TÜRKİYE CUMHURİYETİ
ADANA ALPARSLAN TÜRKEŞ SCIENCE AND TECHNOLOGY UNIVERSITY

GRADUATE SCHOOL
INDUSTRIAL ENGINEERING DEPARTMENT

UAV SELECTION BY USING AN ITARA-BASED HYBRID MULTI-CRITERIA DECISION MAKING MODEL

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M.Sc.

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ÖZET

ITARA TABANLI HİBRİT ÇOK KRİTERLİ KARAR VERME YÖNTEMİ KULLANILARAK İHA SEÇİMİ

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Ekim 2023, 57 sayfa

Bu çalışma, askeri alanda kullanılan İnsansız Hava Aracı (İHA) Sistemlerinin teknik özelliklerini hibrit çok kriterli karar verme yöntemi (ÇKKV) ile karşılaştırarak en uygun kararın verilmesini amaçlamaktadır. Bilindiği üzere modern ordularda yeni bir sistemin benimsenmesi ve sürdürülmesi çok yüksek maliyetlere neden olmaktadır. Bu nedenle karar vericilerin bu kararları vermeden önce bilimsel yaklaşımlara başvurması kaçınılmaz hale gelmiştir. Önceki çalışmalarda bu kapsamda birçok klasik ÇKKV yöntemi kullanılmış olsa da kriterlerin ağırlıklandırılması ve karar verme süreçlerinde minimum hata oranını elde etmek için hibrit modellerin yaygınlaştığı görülmektedir.
Bu amaçla askeri kullanıma uygun dört adet İHA'nın teknik verileri açık kaynaklardan toplanmıştır. Beş uzman görüşü ve teknik verilerle onbir kriterden oluşan karar matrisi oluşturulmuştur. ITARA ve ROC yöntemleri Bayes yaklaşımı ile birleştirilerek kriterlerin ağırlıklandırılması sırasında en iyi sonuca ulaşılması amaçlanmıştır. Birleştirilen kriterler VIKOR ve COPRAS yöntemi ile analiz edilmiş ve karar vericiye yardımcı olacak anlamlı sonuçlar elde edilmiştir.

Anahtar Kelimeler: Hibrit Çok Kriterli Karar Verme, İnsansız Hava Araçları, ITARA

ABSTRACT

UAV SELECTION BY USING AN ITARA-BASED HYBRID MULTI-CRITERIA DECISION MAKING MODEL

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This study aims to make the most appropriate decision by comparing the technical features of Unmanned Aerial Vehicle (UAV) Systems used in the military with hybrid multi-criteria decision making (MCDM) method. As is known, the adoption and maintenance of a new system in modern armies causes very high costs. For this reason, it has become inevitable for decision makers to resort to scientific approaches before making these decisions. Although many classical MCDM methods have been used in previous studies in this context, it is seen that hybrid models have become widespread to weight the criteria and to obtain the minimum error rate in the decision-making processes.

For this purpose, the technical data of four UAVs suitable for military use were collected from open sources. A decision matrix consisting of eleven criteria was created with five expert opinions and technical data. ITARA and ROC methods are combined with the Bayesian approach to reach the best result when weighting the criteria. The single weighted criteria were analyzed with the VIKOR and COPRAS method and meaningful results were obtained to help the decision maker.

Keywords: Unmanned Aerial Vehicles, Hybrid Multi-Criteria Decision Making, ITARA

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LIST OF ABBREVIATIONS

AHP	: Analytical Hierarchy Process
COPRAS	: Complex Proportional Assessment
ÇKKV	: Çok Kriterli Karar Verme
ELECTRE	: Elimination and Choice Translating Reality English
ITARA	: Indifference Threshold-Based Attribute Ratio Analysis
İHA	: İnsansız Hava Aracı
MADM	: Multi-attribute decision making
MCDM	: Multi-criteria decision making
MOORA	: Multi-Objective Optimization by Ratio Analysis
PROMETHEE	: Preference Ranking Organization Method for Enrichment Evaluation
ROC	: Rank Order Centroid
TOPSIS	: Technique for Order of Preference by Similarity to Ideal Solution
UAV	: Unmanned Aerial Vehicles
USA	: United State of America
VIKOR	: VlseKriterijuska Optimizacija I Komoromisno Resenje

LIST OF SYMBOLS

$\mathbf{a_{ij}}$: Value of row i and column j of matrix A

$\mathbf{b_{ij}}$: Normalized value of row i and column j of B vector

$\mathbf{C_i^*}$: Relative closeness of the i^{th} alternative

$\mathbf{d_j}$: Differences of i^{th} alternative with respect to the other alternatives

D : Decision matrix

IT_j : Indifference Threshold

n : Number of elements

NIT_j : Normalized Indifference Threshold

$\mathbf{P_j}$: Preference value for j^{th} criterion

$\mathbf{Q_i}$: Relative importance of i^{th} alternative

$\mathbf{r_{ij}}$: Normalized value of row i and column j

R : Normalized decision matrix

$\mathbf{S_i^-}$: Negative ideal separation measure for i^{th} alternative

$\mathbf{S_i^+}$: Positive ideal separation measure for i^{th} alternative

$\mathbf{S_{+i}}$, $\boldsymbol{S_{-i}}$: Total weighted normalized values

$\mathbf{SN_i}$: Weighted sum of the negative distance from the average solution for i^{th} alternative

$\mathbf{SP_i}$: Weighted sum of the positive distance from the average solution for i^{th} alternative

$\mathbf{v_{ij}}$: Weighted value of row i and column j

V : Weighted normalized decision matrix

$\mathbf{w_j}$: Weight of the j^{th} criteria

β_{ij} : The normalized a_{ij} scores are sorted in ascending order

γ_{ij} : Finding the distances between neighboring β_{ij}s

δ_{ij} : Finding the distance between the ordinal scores of γ_{ij} and NIT_j

$\mathbf{x_{ij}}$: The performance value of i^{th} alternative with respect to j^{th} criterion

1. INTRODUCTION

Air power is typically defined as the employment of aircraft in the airspace to project military force by leveraging their own capabilities and carrying capacity. What sets air power apart from land and sea power is its ability to harness the unique advantages afforded by the third dimension above the ground surface. These advantages include speed, extended range, flexibility, evasion, and the element of surprise. Indeed, the third dimension is utilized not only by bullets and ballistic vehicles discharged by ground and naval forces, but it is also employed by elements of air power. Unlike their terrestrial and maritime counterparts, aerial components possess the unique advantage of maneuverability during their flight. They possess the capability to alter their direction, altitude, and align themselves with the evolving circumstances and requirements of the operation.

As Guttman (2015) highlights, the utilization of the sky for military purposes dates back to the inception of the concept of flight. However, the technological breakthrough that facilitated its practical implementation was the achievement of the first sustained manned flight in a hot air balloon in 1783. This innovative invention, known as a hot air balloon during that era, was employed primarily for battlefield surveillance. The technological leap that marked a real turning point in the development of military aviation and led to the emergence of the concept of 'air power' came when the Wright brothers made the first sustainable manned flight with a "heavier-than-air" aircraft in 1905. The period from 1905 to the outbreak of the First World War in 1914 witnessed the competition of the dominant powers of the era to develop more reliable and higher performance aircraft than the Wright brothers' primitive aircraft and use them for military purposes. In fact, during the Tripoli (Turkish-Italian) War of 1911-1912, aircraft were initially employed for reconnaissance purposes. As the war progressed, they were used to launch assaults on ground targets, albeit under considerably primitive conditions.

The historical development of the air force since its inception over one hundred years ago shows that land and naval forces are still needed to translate the opportunities and advantages offered by the air force into tangible successes. This notion refutes doctrines since the Cold War that claim that air power has now become the military force that alone can determine the outcome of wars. However, it shows how important joint operation is and that all armed forces should improve their training in this direction for the success of the operation.

Evolutionary leaps in military technological advances, high-efficiency weaponry has led to new openings to produce systems. To address the issue in terms of the effects of the prevalence of (UAVs) on the transformation of air power, it is predicted that UAVs, which can be developed and procured faster and cheaper than manned aircraft and can be easily sacrificed by the political authority in case of a crash, will find new areas of use in the coming years and will continue to become widespread. The aforementioned developments have increased the interest of countries in UAV systems and led to significant investments in high-budget research and development. Consequently, it has become increasingly crucial to determine the most appropriate system to be chosen.

