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# Fighter Aircraft Selection Using Technique for Order Preference by Similarity to Ideal Solution with Multiple Criteria Decision Making Analysis

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***Abstract*—**This paper presents a multiple criteria decision making analysis technique for selecting fighter aircraft for the national air force. The selection of military aircraft is a process consisting of contradictory goals and objectives. When a modern air force needs to choose fighter aircraft to upgrade existing fleets, a multiple criteria decision making analysis and scenario planning for defense acquisition has been put forward. The selection of fighter aircraft for the air defense force is a strategic decision making process, since the purchase or lease of fighter jets, maintenance and operating costs and having a fleet is the biggest cost for the air force. Multiple criteria decision making analysis methods are effectively applied to facilitate decision making from various available options. The selection criteria were determined using the literature on the problem of fighter aircraft selection. The selection of fighter aircraft to be purchased for the air defense forces is handled using a multiple criteria decision making analysis technique that also determines a suitable methodological approach for the defense procurement and fleet upgrade planning process. The aim of this study is to originate an approach to evaluate fighter aircraft alternatives, Su-35, F-35, and TF-X (MMU), based on technique for order preference by similarity to ideal solution (TOPSIS).

***Keywords*—**Fighter Aircraft, Fighter Aircraft Selection, Technique for Order Preference by Similarity to Ideal Solution, TOPSIS, Multiple Criteria Decision Making, Multiple Criteria Decision Making Analysis, MCDMA, Su-35, F-35, TF-X (MMU).

## I. Introduction

OPTIMAL engineering design for military stealth fighter aircraft always depends on multiple design indicators to improve efficient optimization creation when dealing with challenging multidimensionality. In terms of desired performance, ultracritical design requirements are needed for modern multirole fighter aircraft.

Also, there is significant ground attack capability in the form of delivering maximum payloads to a target at an appropriate combat range, including precise air-to-air capabilities at certain altitude combinations when engaging with severe operational challenges.

However, from the technological point of view, the resulting size and geometry of such stealth fighter aircraft can result in a poor level of survivability due to increases in radar and infrared signatures, resulting in reduced stealth of fighter aircraft. Additionally, passive improvements in these signatures can significantly increase the cost of stealth fighter aircrafts. Technically, most modern fighter aircraft are expected to have a service period of thirty years or longer, but there are several uncertainties that could affect the feasibility and applicability of the aircraft during the projected service period.

On the other side, survivability directly affects the viability of the fighter aircraft in challenging operations. Therefore, instead of decisive conventional battles, battles become asymmetrical and are fought under unforeseen circumstances in changing geopolitical and geostrategic challenges.

Also, the enemy is no longer well defined, and the front lines are not openly marked to overcome the strategic, tactical, and operational challenges. As such, large numbers of armies are not enough to win wars; instead, it is technology, strategy, tactic, operation, and diplomacy that can lead to wars being won in reginal or international scale. Because of the existence of weapons of mass destruction, nations cannot afford to engage in a regional conflict or total war under these circumstances.

Therefore, to counter these global changes and challenges, effective surgical air strikes are a rapid option, with precise measures, and policies available. At the heart of modern warfare lies a country's air defense force to deal with these defense and security challenges. The Air Force serves as both sword and shield of a nation's air defense structure; thus, while giving a nation the capability and capacity to strike a decisive blow to its enemy, it protects it from both retaliation and aggression.

At present, the Air Force is facing a widespread regional and global challenge in the form of terrorism, and radical extremism as well as the modern wars. To counter these challenges, the Air Force needs efficient state-of-the-art aircraft, equipped, and fully competent with the latest precision strike technology for targeting its enemies with pin-point accuracy, minimum collateral damage, and protected with stealth technology. These stealth fighter aircraft will also be useful in the combat fleets responsible

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for countering international security threats across the globe.

In general, the selection of modern fighter aircraft is a very complex decision problem, governed by multiple economic, geopolitical, technical constraints and factors. In addition, an Air Force must comply with strategic, tactical, operational, and dynamic defense requirements. Therefore, strategic planning is very important to make an effective selection of fighter aircraft under multiple conflicting decision criteria.

