SCIENTIFIC OASIS

Journal of Intelligent Decision Making and Granular Computing

Journal homepage: www. jidmag.org
ISSN: 3042-3759

Prioritizing Design Criteria for Unmanned Helicopter Systems under Uncertainty using Fuzzy Best Worst Method Approach

Hakan Ayhan Dağıstanlı[1,*]

[1] Department of Industrial Engineering, Turkish Military Academy, National Defense University, Ankara, Turkiye

ARTICLE INFO

Article history:
Received 28 April 2025
Received in revised form 21 May 2025
Accepted 28 May 2025
Available online 1 June 2025

Keywords:
Unmanned aerial vehicles; UAV; Unmanned Helicopter; Helicopter; Best-worst method; BWM; Fuzzy sets; Multi-criteria decision making; MCDM.

ABSTRACT

Unmanned helicopter systems, as a subcategory of rotary-wing unmanned aerial vehicles (UAVs), have gained increasing attention in both military and civilian domains due to their vertical take-off and landing (VTOL) capabilities, hovering stability, and operational flexibility in confined or complex environments. However, the limited number of operational platforms and prototypes highlights the need for systematic evaluation and development efforts. This study aims to identify and assess critical performance criteria for unmanned helicopters, drawing on an extensive review of existing models and technological trends. Based on the most commonly emphasized parameters in the global UAV landscape, five core evaluation criteria were selected: payload capacity, endurance, control range, maximum speed, and dimensional constraints. To systematically analyze these criteria, the Fuzzy Best-Worst Method (FBWM) was applied, enabling expert-driven prioritization under uncertainty and linguistic vagueness. The use of FBWM not only enhances the robustness of the decision-making process but also provides a structured foundation for comparative assessment of existing and prototype unmanned helicopter systems. The findings contribute to the literature by proposing a reproducible and adaptable evaluation framework, offering strategic insights for future design priorities and national development programs. This study represents one of the first applications of fuzzy multi-criteria decision-making approaches specifically tailored to unmanned helicopters, marking a significant step toward structured technology assessment in this emerging domain.

1. Introduction

Recent advances in aerospace technologies have led to a growing integration of unmanned systems alongside manned platforms in both military and civil aviation [1]. In this context, unmanned aerial vehicles (UAVs) are defined as aircraft capable of flying without an onboard pilot, either autonomously or via remote control, to perform specific missions [2]. Owing to their capability to operate in both combat and peacetime environments, UAVs have found applications across a wide range of sectors from defense and search-and-rescue operations to agricultural

* *Corresponding author.*
E-mail address: hakanayhand@gmail.com

https://doi.org/10.31181/jidmgc010120251

monitoring and logistics [3]. These systems not only reduce the risk to human pilots but also provide strategic advantages through their low operational costs and extended mission endurance [4].

UAVs are generally classified according to their operational altitude, flight endurance, and structural design. Prominent categories include micro, mini, tactical, Medium Altitude Long Endurance (MALE), and High Altitude Long Endurance (HALE) UAVs [5]. In terms of design, they are grouped into three main types: fixed-wing, rotary-wing, and hybrid systems. While fixed-wing UAVs are preferred for long-range and high-altitude missions, rotary-wing systems owing to their vertical take-off and landing (VTOL) capability are particularly suited for confined areas and precision tasks such as reconnaissance and surveillance [6-8]. UAVs are used across a broad spectrum of applications: military operations for reconnaissance, strike, and logistics support; and civil operations for mapping, fire monitoring, cargo transport, infrastructure inspection, and precision agriculture [9-11].

The rapid development of UAV technology has been driven by progress in sensor integration, artificial intelligence, autonomous control systems, and data transmission protocols. As a natural extension of these advancements, rotary-wing UAVs commonly referred to as unmanned helicopters have come to the forefront [12]. Although unmanned helicopters present more complex aerodynamic and control requirements compared to fixed-wing systems, they offer significant operational advantages due to their superior maneuverability, VTOL capability, and stable hovering performance [13]. These features make them particularly valuable for urban operations, maritime missions, and mountainous terrains. The growing prevalence of these systems has been enabled by the integration of traditional rotorcraft engineering principles with UAV system technologies.

UAVs are also classified by their wing configuration into fixed-wing and rotary-wing systems. Fixed-wing UAVs, operating on the principles of conventional aircraft, generate lift through forward motion and are optimal for long-range, high-speed missions. In contrast, rotary-wing systems (rotorcraft) produce lift through the motion of rotating blades, enabling VTOL operations. This eliminates the need for runways and allows for hovering [14]. Falling within this category, unmanned helicopters combine all the advantages of rotary-wing systems with the flexibility of UAV platforms, forming a hybrid operational class. While fixed-wing UAVs are ideal for wide-area surveillance, unmanned helicopters are better suited for low-speed, precision tasks, target tracking, transport missions, and operations in environments requiring vertical lift. Thus, the term “unmanned helicopter” refers specifically to rotary-wing UAVs that most effectively utilize VTOL capabilities.