According to Dağdeviren (2009), the weapon selection problem is a strategic issue and constitutes an important force multiplier on the success of defense systems. On the other hand, choosing the most suitable system among many complex options is a MCDM problem. The weapon selection problem is a strategic one and has enormous benefits on the success of a defense system. In a weapon or weapon system selection problem, alternative weapons and their criteria must be considered and analyzed, resulting in a large set of subjective, complex, or ambiguous data. Therefore, an effective numerical analysis approach should be applied to increase the accuracy of the decision maker's decisions.

To prevent bias in the decision-making process and to minimize the errors that may occur, more than one decision maker is generally preferred instead of a single decision maker (Bilsel, Büyüközkan, and Ruan, 2006). Since the decisions taken in the Defense Industry of the countries affect the whole society, it would be right to consult expert opinions at all stages of the decision processes. The success and accuracy of the decision taken can be significantly increased by involving expert participants in the process. Therefore, it is particularly important to develop many scientific decision-making systems for national defense issues. This approach combines the ideas of experts in different fields in a scientific method.

The goal of this thesis is to achieve highly effective results by utilizing the proposed hybrid multi-criteria method. It is anticipated that this method will prove to be significantly effective and beneficial for decision-makers. Today, with the development of technology, the technical differences between the options have increased and become more complex, making the decision maker's job exceedingly difficult. Thanks to this hybrid model used, the objective numerical values of the criteria (speed, altitude, and cost, etc.) and the subjective performance scores (invisibility and climbing rate) are handled with a hybrid logic to achieve healthier results.

In this thesis, different novel hybrid models are developed by using ITARA (Indifference Threshold-Based Attribute Ratio Analysis), VIKOR (VlseKriterijuska Optimizacija I Komoromisno Resenje), ROC (Rank Order Centroid) and COPRAS (Complex Proportional Assessment) methods. ITARA and ROC are used to find the criteria weights for the problem, and the final rankings are obtained by using VIKOR and COPRAS. Today, the complexity of determining the criteria and criterion weights causes the inadequacy of single MCDM methods and misleads the decision maker.

The main justification for the inclusion of the ROC and ITARA methods in the criterion weighting process is their ability to support both the subjective definition of the criterion weights and provide insight into the decision maker's subjectivity. For instance, the model's reliability would be low if the ITARA approach was the only one applied because, in contrast to other criteria, the invisibility, rate of climb, and cost criteria all involve subjective evaluation. By using the ROC method, the weighting of the subjective criteria is made more accurate with the help of the order of importance determined by the experts. Then, the Bayesian approach is used to combine the calculated ROC and ITARA weights to obtain a single weight. Thus, by combining these two methods, the weights of the criteria are determined more accurately and reliably.

2. LITERATURE REVIEW

2.1.1. Research in The Field of Unmanned Aerial Vehicles

The initial military utilization of UAVs took place in the USA in 1793, primarily for exploration purposes. In the American Civil War between 1861-1865, UAVs performed reconnaissance missions. The inaugural instance of UAVs being employed for attack occurred in 1849 when balloons, carrying time bombs, were dispatched to the city of Venice by the Austro-Hungarian Empire (Yardımcı, 2019).

In today's sense, the first UAV was used in the USA on March 6, 1918. On March 6, 1918, the inaugural UAV, known as the Curtis N-9 Aerial Torpedo, successfully took off. It flew 1000 yards (approximately 914 meters) and landed at the specified place and time (Erdağ, 2020). In later periods, the development of UAVs was carried out for military purposes. UAVs were actively used in Vietnam (1964-1972), Israel-Lebanon Conflicts (1982) and the First and Second Gulf Wars (Demir K A, Cicibaş H & Arıca N (2015). The first UAV squadron was established by Israel in 1971 as the 200th Air Squadron.

Today, UAVs are used in many areas, both military and civilian. According to the estimates of Teal Group to the Association for Unmanned Vehicle Systems International (AUVSI), one of the UAV industry expert organizations, the size of the universal UAV market is around 6 to 12 billion dollars and is growing 5-10 percent annually.

In the master's thesis study conducted by Özge (2008), UAV selection was carried out by using the MCDM method. In this context, Analytic Hierarchy Process (AHP) was used as one of the MCDM methods. In the model, six main criteria and 25 sub-criteria were determined, and the weight of each criterion was found by making pairwise comparisons. As a result of the evaluation, the best result was selected among five alternatives according to the model.

Ekmekçioğlu and Yıldız (2018) aimed to provide information about the developments that have occurred because of the use of UAVs in the military and civil fields. The study provides information on UAV history, UAV classification, and the utilization of UAVs for military and civilian purposes, among other relevant topics. Based on the information acquired, they concluded that governments' decisions to use UAVs have become a necessity rather than a choice.

Hamurcu and Eren (2020) aimed to enable countries to make the most appropriate choice among UAV alternatives in the field of defense with MCDM techniques. Therefore, the values of weight for the determined seven criteria were calculated by the AHP method. Considering the criteria determined in the last step, six alternatives were listed with the TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) method. In line with the findings obtained as a result of the study, it was determined that the UAV-1 was the right decision for procurement.

Akay, Kuriş and Senan (2021) reviewed and analyzed the compile publications containing autopilot systems in the literature. For this purpose, more than fifty studies published between 2001-2020 were examined and analyzed.

Tansü and Katrancı (2020) aimed to examine the reconnaissance/surveillance activities of UAVs and Armed UAVs, their advantages and disadvantages, and their effects on combat/defense. In addition, evaluations regarding its use in the Turkish Armed Forces were also shared. In line with the information obtained and shared, they concluded that UAVs have gained a particularly important place in the field of intelligence and communications.

According to Gettinger (2020), UAVs were originally designed to serve military purposes, but they have also been used in civilian areas, especially in recent years. UAVs for military purposes are used for reconnaissance, surveillance, tracking, border and coastal security and attack. Armed Unmanned Combat Aerial Vehicles (SİHA-UCAV) are UAVs that can carry ammunition to attack determined targets, are managed from a certain command center, or can autonomously destroy predetermined targets. He stated that the number of armed forces using UAVs in the armed forces of all countries has increased rapidly and the number of countries with UAVs has increased from 60 in 2010 to 95 as of 2019.

In the master's thesis study conducted by Ulucan (2016), UAV was selected for use in military and civil missions. While determining the alternatives, the existing systems were simulated, and 4 UAV alternatives were created intuitively. While determining the criteria, Delphi method was used by using expert opinions. As a result, ten criteria affecting the selection were determined. The objective was to improve resolution by considering uncertainty in the surrounding conditions. To achieve this, Gray Relational Analysis, a method in MCDM, was used.

2.1.2. Research in The Field of MCDM Methods

MCDM is a well-known and important branch of decision analysis (Triantaphyllou et al., 1998). This field is also under the title of Operations Research of decision problems in which there are more than one decision criteria. It is a modeled structure. With the MCDM approach, problems in which the decision space is continuous, such as mathematical programming, and the problems in the discrete decision space where the decision alternatives are defined in a finite number are provided.

Decision makers at all levels within organizational structures apply multiple criteria to analyze their complex problems (Saaty, 1994). Multi-criteria thinking style makes these people's work quite easy at the point of decision making. These processes clarify the advantages and disadvantages of decision options under risk and uncertainty. It is also vital in shaping the corporate strategies needed for effective competition.

Cheng (1997) evaluated three missile systems used by the country's navy by using the fuzzy AHP method with 5 criteria. As a result of the study, the best alternative missile system was presented to decision makers.

Opricovic and Tzeng (2007) compared VIKOR, TOPSIS, PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation) and ELECTRE (Elimination and Choice Translating Reality English) methods in their study. They have made an application for the selection of dam sites for reservoirs that will provide hydroelectricity on the Driena River in Yugoslavia. Eight criteria and six alternatives were determined as profit, cost, total energy produced, maximum energy produced, number of houses to be moved, area flooded by reservoirs, number of villages moved and environmental protection.

There is more than one alternative method in the literature, which method will be applied may vary depending on the situation and structure of the factors in the decision-making process, purposes, judgments, constraints, criteria, alternatives, and decision makers. They have an indirect or direct effect on the selection and implementation of the method. When the studies in the field of MCDM are examined, it is seen that the most popular methods are VIKOR, COPRAS, TOPSIS, CODAS, AHP and ELECTRE. MCDM methods are approaches that help determine the most appropriate option by considering many independent and different criteria (Usta, 2009).

Ertuğrul and Karakaşoğlu (2008) focused on discussing the applicability of the VIKOR method to evaluate the performance of commercial banks, which have an important place in our daily lives. In the study, the performances of a bank's branches were evaluated with the VIKOR method.