The aim of this study is to solve the problem of aircraft selection in the Air Force. This includes replacing its increasingly ageing fleet, and meeting requirements to combat enemies, terrorist operations, considering diplomatic and economic constraints. Also, it is very important to note that the complex decision problem is inherent in a large number of decision making criteria.

The multiple criteria decision making analysis (MCDMA) method (i.e., compensatory / noncompensatory) is employed to reach an optimum decision solution when faced with multiple alternatives with multiple conflicting (i.e., "benefit" and "cost") and noncommensurable decision criteria [1-7].

From the literature review, it was determined that a number of compensatory MCDMA methods were used to solve military fighter aircraft selection problems [8-10]. In that context, application of TOPSIS in evaluating initial training aircraft under a fuzzy environment was considered for the Taiwan Air Force. The fuzzy multiple criteria decision making analysis method was applied to determine the importance weights of evaluation criteria and to synthesize the ratings of candidate aircraft. Aggregated the evaluators' attitude toward preference; then TOPSIS was employed to obtain a crisp overall performance value for each alternative to make a final decision [11].

Evaluating military training aircrafts problem through the combination of multiple criteria decision making processes with fuzzy logic approach was used to solve a real-life decision problem of interest for the Spanish Air Force.

The Analytic Hierarchy Process (AHP) was used to obtain the weights of the criteria and, through the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), the alternatives were evaluated. The selection of the best military training aircraft was based on a set of decision criteria [12].

The selection of military aircraft problem for the Pakistan Air Force was considered using the Analytic Hierarchy Process (AHP) and Cost Benefit Analysis (CBA). A set of ten technical and economic criteria were applied over six alternative aircraft [13].

Military fighter aircraft selection problem was considered using multiplicative multiple criteria decision making analysis method for evaluating nine alternatives under ten decision criteria [7].

In this study, the technique for order preference by similarity to ideal solution, is used to select a suitable aircraft for this purpose [14-16]. This technique has been successfully applied in resource allocation and estimation. Since aircraft selection is a process closely linked to these areas, the use of this technique makes sense in this case.

The technique for order preference by similarity to ideal solution has been applied specifically in a variety of situations, from extensive decision studies to highly critical defense gains. It has been successfully used as a measure of decision making in the acquisition of defense assets and has been claimed to be an appropriate decision making model for defense acquisitions [14-16].

This is reflected in the solution of this problem by considering the cause, which is a variety of decision criteria including economic, environmental, and technical factors.

Multiple criteria decision making analysis is a process that allows one to make decisions in the presence of multiple, potentially conflicting criteria. Multiple criteria decision making analysis is a class of decision models which deal with decision problems under the presence of a number of multiple, potentially conflicting decision criteria. This class is further divided into multiple objective decision making analysis and multiple attribute decision making analysis. There are several methods in each of the above categories. Priority based, outranking, distance based, and mixed methods are also applied to various problems. Each method has its own characteristics, and the methods can also be classified as deterministic, stochastic, and fuzzy methods. There may be combinations of the above methods [1-7].

Multiple criteria decision making analysis is a field of decision science that makes a comparative study of numerous contradictory criteria in decision making. Contradictory criteria can be quite predictable considering the options: cost or price is often one of the main criteria, and some measure of quality is ideally another one that easily conflicts with cost [17-21].

Therefore, this research paper aims to link objective weights to decision criteria using objective weighting methods and further evaluate using the technique for order preference by similarity to ideal solution method. With fully independent alternatives, the use of the technique may allow for excellent results. Thus, the technique provides an appropriate solution to be implemented on the dataset of the fighter aircraft selection problem.

The proposed methodology is a highly quantitative approach to strategically selecting the fighter aircraft supplier. The advantage of this decision support model is that final ranking is achieved based on evaluation between criteria and alternatives, both selected as part of this study. In addition, this comprehensive quantitative MCDMA approach becomes functional, because its algorithm is rational and easy to comprehend.

This rest of the paper is organized as follows: Section 2 presents methodology of the decision making problem, section 3 indicates application of the multiple criteria decision making analysis to the fighter aircraft selection problem, and section 4 presents conclusion, discussion of results, and future considerations.