Globally, numerous countries are making strategic investments in unmanned helicopter technologies. The United States has developed the MQ-8 Fire Scout, a VTOL-capable platform designed for advanced naval surveillance and attack missions [13,15]. Germany-based Schiebel has pioneered the field with the Camcopter S-100, used in both civilian and military applications. Sweden’s Saab has introduced the Skeldar V-200, a multi-role system for both land and maritime operations. Turkey has focused on indigenous production with the ALPİN platform, aimed at autonomous missions in border surveillance and reconnaissance, thereby reducing foreign dependency. China and Russia are also advancing both military and civilian unmanned helicopter platforms, strengthening their technological autonomy. These examples demonstrate that unmanned helicopters are becoming increasingly critical not only for tactical operations but also in securing strategic air superiority.

Driven by these technological advancements, national investments in unmanned helicopters extend beyond operational systems to include a diverse array of prototypes and concept-stage projects. For instance, the AACUS project developed by the U.S.-based Aurora Flight Sciences is notable for its autonomous cargo transport capabilities. Israel's Tactical Robotics has designed the AirMule prototype, a VTOL-capable system with a high payload capacity, specifically suited for urban warfare scenarios such as casualty evacuation. Additionally, the ALIAS program, developed through collaboration between Sikorsky and DARPA, has converted manned UH-60A Black Hawk helicopters into fully autonomous platforms, expanding the scope of unmanned operations. China has also developed a Mars helicopter prototype, similar to NASA's Ingenuity, demonstrating the feasibility of UAV technology for interplanetary missions. These developments underscore that unmanned helicopters are not only addressing current operational needs but also shaping the future vision of aerospace platforms.

Despite recent momentum in the development of unmanned helicopter technologies, the number of existing systems and prototypes remains relatively limited. This highlights the need for further research and development from technical, operational, and systematic perspectives. For widespread and effective deployment, several critical parameters including flight endurance, payload capacity, autonomy level, communication security, and algorithmic decision-making capabilities must be further optimized. For example, developing rotor systems capable of stable flight at high altitudes and under adverse weather conditions would enhance operational flexibility in both military and civilian missions. Secure communication systems offering low-latency, encrypted data transmission are essential to counter electronic warfare threats. Moreover, the advancement of environmental sensing, route planning, and autonomous decision-making algorithms remains a key area of research. Therefore, considering the limitations of existing models, systematic and interdisciplinary R&D efforts are crucial for transforming unmanned helicopters into reliable, durable, and mission-oriented platforms. This would enable their application not just in prototype form but also as scalable and sustainable systems for defense, logistics, disaster management, and reconnaissance.

In this context, determining the key criteria for advancing unmanned helicopter technologies is not merely an engineering task; it represents a multidimensional problem requiring systematic and analytical evaluation. Accordingly, the comprehensive assessment of relevant criteria such as flight endurance, payload, altitude capability, communication integrity, maintainability, and production cost is critical for both academic research and industrial applications. Such decision-making processes can be effectively addressed using multi-criteria decision-making (MCDM) methods, which are widely applied in engineering problems involving uncertainty and expert judgment [16]. Furthermore, when expert evaluations involve vagueness or imprecision, fuzzy set theory provides a valuable analytical tool [17]. Thus, applying MCDM techniques and fuzzy logic-based approaches in a systematic manner can significantly contribute to establishing strategic roadmaps for the development and prioritization of unmanned helicopter technologies.

The primary focus of this study is to evaluate the criteria considered in unmanned helicopter development through expert assessment. In doing so, both the key elements in current systems and the parameters requiring improvement in prototypes will be identified. Moreover, this study represents one of the first attempts in the literature to apply MCDM methods specifically to unmanned helicopters. The remainder of the paper is organized as follows: Section 2 provides a comprehensive review of the literature. Section 3 introduces the methodology used. Finally, Section 4 discusses the results and offers future recommendations.

2. Related Literature

In this study, the literature was prepared from two different perspectives. The first group belongs to studies on unmanned helicopters. The second group belongs to the method used in this study.

Academic interest in unmanned helicopter systems has grown substantially since the early 2000s, parallel to broader developments in UAV research. Initially, the focus was primarily on basic flight control and stabilization challenges, given the inherent aerodynamic complexity of rotary-wing platforms compared to fixed-wing UAVs [18]. These early studies often emphasized the mathematical modeling of rotor dynamics, control algorithms for hover stability, and remote piloting architectures. The transition from remote-controlled systems to semi-autonomous and fully autonomous helicopters marked a significant turning point in the literature [19].

With the maturation of sensor technologies and onboard computing capabilities in the 2010s, the research agenda shifted toward autonomous navigation, object avoidance, and mission planning under uncertain environments. Researchers began exploring SLAM (Simultaneous Localization and Mapping), LiDAR-based terrain following, and GPS-denied navigation techniques, which are particularly vital for unmanned helicopters due to their frequent use in cluttered or dynamic environments such as urban areas or forests [20,21]. In parallel, machine learning techniques were increasingly applied to improve flight efficiency, adaptive control, and real-time decision-making capabilities [22].