Chang and Hsu (2009) conducted a VIKOR application regarding the determination of land use restriction strategies in reservoir basins. The criteria were determined as the amount of precipitation, the slope, the number of curves, the distance between a sub-center and its outlet, and environmental impact in terms of pollution.

Sanayei et al. (2010) used the VIKOR method for supplier selection problems in an uncertain market environment. Criteria such as product quality, on-time delivery, price, technological level of the supplier and flexibility were identified, and linguistic values were used to evaluate the ranking and weights for these factors. These linguistic ratings can be expressed in trapezoidal or triangular fuzzy numbers. Then, a hierarchy MCDM model based on fuzzy sets theory and VIKOR method is proposed to deal with supplier selection problems in the supply chain system.

In Kaya et al. (2011), the quality of life of the European Union (EU) and candidate countries is analyzed with the VIKOR method. The VIKOR method was used to analyze the quality of life indicators for the years 2003, 2005 and 2007 separately for EU countries, Norway, which is an EEA country, and Croatia, Macedonia and Turkey, which are EU candidate countries. By utilizing the results obtained, evaluations were made regarding the quality of life for the years mentioned above.

Dinçer and Görener (2011) aim is to compare the applications of AHP-TOPSIS and AHP-VIKOR in the service sector. The main criteria are divided into various sub-criteria such as capital adequacy, liquidity, profitability, balance sheet structure, income-expenditure structure, sector shares, group shares and branch-oriented data. An application has been made to public and private banks.

Cristobal (2011) applied VIKOR method for renewable energy project selection in Spain. Criteria such as power, investment rate, implementation period, operating hours, useful life, operation and maintenance costs and annual avoided CO2 emissions were considered.

Göktürk et al. (2011) identified fourteen alternatives for supplier selection of a machinery manufacturing company and used the VIKOR method. In the weighting of the evaluation criteria, which play a fundamental role in the solution of the VIKOR method, the Analytic Network Process (ANP) method was utilized due to the mutual interaction of the criteria. Separate VIKOR solutions were obtained for different values of the maximum group utility, which is considered in obtaining the consensus solution, and the results were interpreted.

Özden et al. (2012) evaluated the companies in the cement sector traded in BIST with the help of VIKOR method by using 2011 financial indicators as criteria. Eight financial criteria were determined in the study. Criteria weights were determined by means of a questionnaire among the experts. Whether there is a relationship between the rankings obtained and the stock returns of these companies is analyzed with the rank correlation coefficient.

Popovic et al., (2012) worked on a model using financial analysis criteria and imprecise data to solve the problem based on the selection of investment projects. In the proposed model, full and interval values are used while determining the performance of the projects. Then, the best among the options were selected by using COPRAS and COPRAS-G methods. A numerical example illustrates the applicability and success of the model.

Yücenur and Demirel (2012) used the extended VIKOR method in fuzzy environment for insurance company selection. A foreign investor wants to buy one of five insurance companies. Price, profitability, portfolio structure, portfolio size, sales channel structure, organizational quality and solvency ratio criteria are considered.

Tayyar and Arslan (2013) attempted to choose the top subcontracting firm for sewing orders of renowned brands in the ready-to-wear industry using CRM techniques. The prepared model includes six main criteria, eighteen sub-criteria and four alternatives. A solution was achieved using AHS and VIKOR methods.

Mulliner et al., (2013) successfully demonstrated how sustainable housing affordability can be assessed using the COPRAS method. Three residential areas were selected in the study. The result of the study reveals that considering a number of social and environmental criteria can greatly affect the calculation of the affordability of an area compared to focusing solely on financial characteristics. COPRAS has been found to be an efficient method for rating and can be applied in other residential areas.

Kim and Chung (2013) applied the fuzzy VIKOR method to determine the deficit in water resources that will occur because of climate change. Using the Delphi technique, 24 criteria were basically determined under 3 headings. Then the fuzzy VIKOR method was applied.

Liu et al. (2013) used a hybrid model integrating the VIKOR method and an aggregation operator known as IOWA for material selection. In their study, criteria such as tensile strength, young's modulus, density, and corrosion resistance were considered. Finally, they applied the integrated IOWA-VIKOR method to a multi-criteria decision-making problem for material selection and compared the results for different standardized distance aggregation operators.

Rabbani et al., (2014) stated that the COPRAS method is more effective than the previously used ANP method for calculating the degree of preference of the alternatives. Therefore, the COPRAS technique has been adopted to prioritize viable alternatives in terms of linguistic variants. Using a combination of MCDM methods and the Sustainability Balanced Scorecard (SBSC) approach, the model helps authorities gain significant advantages in the event of competition. Based on this study, the results show that the proposed model is less time consuming.

AHP and VIKOR methods were used to solve the investment project selection problem in a company working in the Air Defense Industry by Uçakcıoğlu and Tamer (2017). In the study, criteria weights were determined based on five main criteria, namely budget, duration, dependency status, number of personnel and economic contribution. Then, eight alternatives were listed by ensuring that the weights of these criteria were reflected in the ranking of the alternatives.

In the study by Jafarzadeh et al., (2018), the optimal location for the deployment of a military unit in Ardabil was selected. In solving this problem, Geographic Information System (GIS) and MCDM methods were used together to choose among the options.

PROMETHEE and VIKOR methods were used for military airbase location selection. Nine main and thirty-three sub-criteria affecting the selection of military airports were determined and their weights were obtained by AHP method. The best place was determined from the four alternatives and the results found were compared with the results from the COPRAS, Multi-Attributive Ideal-Real Comparative Analysis (MAIRCA) and Multi-Attributive Border Approximation Area Comparison (MABAC) methods (Sennaroğlu and Çelebi 2018).

Akman (2019) attempted to enable people to choose the vehicle that best fits their criteria when choosing a car. For this purpose, four different tools were analyzed with AHP and TOPSIS methods in line with the determined criteria. Model four is selected as the best alternative as a result of the study obtained by the AHP method. Besides, the result obtained with the TOPSIS method also gives reliable results. Also, it has been determined that the most important criterion for people who are considering buying a car is the price criterion.

Sofuoğlu (2019) used a different approach than previous studies by using a mixture of ITARA, VIKOR, TOPSIS, and MOORA (Multi-Objective Optimization by Ratio Analysis) methods. Two examples from previous studies (material selection of flywheel and cryogenic storage tank) were selected to test these models. ITARA was used to determine the criterion weights in the problems and rankings were found using VIKOR, TOPSIS and MOORA. The results show that the proposed methods give successful results in terms of material selection.

Hatefi (2019) focused on a new method called ITARA that has been developed to determine the weights of attributes in MADM problems. The method, which consists of a group of techniques based on measuring the data distribution, is based on the concept of "Indifference Threshold (IT)." The mentioned model is applied to solve a technical numerical example. In addition, simulation experiment was also used to measure the efficiency of the proposed method, unlike previous studies. As a result, it has been concluded that the developed model is more effective than the previous models for almost all situations.

Çetin and Alvalı (2020) worked on a model that aims to use the most suitable carbon steel alloy for the bogie used in railway vehicles. For this purpose, TOPSIS and VIKOR methods were used. According to the results of the studies, the most suitable material is S355 steel. Furthermore, it is believed that a construction made with the combination of S355 and S275 will perform better.

Ulutaş et al. (2020) have put forward an MCDM approach aimed at facilitating decision-making within the logistics domain, specifically for selecting the most appropriate equipment to carry out logistics activities. The correlation coefficient and standard deviation (CCSD method) are applied to accurately determine the objective weights of the criteria. In addition, ITARA is used to calculate the semi-objective weights of the determined criteria. By using these two methods, single and more accurate criterion weights are reached. The MARCOS method is used to rank the alternatives.

Demir (2021) proposed a hybrid MCDM model for measuring and rating banking financial performance. The proposed model for performance evaluation includes ROC, ITARA and CODAS techniques. The selection of an up-to-date analysis period within the scope of the study, the use of many evaluation criteria together and the proposal of a new MCDM approach distinguish this study from previous studies in banking literature. The main logic for including the ROC and ITARA methods in the criterion weight determination procedure is that they both allow for the subjective definition of criterion weights and include an insight into the subjectivity of the decision maker. The Bayesian approach was used to combine the calculated ROC and ITARA weights to obtain a single weight.

