$(0.691, 0.021, 0.008)$	$(0.050, 0.033, 0.012)$	$(0.309, 0.021, 0.008)$	$(0.050, 0.033, 0.012)$	$(0.050, 0.033, 0.012)$	$(0.950, 0.033, 0.012)$	$(0.691, 0.021, 0.008)$	$(0.309, 0.021, 0.008)$	$(0.950, 0.033, 0.012)$
	E_1	$(0.050, 0.033, 0.012)$	$(0.500, 0.013, 0.005)$	$(0.309, 0.021, 0.008)$	$(0.691, 0.021, 0.008)$	$(0.691, 0.021, 0.008)$	$(0.050, 0.033, 0.012)$	$(0.500, 0.013, 0.005)$	$(0.500, 0.013, 0.005)$	$(0.691, 0.021, 0.008)$	$(0.691, 0.021, 0.008)$	$(0.691, 0.021, 0.008)$	$(0.309, 0.021, 0.008)$	$(0.691, 0.021, 0.008)$
A_2	E_2	$(0.691, 0.021, 0.008)$	$(0.050, 0.033, 0.012)$	$(0.050, 0.033, 0.012)$	$(0.500, 0.013, 0.005)$	$(0.950, 0.033, 0.012)$	$(0.309, 0.021, 0.008)$	$(0.500, 0.013, 0.005)$	$(0.309, 0.021, 0.008)$	$(0.691, 0.021, 0.008)$	$(0.309, 0.021, 0.008)$	$(0.500, 0.013, 0.005)$	$(0.691, 0.021, 0.008)$	$(0.950, 0.033, 0.012)$
	E_3	$(0.950, 0.033, 0.012)$	$(0.500, 0.013, 0.005)$	$(0.050, 0.033, 0.012)$	$(0.050, 0.033, 0.012)$	$(0.309, 0.021, 0.008)$	$(0.950, 0.033, 0.012)$	$(0.309, 0.021, 0.008)$	$(0.950, 0.033, 0.012)$	$(0.309, 0.021, 0.008)$	$(0.950, 0.033, 0.012)$	$(0.309, 0.021, 0.008)$	$(0.050, 0.033, 0.012)$	$(0.309, 0.021, 0.008)$
	E_1	$(0.691, 0.021, 0.008)$	$(0.500, 0.013, 0.005)$	$(0.309, 0.021, 0.008)$	$(0.950, 0.033, 0.012)$	$(0.500, 0.013, 0.005)$	$(0.500, 0.013, 0.005)$	$(0.950, 0.033, 0.012)$	$(0.309, 0.021, 0.008)$	$(0.691, 0.021, 0.008)$	$(0.691, 0.021, 0.008)$	$(0.309, 0.021, 0.008)$	$(0.500, 0.013, 0.005)$	$(0.050, 0.033, 0.012)$
A_3	E_2	$(0.050, 0.033, 0.012)$	$(0.500, 0.013, 0.005)$	$(0.691, 0.021, 0.008)$	$(0.950, 0.033, 0.012)$	$(0.050, 0.033, 0.012)$	$(0.500, 0.013, 0.005)$	$(0.500, 0.013, 0.005)$	$(0.050, 0.033, 0.012)$	$(0.309, 0.021, 0.008)$	$(0.050, 0.033, 0.012)$	$(0.691, 0.021, 0.008)$	$(0.309, 0.021, 0.008)$	$(0.500, 0.013, 0.005)$
	E_3	$(0.050, 0.033, 0.012)$	$(0.691, 0.021, 0.008)$	$(0.309, 0.021, 0.008)$	$(0.691, 0.021, 0.008)$	$(0.691, 0.021, 0.008)$	$(0.691, 0.021, 0.008)$	$(0.500, 0.013, 0.005)$	$(0.050, 0.033, 0.012)$	$(0.309, 0.021, 0.008)$	$(0.950, 0.033, 0.012)$	$(0.050, 0.033, 0.012)$	$(0.950, 0.033, 0.012)$	$(0.500, 0.013, 0.005)$