Recent studies have increasingly focused on multi-mission capability, payload integration, and platform scalability. For instance, a growing body of literature has examined the use of unmanned helicopters for logistics and cargo delivery in hard-to-reach areas, emphasizing payload optimization and energy-efficient path planning [23]. In military research, attention has been directed toward covert reconnaissance, electronic warfare, and autonomous strike capabilities. These studies often highlight cybersecurity concerns, redundancy in control systems, and communication resilience under adversarial conditions [24]. Moreover, the integration of swarm technologies and cooperative UAV-UGV missions has emerged as a novel direction in recent years, bringing forward the challenge of real-time coordination and distributed control [25].

Despite this progress, literature on rotary-wing UAVs particularly those in the unmanned helicopter class remains more limited compared to fixed-wing or quadrotor systems. This gap has been attributed to the higher mechanical and control complexity, higher cost of development, and limited commercial accessibility of helicopter platforms [26]. However, with the increasing demand for VTOL platforms capable of precise operations in constrained environments, unmanned helicopters have regained scholarly interest. There is a visible shift in recent studies toward addressing sustainability (battery and hybrid propulsion), modular system design, and interoperability with existing manned aviation systems.

In summary, the literature on unmanned helicopters has evolved from control theory and basic automation to system integration, autonomy, and intelligent mission execution. While the field still lags behind in terms of diversity and quantity compared to other UAV types, its strategic and operational advantages continue to make it a promising area of research within the aerospace and robotics communities.

The second part of the literature was made for the method of this study, the fuzzy best worst method. The Best Worst Method (BWM), introduced by Rezaei (2015), is a structured MCDM approach that enables the derivation of criterion weights through pairwise comparisons between the most and least important criteria [27]. Unlike traditional methods such as AHP, BWM minimizes inconsistency in expert judgments by reducing the number of required comparisons, thereby improving the reliability and robustness of the decision model. This method has been widely adopted in complex engineering design problems where expert-based assessments under uncertainty are essential.

In the context of unmanned helicopter development, BWM provides a systematic and effective framework for evaluating different and competing design and performance criteria. The method facilitates the identification of strategic priorities by quantifying the relative importance of each criterion based on expert preferences. Given the multifaceted and interdisciplinary nature of unmanned helicopter systems, BWM is particularly effective in reconciling differing expert opinions and aligning technological priorities with mission requirements. Moreover, the ability of BWM to handle limited but high-quality expert input makes it a valuable tool in early-stage design processes, especially where prototype data is scarce and the cost of design iterations is high. Thus, integrating the Best Worst Method into the decision-support framework for unmanned helicopter R&D enables developers to construct more targeted, scalable, and mission-specific solutions grounded in consistent expert evaluation.

While the traditional BWM provides a robust and consistent approach to MCDM, it assumes that experts can express their preferences in precise numerical values. However, in real-world decision environments especially in the early stages of unmanned helicopter development expert judgments are often characterized by vagueness, ambiguity, and linguistic uncertainty. To address this limitation, the Fuzzy Best Worst Method (Fuzzy BWM) was developed by integrating fuzzy set theory into the original BWM framework [28]. This extension allows experts to express their evaluations using linguistic variables (e.g., "very important," "moderately less important"), which are then converted into triangular or trapezoidal fuzzy numbers to capture the inherent imprecision in human assessments. At this point, it is seen that many studies have been conducted on Fuzzy BWM in the literature [29-35].

In the context of unmanned helicopter systems, Fuzzy BWM enables a more realistic and flexible modeling of expert knowledge when evaluating critical design and operational criteria under uncertainty. For example, when assessing parameters such as sensor integration quality, fault tolerance, or mission-specific adaptability areas where technical knowledge may vary or future performance is uncertain Fuzzy BWM captures expert hesitation and subjectivity more effectively than crisp values. Consequently, this method supports a more inclusive and accurate prioritization of development criteria, ultimately leading to better-informed decision-making in R&D planning, prototyping, and system optimization. As unmanned helicopters continue to evolve with increasing complexity, the adoption of fuzzy MCDM methods like Fuzzy BWM becomes essential for constructing resilient and strategically aligned technology roadmaps.

3. Methodology and Application

The steps of this method are as follows [36]:

Step 1: Defining a set of *n* criteria $C_j = \{C_1, C_2, \ldots, C_n\}$. The set of criteria is defined by the *k* experts participating in the research.

Step 2: Determination of best (C_B) and worst (C_W) criteria. Identification of the best and worst criteria from the set of criteria C_j is performed by experts.

Step 3: Formation of Best-to-Other (BO) and Other-to-Worst (OW) vectors. In BO and OW vectors, experts make comparisons in pairs of criteria. The information obtained in BO and OW vectors is used to define the optimal values of the criteria in the nonlinear BWM model (see *Step 4*).

Step 3.1. Formation of BO vector $A_B^e = (\overset{e}{a}_{B1}, \overset{e}{a}_{B2}, \ldots, \overset{e}{a}_{Bn})$. In the BO vector, information on the advantage of the best criterion (C_B) in relation to all other criteria from the set C_j is presented. The comparison of the best criterion in relation to criterion *j* is represented by the fuzzy number

$\overset{e}{a}_{Bj} = (a_{Bj}^{e(l)}, a_{Bj}^{e(m)}, a_{Bj}^{e(u)})$, where $a_{Bj}^{e(l)}$, $a_{Bj}^{e(m)}$ and $a_{Bj}^{e(u)}$ respectively represent the left limit, the mean value and the right limit of the interval of the triangular fuzzy number $\overset{e}{a}_{Bj}$.