Table 2.1. A summary of literature that used MCDM methods for UAV selection

Reference	Methodology	Number of alternatives	Number of criteria	Combination of criteria with and without numerical equivalents (Yes/No)
Özge (2008)	AHP	5	6	No
Ekmekçioğlu and Yıldız (2018)	TOPSIS and Fuzzy TOPSIS	12	5	No
Hamurcu and Eren (2020)	AHP and TOPSİS	6	7	No
Ulucan (2016)	Grey Relational Analysis	4	10	Yes
This study	ITARA-based Hybrid VIKOR and COPRAS	4	11	Yes

As mentioned above, many MCDM methods have been used in the selection of UAVs before (Table 2.1). In this study, criteria that do not have a numerical equivalent *(invisibility and rate of climb*) and criteria with a numerical equivalent were successfully combined. In addition, by adding the evaluations made by the experts, an ideal and single criterion weighting was successfully achieved.

3. MATERIALS AND METHODS

In this study, a hybrid approach based on ITARA, ROC, VIKOR and COPRAS methods for UAV selection is proposed. The main reason for including the ROC and ITARA methods in the criterion weight determination procedure is that they both allow for the subjective definition of criterion weights and include an insight into the subjectivity of the decision maker. The Bayesian approach is used to combine the calculated ROC and ITARA weights to obtain a single weight. The VIKOR and COPRAS methods are used for the final ranking of the evaluated UAVs.

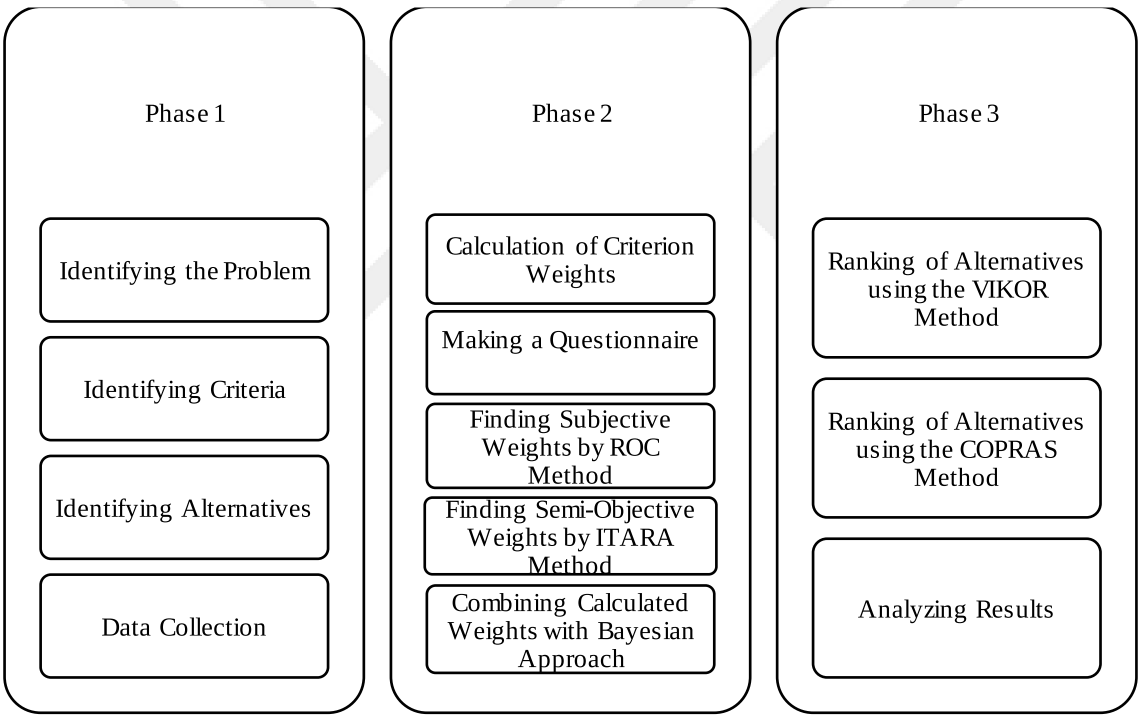

Figure 3.1. Problem solving phases.

3.1.1. Definition of Criteria

In this thesis, UAV selection is studied using the ITARA-based hybrid MCDM model. The criteria required for the study are determined by taking the consideration of experts working on UAVs in the defense industry. (Expert 1 is a UAV pilot with 8 years of experience. Expert 2 is a UAV pilot with 6 years of experience. Expert 3 is a UAV maintenance officer with 8 years of experience. Expert 4 is a UAV pilot with 12 years of experience. Expert 5 is a UAV pilot with 3 years of experience.)

The questionnaire form designed is provided in Appendix A.

The most commonly used criteria in the literature for UAV selection and the criteria that are considered to have the most impact on UAV performance can be listed as follows:

- Maximum Speed(knot)
- Service Level(ft.)
- Maximum Altitude(ft.)
- Endurance(hours)
- Pay Load (lb.)
- Rate Of Climb
- Cost(Million $)
- Range (Km.)
- Power Plant (Hp)
- Invisibility
- Max. Take off Weight(lb.)

Service Level indicates the ideal altitude at which the UAV can operate. Endurance refers to the total mission time of the UAV. *Payload* refers to the maximum weight of materials such as bombs and camera systems that can be loaded onto the UAV according to its operation. *Rate Of Climb*, is an aircraft's vertical speed, which is the positive or negative rate of altitude change with respect to time. *Power Plant* is the value of the power of the UAV engine in horsepower. *Invisibility* is the UAV's success in not being seen on enemy radars.

Including a UAV in the system creates huge costs. For this reason, the above-mentioned criteria should be carefully considered while making the selection. The data created by taking expert opinions about the determined criteria and conducting open-source research is presented in Table 3.1.

Table 3.1. Data on candidate UAVs.

	Specifications/UAVS	UAV-1	UAV-2	UAV-3	UAV-4
C1	Maximum Speed(knot)	117	120	117	151
C2	Service Level(ft.)	23000	18000	25000	16400
C3	Maximum Altitude(ft.)	30000	25000	30000	25000
C4	Endurance(hours)	30	27	24	20
C5	Pay Load (lb.)	770	330	1102	440
C6	Rate Of Climb	8	7	9	6
C7	Cost(Million $)	30	5	4	1
C8	Range (Km.)	250	300	1250	4000
C9	Power Plant (Hp)	150	105	115	100
C10	Invisibility	7	8	9	6
C11	Max. Take off Weight(lb.)	3750	1540	2250	2420

3.1.2. Determination of Criteria Weights

In the UAV selection problem, the weights of the UAV criteria are discussed with the ROC, ITARA, VIKOR and COPRAS methods. As stated in Table 3.1, it was decided to use eleven criteria determined by experts in the field. A score of 1 to 9 is required for the *Rate of Climb and Invisibility* criteria, minimizing the possibility of the model being wrong. In addition, unlike literature, it has ensured that subjective evaluations are successfully included in the decision-making process. The questionnaire form designed is provided in Appendix A. Data for other criteria are obtained from open sources. ("Unmanned aerial vehicle.", 2023; "Medium-altitude long-endurance UAV.", 2023)

3.1.3. ITARA Method

The ITARA method is a semi-objective criterion weighting method introduced to the literature by Hatefi (2019). The method is based on the concept of Indifference Threshold (IT) to determine criterion weights based on decision making data. The steps of ITARA are given below (Hatefi 2019: 5-7; Sofuoğlu 2019: 6718-6719; Du et al. 2020: 12-16; Ulutaş et al. 2020: 6):

Step 1. Creating the decision matrix

A decision matrix with m rows with alternatives and n columns with criteria (A) is created. The element of this matrix is a_{ij}, j. i for the criterion. shows the performance of the alternative. IT_j j∈N={1,2,…,n} for each criterion is determined by the decision maker. It is written as the last row of the decision matrix. IT_j gives the “indifference threshold” of the c_j criterion. Thus, for a given pair of r and s, there is a relation of $|a_{rj} - a_{sj}| \leq IT_j$. That is, the absolute value of the difference between any two performance scores must be less than or equal to the IT.

Step 2. Normalizing the decision matrix

The normalized values (a_{ij}) of the decision matrix are obtained by using Eq.3.1 and the normalized values of IT_j values (NIT_j) are obtained by using Eq.3.2.

$$a_{ij=}\frac{a_{ij}}{\sum a_{ij}}, \forall_j \in N \tag{3.1}$$

$$NIT_j = \frac{IT_j}{\sum a_{ij}}, \forall_j \in N \tag{3.2}$$

Step 3. Sorting the normalized scores

The normalized a_{ij} scores are sorted in ascending order and are called β_{ij} such that $\beta_{ij} \leq \beta_{i+1,j}$.