	E_1	$(0.950, 0.033, 0.012)$	$(0.050, 0.033, 0.012)$	$(0.500, 0.013, 0.005)$	$(0.050, 0.033, 0.012)$	$(0.950, 0.033, 0.012)$	$(0.050, 0.033, 0.012)$	$(0.691, 0.021, 0.008)$	$(0.950, 0.033, 0.012)$	$(0.950, 0.033, 0.012)$	$(0.050, 0.033, 0.012)$	$(0.309, 0.021, 0.008)$	$(0.309, 0.021, 0.008)$	$(0.950, 0.033, 0.012)$
A_4	E_2	$(0.500, 0.013, 0.005)$	$(0.950, 0.033, 0.012)$	$(0.050, 0.033, 0.012)$	$(0.309, 0.021, 0.008)$	$(0.050, 0.033, 0.012)$	$(0.050, 0.033, 0.012)$	$(0.950, 0.033, 0.012)$	$(0.500, 0.013, 0.005)$	$(0.500, 0.013, 0.005)$	$(0.050, 0.033, 0.012)$	$(0.950, 0.033, 0.012)$	$(0.691, 0.021, 0.008)$	$(0.309, 0.021, 0.008)$
	E_3	$(0.500, 0.013, 0.005)$	$(0.500, 0.013, 0.005)$	$(0.050, 0.033, 0.012)$	$(0.309, 0.021, 0.008)$	$(0.050, 0.033, 0.012)$	$(0.050, 0.033, 0.012)$	$(0.309, 0.021, 0.008)$	$(0.500, 0.013, 0.005)$	$(0.050, 0.033, 0.012)$	$(0.950, 0.033, 0.012)$	$(0.950, 0.033, 0.012)$	$(0.500, 0.013, 0.005)$	$(0.500, 0.013, 0.005)$
	E_1	$(0.309, 0.021, 0.008)$	$(0.950, 0.033, 0.012)$	$(0.309, 0.021, 0.008)$	$(0.050, 0.033, 0.012)$	$(0.691, 0.021, 0.008)$	$(0.309, 0.021, 0.008)$	$(0.309, 0.021, 0.008)$	$(0.500, 0.013, 0.005)$	$(0.050, 0.033, 0.012)$	$(0.050, 0.033, 0.012)$	$(0.950, 0.033, 0.012)$	$(0.950, 0.033, 0.012)$	$(0.500, 0.013, 0.005)$
A_5	E_2	$(0.050, 0.033, 0.012)$	$(0.309, 0.021, 0.008)$	$(0.309, 0.021, 0.008)$	$(0.950, 0.033, 0.012)$	$(0.050, 0.033, 0.012)$	$(0.050, 0.033, 0.012)$	$(0.050, 0.033, 0.012)$	$(0.691, 0.021, 0.008)$	$(0.691, 0.021, 0.008)$	$(0.691, 0.021, 0.008)$	$(0.500, 0.013, 0.005)$	$(0.500, 0.013, 0.005)$	$(0.309, 0.021, 0.008)$
	E_3	$(0.691, 0.021, 0.008)$	$(0.050, 0.033, 0.012)$	$(0.691, 0.021, 0.008)$	$(0.050, 0.033, 0.012)$	$(0.309, 0.021, 0.008)$	$(0.691, 0.021, 0.008)$	$(0.691, 0.021, 0.008)$	$(0.050, 0.033, 0.012)$	$(0.950, 0.033, 0.012)$	$(0.691, 0.021, 0.008)$	$(0.500, 0.013, 0.005)$	$(0.500, 0.013, 0.005)$	$(0.500, 0.013, 0.005)$