Step 3.2. Formation of OW vector $A_W^e = (\overset{e}{a}_{1W}, \overset{e}{a}_{2W}, ..., \overset{e}{a}_{nW})$. In the OW vector, information on the advantage of the criteria *j* in relation to the worst criterion is presented. The comparison of criterion *j* in relation to the worst criterion C_W is represented by a fuzzy number $\overset{e}{a}_{jW} = (a_{jW}^{e(l)}, a_{jW}^{e(m)}, a_{jW}^{e(u)})$.

Values $\overset{e}{a}_{Bj}$ and $\overset{e}{a}_{jW}$ are defined based on a predefined fuzzy scale. Since *k* experts participate in the study, the BO and OW vector values obtained for each expert are aggregated using a fuzzy Bonferroni aggregator [37], expression (1). The Bonferroni mean (BM) operator [38] was used to aggregate the BO and OW vectors as it allows the representation of interrelationships between elements.

$$a_{Bj} = BM^{p,q}(a_{B1}, a_{B2}, ..., a_{Bn}) = \left(\frac{1}{k(k-1)} \sum_{\substack{i,j=1 \\ i \neq j}}^{k} a_i^p a_j^q \right)^{\frac{1}{p+q}}$$
$$a_{jW} = BM^{p,q}(a_{1W}, a_{2W}, ..., a_{nW}) = \left(\frac{1}{k(k-1)} \sum_{\substack{i,j=1 \\ i \neq j}}^{k} a_i^p a_j^q \right)^{\frac{1}{p+q}} \tag{1}$$

where *k* represents the number of experts participating in the research, while *p*,*q* ≥ 0 are set of non-negative numbers.

By applying expression (1) we obtain aggregated values of BO and OW vectors, expression (2).

$$A_B = (a_{B1}, a_{B2}, ..., a_{Bn})$$
$$A_W = (a_{1W}, a_{2W}, ..., a_{nW}) \tag{2}$$

Step 4: Calculation of optimal fuzzy weighting coefficients $w_j = \left(w_1, w_2, ..., w_n\right)^T$, $w_j = \left(w_j^l, w_j^m, w_j^u\right)$. Based on the values of BO and OW vectors, expression (2), a nonlinear model, expression (3), was formed to determine the fuzzy criteria weights.

$$\min \xi$$
$$s.t.$$
$$\begin{cases} \left| \dfrac{w_B^l}{w_j^u} - a_{Bj}^u \right| \le \xi; \ \left| \dfrac{w_B^m}{w_j^m} - a_{Bj}^m \right| \le \xi; \\ \left| \dfrac{w_B^u}{w_j^l} - a_{Bj}^l \right| \le \xi; \left| \dfrac{w_j^l}{w_W^u} - a_{jW}^u \right| \le \xi; \\ \left| \dfrac{w_j^m}{w_W^m} - a_{jW}^u \right| \le \xi; \ \left| \dfrac{w_j^u}{w_W^l} - a_{jW}^l \right| \le \xi; \\ \dfrac{w_j^l + 4 \cdot w_j^m + w_j^u}{6} = 1; \\ w_j^l \le w_j^m \le w_j^u, \quad \forall j = 1,2,...,n \\ w_j^l, w_j^m, w_j^u \ge 0, \quad \forall j = 1,2,...,n \end{cases} \tag{3}$$

Step 5. Level of consistency for F-BWM. Based on the input data, we can define the input-based consistency ratio, the expression (4).

$$CR^I = \max_j CR_j^I$$
$$where \tag{4}$$
$$CR_j^I = \begin{cases} \dfrac{\left| a_{Bj}^u \times a_{jW}^u - a_{BW}^u \right|}{a_{BW}^u \times a_{BW}^u - a_{BW}^u} & if \ a_{BW}^u > 1 \\ 0 & if \ a_{BW}^u = 1 \end{cases}$$

where CR^I represents the global input-based consistency ratio for all criteria, CR_j^I represents the local level of consistency associated with the criterion C_j . The CR^I takes a value from the interval $\left[0,1\right]$.

3.1. Definition of Criteria

Identifying and prioritizing the evaluation criteria for unmanned helicopter systems is a crucial step in guiding both design and operational decision-making processes. Given the multifaceted nature of these platforms, which integrate complex subsystems such as propulsion, navigation, communication, and control architectures, the selection of appropriate performance indicators directly affects the reliability and strategic alignment of development efforts. In this context, the present study focuses on a set of core criteria that are commonly emphasized across existing unmanned helicopter platforms developed worldwide. A comparative examination of well-known systems—such as the MQ-8 Fire Scout (USA), Camcopter S-100 (Austria), Skeldar V-200 (Sweden), ALPİN (Turkey), and others—reveals that attributes such as payload capacity, endurance, control range, maximum speed, and physical dimensions consistently emerge as primary performance benchmarks in both military and civilian applications.