Step 4. Finding the distances (γ_{ij}) between neighboring β_{ij}s

The distance between β_{ij} and $\beta_{i+1,j}$ is found so that $\gamma_{ij} = \beta_{i+1,j} - \beta_{ij}, (i = 1, \ldots, m-1)$

Step 5. Finding the distance (δ_{ij}) between the ordinal scores of γ_{ij} and NIT_j

The distance between the ordinal scores of both γ_{ij} and NIT_j is obtained using Eq.3.3.

$$\delta_{ij} = \begin{cases} \gamma_{ij} - NIT_j \; for \; \gamma_{ij} > NIT_j, \\ 0 \qquad\qquad\qquad \gamma_{ij} \leq NIT_j, \end{cases} \forall i \in M, \forall j \in N \Big\} \tag{3.3}$$

Step 6. Calculating the weights of the criteria

To determine the criterion weights, the I_p metric measurement is obtained using Eq.3.4. Basically, this measure is an aggregation rule to get a combined value among multiple individual values. In the model, p ranging from 1 to ∞ is the parameter of the model. The most common and important ones are I_1, I_2 , and I_∞. I_1 is called the Manhattan measure and is the sum of the absolute values of δ_{ij}, which refers to a linear addition along different individual values of δ_{ij}. Of course, for I_1, if $\forall\ NIT_j = 0$, the value of v_j is equal to the data range, which is the difference between the lowest and highest values of a_{ij}. I_2 is called the Euclidean measure. For I_∞ $\lim_{p\to\infty} v_j = \max_{1\le i\le m} \delta_{ij}$ is obtained.

$$V_j = \left(\sum_{i=1}^{m-1} \delta_{ij}^p\right)^{\frac{1}{p}}, \forall j \in N$$

$$w_j = \frac{v_j}{\sum_{i=1}^{n} v_j} \tag{3.4}$$

3.1.4. ROC Methods

The ROC method is the subjective criterion weighting method introduced to literature by Barron et al. (1996). This method is a straightforward way of weighting criteria ranked by their importance. Decision makers can often rank much more easily than weighing the criteria. This method takes these ranking degrees as input and converts them to weights for each criterion. The steps of this method are as follows:

Step 1. Ranking the criteria according to their importance

$$Kr1>Kr2>\cdots>Krn \tag{3.5}$$

where n=1,2,…,N and rn is the nth ranking of criteria

The most important criterion will be in the first place (n=1), and the least important criterion (n=N).

Step 2. Calculating the weights of the criteria

$$w_{n=}\frac{1}{N}.\sum_{k=n}^{N}(\frac{1}{r_k}) \tag{3.6}$$

$$\sum_{n=1}^{N} w_{n=1} = 1 \tag{3.7}$$

The criteria weights are calculated with the formula given in Eq.3.6 and Eq.3.7.

3.1.5. Combining Criterion Weight Values Using Bayesian Approach

As it is known, one of the two main objectives of the MCDM methods is to select the best alternative and the other is to determine the weights of the criteria. The fundamental objective in evaluating criteria weighting is to determine the greatest weight to the most important criterion in any method used for criteria weighting.

The weights of the criteria quantify their importance and their effects on the evaluation result. The criteria weights can be subjective, that is, depending on the estimates assigned by the experts and the so-called goal, i.e., those who evaluate the structure of the data set during evaluation. Objective criteria weights usually use various features of the structure of the data set, or various methods that evaluate the features. Both subjective and objective assessments can be used together for criterion weights. ITARA can be given as an example of this mixed weighting method. Both subjective and objective weighting and mixed weighting can be used in the same study. Therefore, it is necessary to evaluate and increase the accuracy of the weight values and to combine the obtained data into a single value. The resulting criterion weights reflect both a decision maker's subjective thoughts and objective information. The Bayes equation used to recalculate the criterion weights is obtained using Eq.3.8 (Vinogradova et al. 2018).

$$\mathrm{w}(\mathrm{R_j}/\mathrm{X}) = \frac{\mathrm{w}(\mathrm{R_j})\mathrm{w}(\mathrm{X}/\mathrm{R_j})}{\sum_{\mathrm{j}=1}^{\mathrm{m}} \mathrm{w}(\mathrm{R_j})\,\mathrm{w}(\mathrm{X}/\mathrm{R_j})} \tag{3.8}$$

where $\mathrm{w}(\mathrm{R_j}) = \mathrm{w_j}$ is the initial weight of R_j of jth criterion. X indicates the event when new criterion weights are obtained. $\mathrm{w}(\mathrm{X}/\mathrm{R_j}) = \mathrm{W_j}$ indicates the new weights of the criteria calculated by another method or by another expert group. $\mathrm{w}(\mathrm{R_j}/\mathrm{X}) = a_\mathrm{j}$ indicates the recalculated criteria weights. Equation (8), which is applied to the weights of the criteria, is expressed as Eq.3.9.

$$a_j = \frac{w_j W_j}{\sum_{j=1}^{m} w_j W_j} \tag{3.9}$$

3.1.6. Application of ITARA Method

The value of IT_j added to the last row of the decision matrix was determined by the experts and given in Table 3.2.

Table 3.2 Decision matrix.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
	Max	**Max**	**Max**	**Max**	**Max**	**Max**	**Min**	**Max**	**Max**	**Max**	**Max**
UAV-1	117	23000	30000	30	770	8	30	250	150	7	3750
UAV-2	120	18000	25000	27	330	7	5	300	105	8	1540
UAV-3	117	25000	30000	24	1102	9	4	1250	115	9	2250
UAV-4	151	16400	25000	20	440	6	1	4000	100	6	2420
Total	505	82400	110000	101	2642	30	40	5800	470	30	9960
$\boldsymbol{IT_j}$	3	1600	1000	3	100	2	4	50	10	2	170

The normalized values for the elements of the decision matrix are shown in Table 3.3.

Table 3.3 Normalized matrix.

UAV	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
UAV-1	0,232	0,279	0,273	0,297	0,291	0,267	0,750	0,043	0,319	0,233	0,377
UAV-2	0,238	0,218	0,227	0,267	0,125	0,233	0,125	0,052	0,223	0,267	0,155
UAV-3	0,232	0,303	0,273	0,238	0,417	0,300	0,100	0,216	0,245	0,300	0,226
UAV-4	0,299	0,199	0,227	0,198	0,167	0,200	0,025	0,690	0,213	0,200	0,243

Table 3.3 Normalized matrix. (Continue)

NIT_j	0,0059	0,0194	0,0090	0,0297	0,0379	0,0667	0,1000	0,0086	0,0213	0,0667	0,0171

Then, the values obtained by ordering the normalized scores from smallest to largest are given in Table 3.4.

Table 3.4 Ranking of normalized scores.

C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**
0,2317	0,1990	0,2273	0,1980	0,1249	0,2000	0,0250	0,0431	0,2128	0,2000	0,1546
0,2317	0,2184	0,2273	0,2376	0,1665	0,2333	0,1000	0,0517	0,2234	0,2333	0,2259
0,2376	0,2791	0,2727	0,2673	0,2914	0,2667	0,1250	0,2155	0,2447	0,2667	0,2430
0,2990	0,3034	0,2727	0,2970	0,4171	0,3000	0,7500	0,6897	0,3191	0,3000	0,3765

The distance between neighboring β_{ij}s is calculated by taking the difference between two consecutive terms and Table 3.5. is also shown.

Table 3.5 Distance between neighboring β_{ij}s.

C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**
0,0059	0,0607	0,0455	0,0297	0,1665	0,0333	0,6250	0,0086	0,0957	0,0333	0,2219
0,0059	0,0850	0,0455	0,0297	0,2922	0,0667	0,0250	0,1638	0,0213	0,0667	0,0713
0,0673	0,1044	0,0455	0,0396	0,2506	0,1000	0,0750	0,4741	0,0319	0,1000	0,0171

The distances calculated using Eq.3.2 for the distances between the ordinal points of γ_{ij} and NIT_j are given in Table 3.6.