	E_1	$(0.309, 0.021, 0.008)$	$(0.500, 0.013, 0.005)$	$(0.500, 0.013, 0.005)$	$(0.950, 0.033, 0.012)$	$(0.691, 0.021, 0.008)$	$(0.691, 0.021, 0.008)$	$(0.309, 0.021, 0.008)$	$(0.950, 0.033, 0.012)$	$(0.500, 0.013, 0.005)$	$(0.309, 0.021, 0.008)$	$(0.950, 0.033, 0.012)$	$(0.950, 0.033, 0.012)$	$(0.500, 0.013, 0.005)$
A_6	E_2	$(0.691, 0.021, 0.008)$	$(0.500, 0.013, 0.005)$	$(0.309, 0.021, 0.008)$	$(0.309, 0.021, 0.008)$	$(0.500, 0.013, 0.005)$	$(0.309, 0.021, 0.008)$	$(0.950, 0.033, 0.012)$	$(0.050, 0.033, 0.012)$	$(0.309, 0.021, 0.008)$	$(0.050, 0.033, 0.012)$	$(0.309, 0.021, 0.008)$	$(0.500, 0.013, 0.005)$	$(0.309, 0.021, 0.008)$
	E_3	$(0.950, 0.033, 0.012)$	$(0.500, 0.013, 0.005)$	$(0.050, 0.033, 0.012)$	$(0.950, 0.033, 0.012)$	$(0.950, 0.033, 0.012)$	$(0.500, 0.013, 0.005)$	$(0.050, 0.033, 0.012)$	$(0.309, 0.021, 0.008)$	$(0.500, 0.013, 0.005)$	$(0.500, 0.013, 0.005)$	$(0.309, 0.021, 0.008)$	$(0.691, 0.021, 0.008)$	$(0.691, 0.021, 0.008)$
	E_1	$(0.309, 0.021, 0.008)$	$(0.050, 0.033, 0.012)$	$(0.309, 0.021, 0.008)$	$(0.309, 0.021, 0.008)$	$(0.500, 0.013, 0.005)$	$(0.500, 0.013, 0.005)$	$(0.050, 0.033, 0.012)$	$(0.309, 0.021, 0.008)$	$(0.950, 0.033, 0.012)$	$(0.050, 0.033, 0.012)$	$(0.950, 0.033, 0.012)$	$(0.691, 0.021, 0.008)$	$(0.500, 0.013, 0.005)$
A_7	E_2	$(0.500, 0.013, 0.005)$	$(0.309, 0.021, 0.008)$	$(0.500, 0.013, 0.005)$	$(0.950, 0.033, 0.012)$	$(0.500, 0.013, 0.005)$	$(0.500, 0.013, 0.005)$	$(0.309, 0.021, 0.008)$	$(0.500, 0.013, 0.005)$	$(0.691, 0.021, 0.008)$	$(0.691, 0.021, 0.008)$	$(0.309, 0.021, 0.008)$	$(0.309, 0.021, 0.008)$	$(0.950, 0.033, 0.012)$
	E_3	$(0.050, 0.033, 0.012)$	$(0.950, 0.033, 0.012)$	$(0.950, 0.033, 0.012)$	$(0.691, 0.021, 0.008)$	$(0.050, 0.033, 0.012)$	$(0.309, 0.021, 0.008)$	$(0.309, 0.021, 0.008)$	$(0.691, 0.021, 0.008)$	$(0.050, 0.033, 0.012)$	$(0.691, 0.021, 0.008)$	$(0.050, 0.033, 0.012)$	$(0.691, 0.021, 0.008)$	$(0.500, 0.013, 0.005)$