Accordingly, these five criteria were selected for detailed evaluation in this study, as they not only represent the operational capabilities of unmanned helicopters but also reflect the constraints and priorities of contemporary aerospace system design. By applying the Fuzzy Best Worst Method (FBWM), as detailed in Section 3, expert judgments under uncertainty were systematically incorporated into the weighting of these criteria, allowing for a more nuanced and realistic prioritization. The use of FBWM contributes to the literature by providing a structured and fuzzy logic-based evaluation framework tailored specifically for rotary-wing unmanned aerial systems—a relatively underexplored area in existing MCDM research. This approach offers a replicable and adaptable model for future studies aiming to assess unmanned helicopter platforms, and also serves as a decision-support tool for stakeholders involved in procurement, development, and technological benchmarking.

C1. Payload Capacity

Payload capacity refers to the maximum weight of equipment, sensors, weapons, or other mission-specific devices that an unmanned helicopter can carry in addition to its structural and operational components. In military applications, this may include surveillance radars, communication jammers, or weapon systems, while in civilian use it may encompass imaging payloads or cargo. A higher payload capacity enables the platform to perform a wider range of complex tasks and increases its adaptability to mission requirements. In the context of unmanned helicopters, optimizing payload capacity is particularly challenging due to constraints in lift, balance, and energy efficiency.

C2. Endurance

Endurance denotes the total time an unmanned helicopter can remain airborne under standard operating conditions without refueling or recharging. This parameter directly correlates with mission coverage, operational flexibility, and logistics requirements. For reconnaissance, surveillance, or long-duration mapping missions, higher endurance provides critical tactical and strategic advantages. Rotorcraft systems, such as unmanned helicopters, typically have lower endurance than fixed-wing UAVs due to higher energy consumption in hover and VTOL operations; hence, enhancing endurance remains a key design challenge in this category.

C3. Control Range

Control range refers to the maximum distance over which the ground control station (GCS) can maintain stable communication and command with the unmanned helicopter. This includes line-of-sight (LOS) and beyond-line-of-sight (BLOS) capabilities depending on communication infrastructure such as radio frequency (RF) links or satellite communications (SATCOM). A larger control range expands the operational envelope of the platform, allowing for missions in remote or contested environments. For rotary-wing UAVs, ensuring reliable control over long distances is more complex due to the interplay between communication hardware, terrain effects, and flight dynamics.

C4. Maximum Speed

Maximum speed indicates the highest airspeed an unmanned helicopter can achieve under nominal flight conditions without compromising structural integrity or system stability. While not the primary performance goal in most rotary-wing missions, speed becomes crucial in time-sensitive operations such as rapid deployment, search and rescue, or threat interception. It also affects overall mission time, exposure to adversarial threats, and coverage capabilities. In design terms, achieving higher speeds in rotorcraft involves trade-offs with maneuverability, vibration management, and aerodynamic efficiency.

C5. Dimensions

Dimensions—typically referring to overall length, width, and height—determine the physical footprint of the unmanned helicopter and affect its portability, deployability, and compatibility with storage or transport infrastructure. In tactical applications, smaller and more compact platforms are often preferred for shipborne or urban operations. Conversely, larger dimensions may accommodate higher payloads and fuel capacity but demand more space and logistical support. Additionally, the rotor diameter and body configuration influence aerodynamic behavior and VTOL stability, making dimensional optimization a key concern in performance engineering.

The linguistic scale used in evaluating the criteria is given in Table 1.

Table 1
Linguistic Scale

Scale	Terms	Membership Function
EI	Equally Important	(1,1,1)
WI	Weakly Important	(2/3,1,3/2)
FI	Fairly Important	(3/2,2,5/2)
VI	Very Important	(5/2,3,7/2)
AI	Absolutely Important	(7/2,4,9/2)

Sample evaluation of the criteria using Table 1 is presented in Table 2.

Table 2
Evaluation of Criteria

Best:C3	Expert Evaluation	Wost:C5	Expert Evaluation
C1	EI,EI,EI,EI	C1	AI,AI,AI,VI
C2	WI,FI,WI,WI	C2	VI,VI,FI,FI
C3	VI,AI,AI,VI	C3	WI,WI,WI,WI
C4	VI,VI,FI,FI	C4	WI,WI,FI,FI
C5	EI,EI,WI,EI	C5	EI,EI,WI,EI

After completing the steps of Step 1 and 2, the steps given between Step 3-5 are applied for the criteria. The results obtained for the criteria are given in Figure 1.