Table 3.6 δ_{ij} Distances of criteria.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
	0,000	0,041	0,036	0,000	0,129	0,000	0,525	0,000	0,074	0,000	0,205
	0,000	0,066	0,036	0,000	0,254	0,000	0,000	0,155	0,000	0,000	0,054
	0,061	0,085	0,036	0,010	0,213	0,033	0,000	0,466	0,011	0,033	0,000
Total	0,061	0,192	0,109	0,010	0,596	0,033	0,525	0,621	0,085	0,033	0,259

V_j =(0,061+0,192+0,109….0.033+0,259)= 2,524385 can be calculated as by using the values from Table 3.6. The weights of the criteria were found as shown in Table 3.7 by using Eq.3.4. For example:

$v_1=\frac{0,061}{2,5243}$=0,24317,$v_2=\frac{0,192}{2,5243}$=0,07595

Table 3.7 ITARA weighting results.

Criteria	Weight
C1	0,24317
C2	0,07595
C3	0,43215
C4	0,00392
C5	0,23600
C6	0,01320
C7	0,20797
C8	0,24587
C9	0,03371
C10	0,01320
C11	0,10261

3.1.7. Application of ROC Method

Since there are eleven criteria in the application, there is a possibility of 11! rankings. As a result of the questionnaire applied to the expert group, the order of importance is made as follows. The designed questionnaire form is provided in Appendix A.

C4>C8>C5>C2>C10>C3>C1>C11>C7>C6>C9

According to this order, criteria weight for criteria four is calculated using Eq.3.6 as follows:

$$w_{4=}\frac{1}{11}.\sum_{k=1}^{11}(\frac{1}{r_k})=\left(\frac{1}{11}\right)\left(\frac{1}{1}+\frac{1}{2}+\frac{1}{3}+\frac{1}{4}+\frac{1}{5}+\frac{1}{6}+\frac{1}{7}+\frac{1}{8}+\frac{1}{9}+\frac{1}{10}+\frac{1}{11}\right)=0{,}2745$$

By making similar calculations, the weights of the other criteria are calculated and given in Table 3.8. Detailed operations are shown in Appendix A.

Table 3.8 ROC weighting results.

Criteria	Weight
C1	0,1297
C2	0,1760
C3	0,1427
C4	0,2745
C5	0,1988
C6	0,0992
C7	0,1083
C8	0,2291
C9	0,0909
C10	0,1579
C11	0,1184

3.1.8. Application of Combining Weights Using the Bayesian Approach

A single weight was obtained by combining the weights calculated by both the ROC method and the ITARA method using Eq.3.8 and Eq.3.9.

$$a_1 = \frac{0{,}3174 * 0{,}1297}{0{,}3174 * 0{,}1297 + 0{,}0991 * 0{,}1760 + \cdots + 0{,}1339 * 0{,}1183} = 0{,}0223$$

By making similar calculations, the weights of the other criteria are calculated and given in Table 3.9. Detailed operations are shown in Appendix A.

Table 3.9. Weighting results combined with the Bayesian approach.

Criteria	Weight
C1	0,02232
C2	0,09463
C3	0,00000
C4	0,00762
C5	0,33198
C6	0,00927
C7	0,01320
C8	0,39859
C9	0,02169
C10	0,01475
C11	0,08595

3.1.9. MCDM Methods Used in Criteria Evaluation

3.1.10. VIKOR Method

VIKOR is a method that aims to determinate the correct ranking between alternatives and to reach a successful solution by taking into account the previously calculated weights. It determines the ranking of the alternatives by evaluating the determined criteria and ensures the selection of the most suitable one. The VIKOR method considers the multi-criteria ranking index based on closeness to the ideal solution. Consensus resolution for problems with conflicting criteria helps decision makers reach a decision. The VIKOR method was first proposed by Opricovic and Tzeng (2004) for multi-criteria optimization of complex systems. Evaluation of bus fuel usage, software development projects and suppliers in the context of environmental awareness can be given as examples of VIKOR use cases (Tzeng et al., (2005), Büyüközkan and Ruan (2008), Büyüközkan and Feyzioğlu (2008))

The first studies on the compromise solution were made by Yu (1973). Compromise solution is the closest suitable solution to the ideal, and compromise is to agree on common acceptance (Opricovic and Tzeng, 2004). The VIKOR method deals with choosing one of the alternatives set or ranking the alternatives in case of conflicting criteria (Büyüközkan and Ruan, 2008). Under the assumption that each alternative is evaluated for each criterion, a consensus ranking is reached by comparing the closeness values to the ideal alternative (Opricovic and Tzeng, 2007).

The basis of the consensus ranking for multi-criteria measurement is the $L_p$criterion, which is used as an addition function in compromise programming (Yu, 1973). If J alternatives are expressed as a_1, a_2 ,..., a_j, the evaluation result of a_j alternative according to i criterion is expressed as f_{ij}. The basis of the VIKOR method is the following form of the L_p criterion:

$$L_{pj} = \left\{ \sum_{i=1}^{n} \left[w_i \left(f_i^* - f_{ij} \right) / \left(f_i^* - f_i^- \right) \right]^p \right\}^{\frac{1}{p}} \qquad 1 \leq p \leq \infty; j = 1, 2, \ldots, J \qquad (3.10)$$

where n represents the number of criteria.

In the VIKOR method, L_{ij} (S_j in Equation 3) and $L_{\infty j}$ (R_j in Equation 4) are used to create the sorting criteria. The result from $min_j R_j$ indicates the maximum group benefit, and the minimum personal regret of the dissidents from the $min_j R_j$. A ranking is reached for the set of alternatives given in the VIKOR method.

Adding or removing an alternative from this set of alternatives will affect the result. The compromise solution, F^c is the closest fit to the ideal solution F^*. The term compromise means mutual acceptance of the agreement and is expressed by $\Delta f_1 = f_1^* - f_1^c$ and $\Delta f_2 = f_2^* - f_2^c$ as seen in Figure 3.1 (Opricovic and Tzeng, 2004):

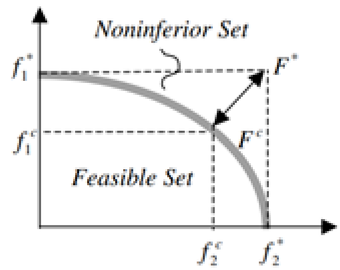

Figure 3.2. Ideal and compromise solution

The steps of the VIKOR method can be summarized as follows:

Step 1. Determine the best (f_i^*) and worst (f_i^-) values of evaluations of alternatives j (j = $1, \ldots, $m) each criterion i ($i = 1,2,\ldots,n$). If it is a benefit criterion that is to be maximized:

$$f_i^* = \max_j f_{ij} \qquad f_i^- = \min_j f_{ij} \qquad i = 1,2,\ldots,n \tag{3.11}$$

Step 2. S_j and R_j values are calculated for j = 1,2,...,J. The S_j and R_j values represent the mean and worst group scores for the alternative j.

$$S_j = \sum_{i=1}^{n} w_i\left(f_i^* - f_{ij}\right)/(f_i^* - f^-) \tag{3.12}$$

$$R_j = max\left[w_i\left(f_i^* - f_{ij}\right)/(f_i^* - f^-)\right] \quad (3.13)$$

where w_i denotes criterion weights indicating relative importance. The sum of the weights will be equal to 1.

Step 3. Compute Q_i for all j = 1,2,…, J.

$$Q_j = v\left(S_j - S^*\right)/(S^- - S^*) + (1 - v)(R_j - R^*)/(R^- - R^*) \quad (3.14)$$

where $S^* = \min_j S_j$, $S^- = \max_j S_j$, $R^* = \min_j R_j$, $R^- = \max_j R_j$ and "v" indicate the weight of the majority of the criteria (maximum group benefit). In other words, while the value of "v" expresses the weight for the strategy that provides maximum group benefit, (1-v) expresses the weight of the minimum regret of the opponents. (Opricovic and Tzeng, 2007). Consensus can be achieved by "majority vote" (v > 0.5), "consensus" (v = 0.5) or "veto" (v < 0.5).

Step 4. Rank the alternatives by the values S, R and Q in ascending order by forming three ranking lists such that the lower the value, the better the alternative.

Step 5. Propose the alternative a′ as a compromise solution which is ranked the best by the minimum value of Q if the following two conditions are satisfied.

1. C_1 Acceptable advantage

   $Q(a'') - Q(a') \geq DQ$

   where a'' is the second-ranked alternative to sort by the Q value.

   $DQ = \frac{1}{J-1}$, J represents the number of alternatives.

2. C_2 Acceptable stability in decision making.

   Also, alternative a' is the best alternative ranked by S and/or R values. This compromise solution is stable in the decision-making process.

Step 6. If either of these two conditions is not met, the compromise solution set is suggested as:

- Alternatives a' and a'' if condition C_2 is not satisfied
- If condition C_1 is not satisfied, alternatives to $a', a'', \dots, a^{(M)}$ and its value are determined as $Q\left(a^{(M)}\right) - Q(a') < DQ$ for maximum M.