TABLE IV. AGGREGATED DECISION MATRIX

Criterion	A_1	A_2	A_3	A_4	A_5	A_6	A_7
C_{11}	$(0.6895, 0.0210, 0.0080)$	$(0.9480, 0.0330, 0.0120)$	$(0.0499, 0.0330, 0.0120)$	$(0.4989, 0.0130, 0.0050)$	$(0.6895, 0.0210, 0.0080)$	$(0.9480, 0.0330, 0.0120)$	$(0.0499, 0.0330, 0.0120)$
C_{12}	$(0.3083, 0.0210, 0.0080)$	$(0.4989, 0.0130, 0.0050)$	$(0.6895, 0.0210, 0.0080)$	$(0.4989, 0.0130, 0.0050)$	$(0.0499, 0.0330, 0.0120)$	$(0.4989, 0.0130, 0.0050)$	$(0.9480, 0.0330, 0.0120)$
C_{13}	$(0.6895, 0.0210, 0.0080)$	$(0.0499, 0.0330, 0.0120)$	$(0.3083, 0.0210, 0.0080)$	$(0.0499, 0.0330, 0.0120)$	$(0.6895, 0.0210, 0.0080)$	$(0.0499, 0.0330, 0.0120)$	$(0.9480, 0.0330, 0.0120)$
C_{21}	$(0.0499, 0.0330, 0.0120)$	$(0.0499, 0.0330, 0.0120)$	$(0.6895, 0.0210, 0.0080)$	$(0.3083, 0.0210, 0.0080)$	$(0.0499, 0.0330, 0.0120)$	$(0.9480, 0.0330, 0.0120)$	$(0.6895, 0.0210, 0.0080)$
C_{22}	$(0.6895, 0.0210, 0.0080)$	$(0.3083, 0.0210, 0.0080)$	$(0.6895, 0.0210, 0.0080)$	$(0.0499, 0.0330, 0.0120)$	$(0.3083, 0.0210, 0.0080)$	$(0.9480, 0.0330, 0.0120)$	$(0.0499, 0.0330, 0.0120)$
C_{23}	$(0.0499, 0.0330, 0.0120)$	$(0.9480, 0.0330, 0.0120)$	$(0.6895, 0.0210, 0.0080)$	$(0.0499, 0.0330, 0.0120)$	$(0.6895, 0.0210, 0.0080)$	$(0.4989, 0.0130, 0.0050)$	$(0.3083, 0.0210, 0.0080)$
C_{31}	$(0.3083, 0.0210, 0.0080)$	$(0.3083, 0.0210, 0.0080)$	$(0.4989, 0.0130, 0.0050)$	$(0.3083, 0.0210, 0.0080)$	$(0.6895, 0.0210, 0.0080)$	$(0.0499, 0.0330, 0.0120)$	$(0.3083, 0.0210, 0.0080)$
C_{32}	$(0.0499, 0.0330, 0.0120)$	$(0.9480, 0.0330, 0.0120)$	$(0.0499, 0.0330, 0.0120)$	$(0.4989, 0.0130, 0.0050)$	$(0.0499, 0.0330, 0.0120)$	$(0.3083, 0.0210, 0.0080)$	$(0.6895, 0.0210, 0.0080)$
C_{41}	$(0.0499, 0.0330, 0.0120)$	$(0.3083, 0.0210, 0.0080)$	$(0.3083, 0.0210, 0.0080)$	$(0.0499, 0.0330, 0.0120)$	$(0.9480, 0.0330, 0.0120)$	$(0.4989, 0.0130, 0.0050)$	$(0.0499, 0.0330, 0.0120)$
C_{42}	$(0.9480, 0.0330, 0.0120)$	$(0.9480, 0.0330, 0.0120)$	$(0.9480, 0.0330, 0.0120)$	$(0.9480, 0.0330, 0.0120)$	$(0.6895, 0.0210, 0.0080)$	$(0.4989, 0.0130, 0.0050)$	$(0.6895, 0.0210, 0.0080)$
C_{51}	$(0.6895, 0.0210, 0.0080)$	$(0.3083, 0.0210, 0.0080)$	$(0.0499, 0.0330, 0.0120)$	$(0.9480, 0.0330, 0.0120)$	$(0.4989, 0.0130, 0.0050)$	$(0.3083, 0.0210, 0.0080)$	$(0.0499, 0.0330, 0.0120)$
C_{52}	$(0.3083, 0.0210, 0.0080)$	$(0.0499, 0.0330, 0.0120)$	$(0.9480, 0.0330, 0.0120)$	$(0.4989, 0.0130, 0.0050)$	$(0.4989, 0.0130, 0.0050)$	$(0.6895, 0.0210, 0.0080)$	$(0.6895, 0.0210, 0.0080)$
C_{53}	$(0.9480, 0.0330, 0.0120)$	$(0.3083, 0.0210, 0.0080)$	$(0.4989, 0.0130, 0.0050)$	$(0.4989, 0.0130, 0.0050)$	$(0.4989, 0.0130, 0.0050)$	$(0.6895, 0.0210, 0.0080)$	$(0.4989, 0.0130, 0.0050)$