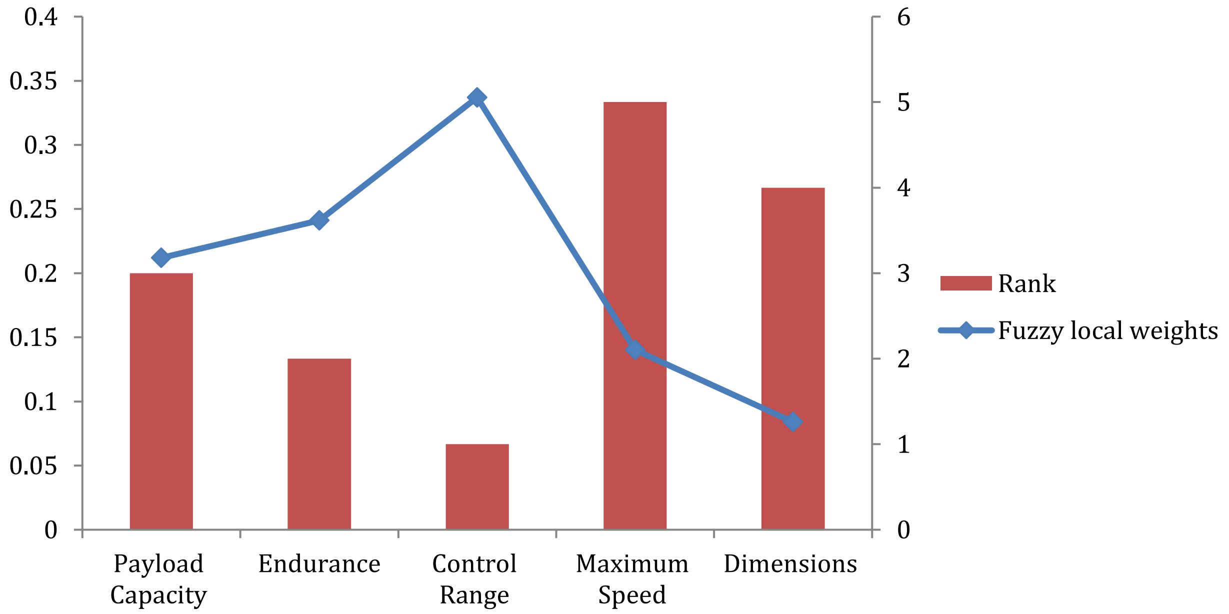

Fig. 1. Evaluation of Unmanned Helicopter Criteria

4. Conclusions

As a result, the weights obtained with the fuzzy logic approach and the related priority rankings of the five criteria used in the evaluation of unmanned helicopters are presented. According to the analysis results, the highest fuzzy weight belongs to the Control Range (C3) criterion; this shows that the safe and effective control of unmanned helicopters from long distances is the most critical factor for decision makers. Especially in applications such as military, search and rescue or border surveillance, the width of the helicopter's control range stands out as the basic component of operational success. The Endurance (C2) criterion, which is in the second place, expresses the helicopter's endurance in the air and highlights the system's durability for long-term missions. Payload Capacity (C1) is in the third place, and although the amount of payload that an unmanned helicopter can carry is an important operational capacity indicator, it falls behind range and durability. Maximum Speed (C4) is in the fourth place, and Dimensions (C5) is in the last place. This ranking reveals that decision makers prioritize performance-based technical factors such as mission range and continuity rather than physical features such as speed and compact design. As a result, in the multi-criteria evaluation of unmanned helicopters, it was determined that operational qualities such as range and endurance, which directly affect mission effectiveness, have a higher degree of importance compared to physical design features.

The criteria discussed in this study are considered because they play a decisive role in the multi-dimensional performance evaluation of unmanned helicopters and are highlighted by companies. Each of these criteria is of critical importance in terms of both system design and operational applications. While the payload capacity directly affects the platform's mission diversity and operational flexibility; the endurance in the air offers a strategic advantage for the execution of long-term missions. While the control range provides both safe command-control continuity and a wide operational area; maximum speed is important for the success of emergency response and time-critical missions. Dimensions are directly related to carrying, deployment and maneuvering capabilities and are a parameter that limits or expands the usability of the platform.

In this context, these criteria must be considered together in order to systematically evaluate unmanned helicopters. In parallel with developing technologies, it should be taken into account that the priority levels of these criteria may differ depending on the mission type and area of use; therefore, FMCDM methods should be applied within the framework of decision support systems. The approach proposed in this study allows for a holistic examination of unmanned helicopter performance and fills the methodological gap in the literature, providing a reference point for future studies. Because, although there is a very wide scope of UAV systems in the literature, no study has been found specifically for unmanned helicopters. In future studies, the pool of alternative unmanned helicopter criteria should be expanded and evaluated. For this purpose, hybrid and current FMCDM models to be created in the field should definitely be taken into consideration. In this way, prototype studies will be shed light on R&D activities.

Acknowledgement
This research was not funded by any grant.

Conflicts of Interest
The authors declare no conflicts of interest.

References

[1] Yılmaz, N., & Gencer, C. T. (2019). Sensör görüş yeteneklerinin İHA rota optimizasyonuna entegrasyonu: doğrusal bir model ve sezgisel bir algoritma önerisi. Gazi Üniversitesi Mühendislik Mimarlık Fakültesi Dergisi, 34(4), 1917–1928. https://doi.org/10.17341/gazimmfd.571630

[2] Altundaş, A., Arıkan, M., & Erol, S. Çok üslü heterojen filolu insansız hava araçlarının zaman pencereli görevlere rotalanması ve faydalı yük planlaması. Gazi Üniversitesi Mühendislik Mimarlık Fakültesi Dergisi, 40(3), 1611–1624. https://doi.org/10.17341/gazimmfd.1559891

[3] Rojas Viloria, D., Solano-Charris, E. L., Muñoz-Villamizar, A., & Montoya-Torres, J. R. (2021). Unmanned aerial vehicles/drones in vehicle routing problems: A literature review. International Transactions in Operational Research, 28(4), 1626–1657. https://doi.org/10.1111/itor.12783

[4] Ercan, C., & Gencer, C. (2018). A decision support system for dynamic heterogeneous unmanned aerial system fleets. Gazi University Journal of Science, 31(3), 863–877.