The best alternative ranked according to their Q values is one of the alternatives with the minimum Q value (Opricovic & Tzeng, 2004).
The VIKOR method is an effective tool in MCDM, in case the decision maker cannot specify his preferences at the beginning while the system is being designed. The compromise solution obtained will be accepted by the decision maker as it will provide maximum group benefit for the majority and minimum regret for those who disagree (Opricovic & Tzeng, 2007).

3.1.11. COPRAS Method

In 1996, researchers Zavadskas and Kaklauskas of Vilnius Gediminas Technical University discovered a method called COPRAS for complex proportional assessment.

The method is used to rank and evaluate the alternatives in terms of the weight and usefulness of the criteria. Criterion values are used for evaluation of maximizing the benefit criterion and minimizing the useless criteria in criterion evaluation.

The advantages of the COPRAS method can be listed as follows (Mulliner et al., 2013: 274):

- It is a less time consuming and more useful method than other MCDM methods such as AHP and TOPSIS.
- It provides the possibility to sort the alternatives or options.
- The method enables alternatives to be evaluated in quantitative criteria in addition to the qualitative criteria they have.

COPRAS can calculate both maximum and minimum criteria. In the evaluation process, both criteria are evaluated separately. Some MCDM methods, such as SAW, require conversion to evaluate negative values, which is time consuming and confusing for the decision maker.

Unlike other MCDM methods for COPRAS, it shows the degree of benefit of the alternatives. By comparing alternatives with each other, it can clearly show how good or how bad they are.

The stages of the COPRAS method are listed as follows. (Zavadskas et al., 2008; Podvezko, 2011; Özdağoğlu, 2013b). Variables in the model are given below:

A_j = ith alternative i=1,2,...,m

C_j =jth evaluation criterion j=1,2,...,n

W_j= jth significance level of assessment criterion j=1,2,...,n

X_{ij}=jth value of the ith alternative in terms of evaluation criteria i=1,2,...,m j=1,2,...,n

Step 1. Creating the Decision Matrix

In the first step of the COPRAS Method, the decision matrix is created and shown in Eq.3.15

$$D = \begin{array}{c} A_1 \\ A_2 \\ A_3 \\ . \\ A_m \end{array} \begin{bmatrix} x_{11} & x_{12} & x_{13} & . & x_{1n} \\ x_{21} & x_{22} & x_{23} & . & x_{2n} \\ x_{31} & x_{32} & x_{33} & . & x_{3n} \\ . & . & . & . & . \\ x_{m1} & x_{m2} & x_{m3} & . & x_{mn} \end{bmatrix} \quad (3.15)$$

. **Step 2.** Generating the Normalized Decision Matrix

The normalized decision matrix is performed with the help of Eq.3.16.

$$x_{ij}^* = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \forall_j = 1,2,\dots,n \quad (3.16)$$

Step 3. Creating the Weighted Decision Matrix

Weighted decision matrix is found by multiplying the normalized decision matrix columns with the w_j weight values given to the criteria and is performed with the help of the Eq.3.17.

$$D' = d_{ij} = x_{ij}^*.w_j \quad (3.17)$$

Step 4. Calculating Useful and Useless Metrics

At this stage, useful criteria express the criteria where higher values indicate a better situation in achieving the objective. Unhelpful measures refer to criteria where lower values indicate a better situation in achieving the objective.

$$S_i^+ = \sum_{J=1}^{k} d_{ij} \qquad j = 1,2,\dots..,k \qquad \text{useful criteria} \quad (3.18)$$

$$S_i^- = \sum_{J=k+1}^{n} d_{ij} \quad j = k+1, k+2, \ldots\ldots, n \quad useless\ criteria \tag{3.19}$$

Step 5: Calculating Q_i Relative Importance Values

Q_i is the relative importance value for each alternative and is calculated with the help of Eq.3.20. The alternative with the highest relative importance value as a result of the calculations is determined as the best alternative.

$$Q_i = S_i^+ + \frac{\sum_{i=1}^{m} S_i^-}{S_i^- . \sum_{i=1}^{m} \frac{1}{S_i^-}} \tag{3.20}$$

Step 6: Calculating Peak Relative Significance Values

The highest relative priority value is found by Eq.3.21.

$$Q_{max} = the\ biggest\{Q_i\}\ \forall_i = 1,2, \ldots, m \tag{3.21}$$

Step 7: Calculating Performance Index P_i Values for Alternatives

The performance index specified as P_i for each alternative is calculated with the help of Eq.3.22.

$$P_i = \frac{Q_i}{Q_{max}} . 100\% \tag{3.22}$$

The alternative with a P_i performance index of 100 found is the best alternative. The order of preference of the alternatives is found by ranking the performance index values from the largest to the smallest.

3.1.12. Application of MCDM Methods For Criteria Evaluation

3.1.13. Application of VIKOR Method

The decision matrix is same as in the ITARA method and shown in Table 3.1.

The best (f_i^*) and worst (f_i^-) values of the alternatives for each criterion are given in Table 3.10.

Table 3.10. Best (f_i^*) and worst (f_i^-)values.

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**
$(\boldsymbol{f_i^*})$	151	25000	30000	30	1102	9	30	4000	150	9	3750
$(\boldsymbol{f_i^-})$	117	16400	25000	20	330	6	1	250	100	6	1540

Using Eq. 3.12 and Eq. 3.13 S_j and R_j values are calculated for j= 1,2,...,J. The values of w_i in the calculations, which are specified in Table 3.4 and the Combined Weight Results with the Bayesian Approach, were used. S_j and R_j values are given in Table 3.11.

Table 3.11. S_j and R_j values.

C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**	$\boldsymbol{S_j}$	$\boldsymbol{R_j}$
0,019	0,019	0,000	0,000	0,125	0,003	0,000	0,348	0,000	0,009	0,000	0,5223	0,3478
0,018	0,067	0,035	0,002	0,290	0,005	0,597	0,343	0,017	0,004	0,075	1,4536	0,5970
0,019	0,000	0,000	0,004	0,000	0,000	0,601	0,255	0,013	0,000	0,051	0,9437	0,6011
0,000	0,083	0,035	0,007	0,248	0,008	0,613	0,000	0,019	0,013	0,045	1,0711	0,6133

According to Table 3.10 S^*=1,453562517, S^-=0,522288104, R^*=0,613323, R^-=0,34777

Then using Table 3.10 and Eq.3.14 Q_j values are calculated for j= 1,2,...,J. All Q_j values are given in Table 3.12.

Table 3.12. Q_j values and Rank.

UAV	$\boldsymbol{Q_j}$	**Rank**
UAV-1	1	4
UAV-2	0,03079483	1

Table 3.12. Q_j values and Rank. (Continue)

UAV-3	0,296840307	3
UAV-4	0,205356622	2

3.1.14. Application of COPRAS Method

The decision matrix is same as in the ITARA and VIKOR methods. The values of w_i in the calculations, which are specified in Table 3.4 and the Combined Weight Results with the Bayesian Approach. Using Eq. 3.16, the normalized decision matrix indicated in Table 3.13.

Table 3.13. COPRAS normalized decision matrix .

UAV	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
UAV-1	117	23000	30000	30	770	8	30	250	150	7	3750
UAV-2	120	18000	25000	27	330	7	5	300	105	8	1540
UAV-3	117	25000	30000	24	1102	9	4	1250	115	9	2250
UAV-4	151	16400	25000	20	440	6	1	4000	100	6	2420
w_i	0,0195	0,0826	0,0352	0,0066	0,2896	0,0081	0,1390	0,3478	0,0189	0,0129	0,0750

The weighted normalized decision matrix is given in Table 3.14 which is calculated by using Eq.3.17.

Table 3.14. COPRAS weighted normalized decision matrix.

UAV	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
UAV-1	0,0074	0,0330	0,0124	0,0028	0,1161	0,0031	0,0018	0,0180	0,0102	0,0045	0,0519

Table 3.14. COPRAS weighted normalized decision matrix. (Continue)

UAV-2	0,0076	0,0258	0,0103	0,0025	0,0498	0,0027	0,0003	0,0215	0,0071	0,0051	0,0213
UAV-3	0,0074	0,0358	0,0124	0,0023	0,1661	0,0035	0,0002	0,0898	0,0078	0,0058	0,0311
UAV-4	0,0095	0,0235	0,0103	0,0019	0,0663	0,0023	0,0001	0,2873	0,0068	0,0038	0,0335

Using Eq. 3.18 and 3.19, total weighted normalized values (S_{+i}) and (S_{-i}) based on benefit and cost criteria have been calculated as in the Table 3.15.