TABLE V. CRITERIA WEIGHTS

Criterion	Weight	Sub-criterion	Local weight	Global weight
C_1	0.1290	C_{11}	0.6370	0.0822
		C_{12}	0.1047	0.0135
		C_{13}	0.2583	0.0333
C_2	0.0634	C_{21}	0.2583	0.0164
		C_{22}	0.6370	0.0404
		C_{23}	0.1047	0.0066
C_3	0.0333	C_{31}	0.7500	0.0250
		C_{32}	0.2500	0.0083
C_4	0.5128	C_{41}	0.2500	0.1282
		C_{42}	0.7500	0.3326
C_5	0.2615	C_{51}	0.6000	0.1569
		C_{52}	0.2000	0.0523
		C_{52}	0.2000	0.0523

TABLE VI. BEST AND WORST SOLUTIONS

Criterion	Best solution	Worst solution
C_{11}	$(0.9480, 0.0330, 0.0120)$	$(0.0499, 0.0330, 0.0120)$
C_{12}	$(0.9480, 0.0330, 0.0120)$	$(0.0499, 0.0330, 0.0120)$
C_{13}	$(0.9480, 0.0330, 0.0120)$	$(0.0499, 0.0330, 0.0120)$
C_{21}	$(0.9480, 0.0330, 0.0120)$	$(0.0499, 0.0330, 0.0120)$
C_{22}	$(0.9480, 0.0330, 0.0120)$	$(0.0499, 0.0330, 0.0120)$
C_{23}	$(0.9480, 0.0330, 0.0120)$	$(0.0499, 0.0330, 0.0120)$
C_{31}	$(0.6895, 0.0210, 0.0080)$	$(0.0499, 0.0330, 0.0120)$
C_{32}	$(0.9480, 0.0330, 0.0120)$	$(0.0499, 0.0330, 0.0120)$
C_{41}	$(0.9480, 0.0330, 0.0120)$	$(0.0499, 0.0330, 0.0120)$
C_{42}	$(0.9480, 0.0330, 0.0120)$	$(0.4989, 0.0130, 0.0050)$
C_{51}	$(0.9480, 0.0330, 0.0120)$	$(0.0499, 0.0330, 0.0120)$
C_{52}	$(0.9480, 0.0330, 0.0120)$	$(0.0499, 0.0330, 0.0120)$
C_{53}	$(0.9480, 0.0330, 0.0120)$	$(0.3083, 0.0210, 0.0080)$

is inferior to A_7 in group utility. As the decision coefficient varies, the preference of the final results changes from "with veto" to "maximum group", leading to the preference of A_7. Nevertheless, it is worth noting that in all cases, both condition 1 and condition 2 are satisfied. In other words, the obtained results are optimal solutions. Therefore, from the results of the sensitivity analysis, it can be concluded that the decision coefficient could directly affect the results of the case; however,

TABLE VII. Group Utility and Individual Regret of the Equipment Systems

Alternative	Group utility	Individual regret
A_1	0.8551	0.3295
A_2	0.8792	0.3295
A_3	0.8882	0.3295
A_4	0.8689	0.3295
A_5	0.8607	0.3542
A_6	0.9044	0.3846
A_7	0.9317	0.3542

TABLE VIII. Evaluation Results of the Equipment Systems

Alternative	Aggregating index	Ranking
A_1	0	7
A_2	0.1573	5
A_3	0.2158	4
A_4	0.0902	6
A_5	0.2610	3
A_6	0.8217	1
A_7	0.7243	2

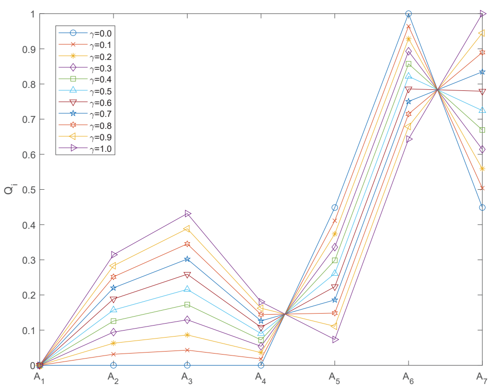

Fig. 4. Sensitivity analysis results.

it can be guaranteed that the obtained results are optimal, demonstrating the effectiveness and robustness of the proposed method.

B. Comparative Analysis

In order to further show the effectiveness and reliability of the proposed method, the ranking result of the proposed method is compared with those of other comparative methods, including VIKOR, TOPSIS, MULTIMOORA, cloud TOPSIS, and cloud MULTIMOORA, and the results are listed in Table IX.