[5] Goraj, Z., Frydrychewicz, A., Świtkiewicz, R., Hernik, B., Gadomski, J., Goetzendorf-Grabowski, T., ... & Chajec, W. (2004). High altitude long endurance unmanned aerial vehicle of a new generation—a design challenge for a low cost, reliable and high performance aircraft. Bulletin of the Polish Academy of Sciences Technical Sciences, 173–194.

[6] Panagiotou, P., & Yakinthos, K. (2020). Aerodynamic efficiency and performance enhancement of fixed-wing UAVs. Aerospace Science and Technology, 99, 105575. https://doi.org/10.1016/j.ast.2019.105575

[7] Zeng, Y., Xu, J., & Zhang, R. (2019). Energy minimization for wireless communication with rotary-wing UAV. IEEE Transactions on Wireless Communications, 18(4), 2329–2345. https://doi.org/10.1109/TWC.2019.2902559

[8] Misra, A., Jayachandran, S., Kenche, S., Katoch, A., Suresh, A., Gundabattini, E., ... & Legesse, A. A. (2022). A review on vertical take-off and landing (VTOL) tilt-rotor and tilt wing unmanned aerial vehicles (UAVs). Journal of Engineering, 2022(1), 1803638. https://doi.org/10.1155/2022/1803638

[9] Mohsan, S. A. H., Khan, M. A., Noor, F., Ullah, I., & Alsharif, M. H. (2022). Towards the unmanned aerial vehicles (UAVs): A comprehensive review. Drones, 6(6), 147. https://doi.org/10.3390/drones6060147
[10] Torresan, C., Berton, A., Carotenuto, F., Di Gennaro, S. F., Gioli, B., Matese, A., ... & Wallace, L. (2017). Forestry applications of UAVs in Europe: A review. International Journal of Remote Sensing, 38(8–10), 2427–2447. https://doi.org/10.1080/01431161.2016.1252477
[11] Elmeseiry, N., Alshaer, N., & Ismail, T. (2021). A detailed survey and future directions of unmanned aerial vehicles (UAVs) with potential applications. Aerospace, 8(12), 363. https://doi.org/10.3390/aerospace8120363
[12] Alvarenga, J., Vitzilaios, N. I., Valavanis, K. P., & Rutherford, M. J. (2015). Survey of unmanned helicopter model-based navigation and control techniques. Journal of Intelligent & Robotic Systems, 80, 87–138. https://doi.org/10.1007/s10846-014-0143-5
[13] Petrescu, R. V., Aversa, R., Akash, B., Berto, F., Apicella, A., & Petrescu, F. I. (2017). Unmanned helicopters. Journal of Aircraft and Spacecraft Technology, 1(4), 241–248. https://doi.org/10.3844/jastsp.2017.241.248
[14] Haider, B. A., Sohn, C. H., Won, Y. S., & Koo, Y. M. (2017). Aerodynamically efficient rotor design for hovering agricultural unmanned helicopter. Journal of Applied Fluid Mechanics, 10(5), 1461–1474. https://doi.org/10.18869/acadpub.jafm.73.242.27541
[15] Dalamagkidis, K., Valavanis, K. P., Piegl, L. A., Dalamagkidis, K., Valavanis, K. P., & Piegl, L. A. (2012). Aviation history and unmanned flight. On Integrating Unmanned Aircraft Systems into the National Airspace System: Issues, Challenges, Operational Restrictions, Certification, and Recommendations, 11–42. https://doi.org/10.1007/978-94-007-2479-2_2
[16] Kumar, R. (2025). A comprehensive review of MCDM methods, applications, and emerging trends. Decision Making Advances, 3(1), 185–199. https://doi.org/10.31181/dma31202569
[17] Kahraman, C., Onar, S. C., & Oztaysi, B. (2015). Fuzzy multicriteria decision-making: A literature review. International Journal of Computational Intelligence Systems, 8(4), 637–666. https://doi.org/10.1080/18756891.2015.1046325
[18] Pines, D. J., & Bohorquez, F. (2006). Challenges facing future micro-air-vehicle development. Journal of Aircraft, 43(2), 290–305. https://doi.org/10.2514/1.4922
[19] Johnson, E., & Kannan, S. (2002, August). Adaptive flight control for an autonomous unmanned helicopter. In AIAA Guidance, Navigation, and Control Conference and Exhibit (p. 4439). https://doi.org/10.2514/6.2002-4439
[20] Caballero, F., Merino, L., Ferruz, J., & Ollero, A. (2009). Vision-based odometry and SLAM for medium and high altitude flying UAVs. Journal of Intelligent and Robotic Systems, 54, 137–161. https://doi.org/10.1007/s10846-008-9257-y
[21] Shen, S., Michael, N., & Kumar, V. (2011, May). Autonomous multi-floor indoor navigation with a computationally constrained MAV. In 2011 IEEE International Conference on Robotics and Automation (pp. 20–25). IEEE. https://doi.org/10.1109/ICRA.2011.5980357
[22] Bouabdallah, S., & Siegwart, R. (2007, October). Full control of a quadrotor. *In 2007 IEEE/RSJ International Conference on Intelligent Robots and Systems* (pp. 153–158). IEEE. https://doi.org/10.1109/IROS.2007.4399042
[23] Jin, Z., Nie, L., Li, D., Tu, Z., & Xiang, J. (2022). An autonomous control framework of unmanned helicopter operations for low-altitude flight in mountainous terrains. Drones, 6(6), 150. https://doi.org/10.3390/drones6060150
[24] Anagnostis, I., Kotzanikolaou, P., & Douligeris, C. (2025). Understanding and securing the risks of unmanned aerial vehicle services. IEEE Access. https://doi.org/10.1109/ACCESS.2025.3549861
[25] Laghari, A. A., Jumani, A. K., Laghari, R. A., & Nawaz, H. (2023). Unmanned aerial vehicles: A review. Cognitive Robotics, 3, 8–22. https://doi.org/10.1016/j.cogr.2022.12.004
[26] Hoffmann, G., Huang, H., Waslander, S., & Tomlin, C. (2007, August). Quadrotor helicopter flight dynamics and control: Theory and experiment. In AIAA Guidance, Navigation and Control Conference and Exhibit (p. 6461). https://doi.org/10.2514/6.2007-6461
[27] Rezaei, J. (2015). Best-worst multi-criteria decision-making method. Omega, 53, 49–57. https://doi.org/10.1016/j.omega.2014.11.009
[28] Guo, S., & Zhao, H. (2017). Fuzzy best-worst multi-criteria decision-making method and its applications. *Knowledge-Based Systems, 121*, 23–31. https://doi.org/10.1016/j.knosys.2017.01.010
[29] Pamučar, D., Ecer, F., Cirovic, G., & Arlasheedi, M. A. (2020). Application of improved best worst method (BWM) in real-world problems. Mathematics, 8(8), 1342. https://doi.org/10.3390/math8081342
[30] Shang, Z., Yang, X., Barnes, D., & Wu, C. (2022). Supplier selection in sustainable supply chains: Using the integrated BWM, fuzzy Shannon entropy, and fuzzy MULTIMOORA methods. Expert Systems with Applications, 195, 116567. https://doi.org/10.1016/j.eswa.2022.116567