Table 3.15. COPRAS total weighted normalized values.

UAV	$\mathbf{S_{+i}}$	$\mathbf{S_{-i}}$
UAV-1	0,2593	0,0018
UAV-2	0,1538	0,0003
UAV-3	0,3620	0,0002
UAV-4	0,4453	0,0001

Using Eq. 3.20, relative importance of each alternative (Q_i) has been calculated. Then, using Eq. 3.22, performance index (P_i) of each alternative has been calculated. Calculated values are indicated in Table 3.16.

Table 3.16. COPRAS relative importance and performance index values.

UAV	$\boldsymbol{Q_i}$	$\boldsymbol{P_i}$	**Rank**
UAV-1	0,2593	58,03	3
UAV-2	0,1541	34,49	4
UAV-3	0,3624	81,09	2
UAV-4	0,4469	100,00	1

4. RESULTS AND DISCUSSIONS

In this thesis, different novel hybrid models are developed by using ITARA, VIKOR, ROC and COPRAS methods. ITARA and ROC are used to find the criteria weights for the problem, and the final rankings are obtained by using VIKOR and COPRAS. Today, the complexity of determining the criteria and criterion weights causes the inadequacy of single MCDM methods and misleads the decision maker. The comparison of the VIKOR and COPRAS is given in Table 4.1.

Table 4.1. Final rankings found by proposed hybrid MCDM methods.

UAV	**VIKOR**		**COPRAS**	
	Q_j **values**	**Rank**	**Performance index**	**Rank**
UAV-1	1	4	58,03	3
UAV-2	0,03079483	1	34,49	4
UAV-3	0,296840307	3	81,09	2
UAV-4	0,205356622	2	100,00	1

It is seen from Table 4.1 that all the applied MCDM methods give the close ranking with different performance scores.

Performance ranking according to the results obtained with the VIKOR method; UAV-2, UAV-4, UAV-3, UAV-1.

Performance ranking according to the results obtained with the COPRAS method; UAV-4, UAV-3, UAV-1, UAV-2.

The UAV with the best performance is UAV-4 and the UAV with the worst performance is UAV-1.

5. CONCLUSIONS

With the development of technology, the complexity and technical details of modern systems are constantly increasing. Especially in the field of aviation, there are new developments every day and it is becoming difficult for decision makers to follow them. As is known, the adoption and maintenance of a new system in modern armies causes extremely high costs. For this reason, it has become inevitable for decision makers to resort to scientific approaches before making these decisions. In this context MCDM has been used for a while. However, as mentioned above, the complexity of the systems and the increase in technical details have led us to use hybrid decision-making methods.

In this study, unlike previous studies, these methods were evaluated for the first time using this problem. When the literature studies are taken into consideration, it is seen that criteria determinations are based on objective values such as *Speed, Maximum Altitude and Pay Load*. This situation negatively affects the reliability of the model. Thus, in this study subjective criteria are added to the model and thus more meaningful results are achieved for the decision maker. In addition, values between 1 and 9 are given for the *Invisibility* and *Rate of Climb* criteria to ensure the compatibility of two subjective criteria with the model.

Since the most basic problem in MCDM methods is the problems experienced in weighting the criteria, ITARA and ROC methods are combined with the Bayesian approach. The main reason why the ROC and ITARA methods are included in the criterion weighting procedure is that they allow both the subjective definition of the criterion weights and give the decision maker insight into subjectivity. With this model, the model can be easily designed according to the needs of the decision maker and the most suitable system can be selected for the needs of the country in question. For example, in cases where the operation area you will be working is not exceptionally large, meaningful results can be obtained by easily designing the model by giving low scores to the *Endurance and Range* criteria. To give a second example, if the air defense systems of the enemy country are not good, meaningful results can be obtained by giving low scores to the *Sevice Level, Maximum Altitude and Invisibility* criteria.

The criteria for which weight value was obtained with the methods mentioned above are evaluated with the VIKOR and COPRAS methods and it is seen that noteworthy results are obtained. It is seen that the order of importance of the criteria is ***Range, Pay Load, Cost, Service Level, Max. Take off Weight, Maximum Altitude, Maximum Speed, Power Plant, Invisibility, Rate of Climb and Endurance.*** As a result of the application of VIKOR method UAV-2 is found to be the best and UAV-1 is the worst UAV. As a result of the application of COPRAS method UAV-4 is found to be the best and UAV-2 is the worst UAV. Evaluation of UAV performances requires the use of MCDM techniques. The close results of VIKOR and COPRAS methods prove the accuracy of both methods when using them in UAV selection.

The methods employed in this study have the potential to be applied to future aviation scenarios involving UAV selection. Furthermore, with slight adjustments to accommodate specific aircraft types, these approaches can also be utilized for selecting fighter jets, military helicopters, air refueling aircraft, or other categories of civil aircraft. Additionally, to verify the accuracy of the findings in this study, alternative MCDM techniques can be employed.

Finally, this study has shown that with the industrial engineering perspective, qualitative and quantitative criteria can be successfully combined and weighted, and a useful and successful tool can be obtained for decision makers with the MCDM methods to be applied. This is an important indicator of how necessary the mentality of industrial engineering and analytical thinking is for institutions.

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APPENDIX

Appendix A

A.1. Questionnaire form for ranking of criteria.

	Specifications/Questions	According to you to what extent is it more important?(Scale 1 to 9)							Rank from most important to least important to you							
		Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Average	Sorting	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Average	Sorting	Average of Q2-Q3
1	Maximum Speed(knot)	7	6	7	7	6	6,6	6	5	8	6	5	6	6	7	6,5
2	Service Level(ft.)	5	5	5	9	9	6,6	7	7	2	4	4	5	4,4	2	4,5
3	Maximum Altitude(ft.)	4	9	7	7	7	6,8	5	8	4	2	6	9	5,8	6	5,5
4	Endurance(hours)	9	8	8	9	9	8,6	1	3	7	3	2	2	3,4	1	1
5	Pay Load (lb.)	6	8	5	7	9	7	4	11	5	5	1	1	4,6	3	3,5
6	Rate Of Climb	7	5	8	7	5	6,4	8	6	9	7	9	10	8,2	10	9
7	Cost(Million $)	5	1	7	5	6	4,8	11	10	10	9	7	3	7,8	9	10
8	Range (Km.)	9	8	9	7	9	8,4	2	1	3	8	8	4	4,8	4	3
9	Power Plant (Hp)	5	7	5	6	4	5,4	10	9	6	11	10	11	9,4	11	10,5
10	Invisibility	9	9	6	7	8	7,8	3	2	1	10	11	8	6,4	8	5,5
11	Max. Take off Weight(lb.)	8	3	6	9	6	6,4	9	4	11	1	3	7	5,2	5	7

A.2. Questionnaire form for scoring the 10th criterion.

	Give a score between 1 to 9 for criteria 6 (Rate of Climb)					
	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Average
UAV-1	8	6	7	9	9	8
UAV-2	8	7	6	8	6	7
UAV-3	9	9	8	9	9	9
UAV-4	6	7	6	6	7	6

A.3. Questionnaire form for scoring the 10th criterion.

	Give a score between 1 to 9 for criteria 10 (Invisibility)					
	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Average
UAV-1	7	7	7	7	6	7
UAV-2	8	8	9	8	8	8
UAV-3	9	9	8	9	9	9
UAV-4	6	7	6	6	7	6

A4. Combining Criterion Weight Values Using Bayesian Approach

	ITARA	ROC	ITARA*ROC	WEIGHT COMBINED WITH THE BAYES APPROACH
C1	0,025416	0,129729	0,003297142	0,018793058
C2	0,079389	0,176049	0,013976374	0,079662559
C3	0,043215	0,142716	0,006167455	0,035153269
C4	0,004099	0,274534	0,001125396	0,006414531
C5	0,246662	0,198777	0,049030621	0,279464819
C6	0,013801	0,099174	0,001368688	0,007801252
C7	0,217365	0,108264	0,023532885	0,134132778
C8	0,256983	0,22908	0,05886961	0,335545111
C9	0,035236	0,090909	0,003203313	0,01825825
C10	0,013801	0,157868	0,002178722	0,012418283
C11	0,107248	0,118365	0,012694492	0,072356091
		TOTAL	0,175444697	