TABLE IX. Comparative Analysis Results

Method	Ranking
TOPSIS	$A_6 \succ A_7 \succ A_4 \succ A_2 \succ A_3 \succ A_5 \succ A_1$
MULTIMOORA	$A_6 \succ A_7 \succ A_3 \succ A_2 \succ A_4 \succ A_5 \succ A_1$
VIKOR	$A_6 \succ A_3 \succ A_7 \succ A_5 \succ A_2 \succ A_4 \succ A_1$
Cloud TOPSIS	$A_6 \succ A_5 \succ A_3 \succ A_7 \succ A_4 \succ A_2 \succ A_1$
Cloud MULTIMOORA	$A_6 \succ A_7 \succ A_2 \succ A_5 \succ A_3 \succ A_4 \succ A_1$
Proposed method	$A_6 \succ A_7 \succ A_5 \succ A_3 \succ A_2 \succ A_4 \succ A_1$

From the results in Fig. 5, it is evident that alternative A_6 consistently emerges as the optimal choice across all

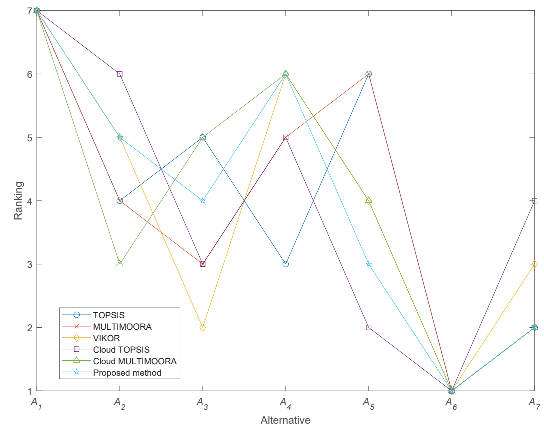

Fig. 5. Comparative analysis results.

evaluation methods. This consistent outcome underscores the effectiveness and reliability of the proposed method, as the optimal alternative identified aligns with the conclusions drawn by other methods. It is noteworthy, however, that the ranking results of the comparative methods do not always mirror those of the proposed method, particularly for certain lower-ranked alternatives. This discrepancy can be attributed to variations in criteria weights and evaluation representations employed by different methods. In summary, the reliability and rationality of the proposed method receive further validation through comparative analysis, with its results generally finding support from other evaluation methods. The specific ranking outcomes from the comparative analysis are visually presented in Fig. 5.

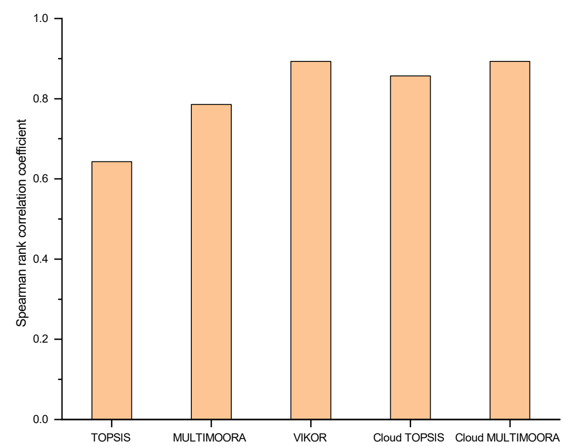

Fig. 6. Spearman's ranking correlation coefficient.

To further assess the consistency and reliability of the proposed method, a consistency test on the ranking results is conducted. Spearman's rank correlation coefficient is employed to gauge the consistency among the comparative methods, and the results are depicted in Fig. 6. The rank correlation coefficients between the proposed method and the comparative methods are calculated as $(0.6429, 0.7857, 0.8929, 0.8571, 0.8929)$. These correlation coefficients, being close to $+1$, signify a robust positive correlation among the methods. In simpler terms, the results of the proposed method are well-supported by the outcomes of the comparative methods. This high level of consistency further validates the effectiveness and reliability of the proposed method. Moreover, the advantages of the proposed method, as highlighted through comparative analysis, can be summarized as follows:

(1) In contrast to TOPSIS, MULTIMOORA, and VIKOR, the proposed method is developed based on the cloud model rather than crisp numbers. Given the inherent fuzziness and randomness in equipment evaluation problems, the cloud model provides a more reliable and effective means of modeling uncertain information, thereby enhancing the overall reliability of the proposed method.