[31] Salari, S., Karimi, A., Farvaresh, E., & Hokmabadi, R. (2025). An integrated approach to a predictive and ranking model of use error using fuzzy BWM and fuzzy TOPSIS. International Journal of Occupational Safety and Ergonomics, 31(1), 195–204. https://doi.org/10.1080/10803548.2024.2419283

[32] Ecer, F., & Pamucar, D. (2020). Sustainable supplier selection: A novel integrated fuzzy best worst method (F-BWM) and fuzzy CoCoSo with Bonferroni (CoCoSo'B) multi-criteria model. Journal of Cleaner Production, 266, 121981. https://doi.org/10.1016/j.jclepro.2020.121981

[33] Otay, I., Onar, S. Ç., Öztayşi, B., & Kahraman, C. (2024). Evaluation of sustainable energy systems in smart cities using a Multi-Expert Pythagorean fuzzy BWM & TOPSIS methodology. Expert Systems with Applications, 250, 123874. https://doi.org/10.1016/j.eswa.2024.123874

[34] Banihashemi, S. A., Khalilzadeh, M., Antucheviciene, J., & Edalatpanah, S. A. (2023). Identifying and prioritizing the challenges and obstacles of the green supply chain management in the construction industry using the fuzzy BWM method. Buildings, 13(1), 38. https://doi.org/10.3390/buildings13010038

[35] Hafezalkotob, A., & Hafezalkotob, A. (2017). A novel approach for combination of individual and group decisions based on fuzzy best-worst method. Applied Soft Computing, 59, 316–325. https://doi.org/10.1016/j.asoc.2017.05.036

[36] Pamucar, D., Iordache, M., Deveci, M., Schitea, D., & Iordache, I. (2021). A new hybrid fuzzy multi-criteria decision methodology model for prioritizing the alternatives of the hydrogen bus development: A case study from Romania. International Journal of Hydrogen Energy, 46(57), 29616–29637. https://doi.org/10.1016/j.ijhydene.2020.10.172

[37] Pamucar, D., Deveci, M., Canıtez, F., & Bozanic, D. (2020). A fuzzy Full Consistency Method-Dombi-Bonferroni model for prioritizing transportation demand management measures. Applied Soft Computing, 87, 105952. https://doi.org/10.1016/j.asoc.2019.105952

[38] Bonferroni, C. (1950). Sulle medie multiple di potenze. Bollettino dell'Unione Matematica Italiana, 5(3–4), 267–270.