(2) The proposed method incorporates an objective expert weight calculation method to determine the relative importance of different experts. Considering the varying experiences and knowledge of experts, the proposed method employs a similarity-based expert weight calculation method, enhancing the reliability and rationality of expert weight calculations. Comparative methods lack a comparable process to support expert weight calculation.

(3) The proposed method systematically considers a two-level hierarchical structure for equipment system evaluation, utilizing the AHP to determine criteria weights. By incorporating expert judgments on the relative importance of different criteria, the proposed method ensures that obtained results are both reasonable and reliable.

(4) The proposed method integrates group utility, individual regret, and aggregating index to derive the optimal solution that satisfies predefined conditions. The optimal solution consistently demonstrates superior performance and lower regret in most cases, enhancing the overall reliability and effectiveness of the results. The comparative analysis reinforces that the proposed method yields more reasonable and reliable outcomes.

C. Discussion

In this study, focusing on the equipment evaluation problem, a cloud-VIKOR-based MCDM method is proposed. A practical case of UCAV evaluation and selection is studied by using the proposed method, where A_6 is identified as the optimal UCAV considering thirteen criteria. The results are then validated through sensitivity analysis and comparative analysis. From the results, the following implications could be obtained:

(1) In equipment evaluation problem, the consideration of multiple criteria is necessary to ensure the balanced and comprehensive evaluation results. Moreover, due to the different characteristics of these criteria, it is impractical to assume them to have the same importance. To this end, this study considers thirteen different criteria from four aspects for equipment evaluation and utilizes the AHP to determine criteria weights, thus enabling more reliable results.

(2) For equipment evaluation, one of the most crucial characteristics is the inherent uncertainty and complexity within the problem. Cloud model, as an effective tool to convert qualitative judgments into quantitative data, could serve as a useful means to represent the uncertain information in equipment evaluation. Hence, the employment of cloud model in this study could enhance the reliability and rationality of the results.

(3) The evaluation of different equipment systems should be based on various indicators rather than simply the overall utility, and the consideration of group utility and individual regret at the same time could enhance the effectiveness of the results. Therefore, this study adopts the VIKOR method with cloud model for equipment evaluation considering different indicators, thus increasing the effectiveness of the proposed method.

VII. Conclusion

In this study, a decision-making approach for equipment evaluation based on cloud models is proposed. The method integrates the AHP and the VIKOR method within a unified framework employing cloud models. The cloud model is utilized to represent the evaluation of various equipment systems, accommodating the inherent fuzziness and randomness of information. A similarity-based method is employed to calculate expert weights, and the AHP is leveraged to determine criteria weights. Then, the VIKOR method is extended with cloud models to assess and rank diverse equipment systems. The results show that the proposed method provides a novel and effective way for equipment evaluation under uncertainty. In conclusion, this study contributes to the literature in the following ways:

(1) Introduction of a novel equipment evaluation method that considers the fuzziness and randomness of results. By utilizing cloud models to represent uncertain expert evaluations, the method provides reliable and reasonable assessments.

(2) Extension of the VIKOR method with cloud models, presenting the cloud VIKOR method. This extension broadens the application domain of the VIKOR method by incorporating cloud models to represent uncertain information, enhancing reliability compared to the conventional VIKOR method.

(3) Proposal of a comprehensive framework for equipment evaluation, considering both capability and characteristics of equipment systems. A two-level hierarchical evaluation structure is introduced to support the evaluation process, and the AHP is integrated with the cloud VIKOR method to produce more reliable and comprehensive results.

However, this study has some limitations. Firstly, a group of three experts is considered for evaluating different UCAV alternatives. While prior research suggests the efficiency of three experts for such problems, future investigations might explore the inclusion of more experts. Secondly, considering the substantial uncertainty and randomness in equipment evaluation, developing a more reliable cloud model construction framework is a potential avenue for future research.

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