## II. Methodology

### A. Technique for Order Preference by Similarity to Ideal Solution

Prioritizing or selecting alternatives from a set of available alternatives with respect to multiple decision criteria, is often referred to multiple criteria decision making analysis (MCDMA). The technique for order preference by similarity to ideal solution (TOPSIS MCDMA model) is used to solve multiple criteria decision making analysis problems based upon the concept that the chosen alternative should have the shortest distance to the positive ideal solution and the longest distance from the negative ideal solution.

For instance, the positive ideal solution maximizes the functionality, and minimizes the cost, whereas the negative ideal solution maximizes the cost and minimizes the functionality. The positive ideal solution consists of all the best achievable values of the criteria, and the negative ideal solution consists of all the worst achievable values of the criteria. In this method, the performance ratings and the weights of the criteria are given as exact values or linguistic variables. The procedural steps of the model are as follows:

Step 1: Establish the decision matrix

$$X = \begin{pmatrix} x_1 \\ \vdots \\ x_i \end{pmatrix} \begin{array}{c} \begin{array}{ccc} g_1 & & g_j \end{array} \\ \begin{pmatrix} x_{11} & \cdots & x_{1j} \\ \vdots & \ddots & \vdots \\ x_{i1} & \cdots & x_{ij} \end{pmatrix}_{ixj} \end{array} \tag{1}$$

where $X_i = (x_1, x_2, ..., x_i)$ denote the set of all the alternatives under evaluation. Assume that the preference of the alternatives $(x_1, x_2, ..., x_i)$ with respect to a single criterion $g_j$ is completely known and measured explicitly.

Step 2: Normalize the decision matrix

$$n_{ij} = \frac{g_j(a_i)}{\sqrt{\sum_{i=1}^{I} g_j(a_i)^2}} \tag{2}$$

$$\begin{cases} i = 1, 2, ..., I \\ j = 1, 2, ..., J \end{cases} \tag{3}$$

where $g_j$ is deterministic value of alternative $i$ for criterion $g_j$. $n_{ij}$ is the normalized criteria values of alternatives.

Step 3: Calculate the weighted normalized decision matrix by multiplying the normalized decision matrix with its associated weights as:

$$u_{ij} = \omega_j n_{ij} \tag{4}$$

Additive MCDMA model

$$U_i^a = \sum_{j=}^{J} \omega_j n_{ij} \tag{5}$$

Multiplicative MCDMA model

$$U_i^m = \prod_{j=1}^{J} \omega_j n_{ij} \tag{6}$$

where $\omega_j$ is the weight of *j*th criterion $g_j$.

Step 4: Identify the positive ideal solution ( $a^*$ ) and negative ideal solution ( $a^{**}$ ).

$$a^* = \left\{u_1^*, ..., u_n^*\right\} = \left\{(\max_i u_{ij} \mid j \in I), (\min_i u_{ij} \mid j \in J)\right\} \tag{7}$$

$$a^{**} = \left\{u_1^{**}, ..., u_n^{**}\right\} = \left\{(\min_i u_{ij} \mid j \in I), (\max_i u_{ij} \mid j \in J)\right\} \tag{8}$$

Step 5: Determine the Euclidean distance of each alternative from the positive and negative ideal solutions.

$$D_i^* = \sqrt{\sum_{j=1}^{J} (u_{ij} - u_j^*)^2} \tag{9}$$

$$D_i^{**} = \sqrt{\sum_{j=1}^{J} (u_{ij} - u_j^{**})^2} \tag{10}$$

Step 6: Calculate the relative closeness coefficient of the *i*th alternative to ideal solution

$$C_i = \frac{D_i^{**}}{D_i^* + D_i^{**}} \tag{11}$$

Step 7: Rank all alternatives based on decreasing values of $C_i$ ( $0 \le C_i \le 1$ ) and selecting the optimal one.

### B. Euclidean Distance MCDMA model

Euclidean distance MCDMA model finds the ideal solution in the feasible region of the *n* dimensional space closest to the optimal point. The procedural steps of the model are as follows:

Step 1: Establish the decision matrix

$$X = \begin{pmatrix} x_1 \\ \vdots \\ x_i \end{pmatrix} \begin{array}{c} \begin{array}{ccc} g_1 & & g_j \end{array} \\ \begin{pmatrix} x_{11} & \cdots & x_{1j} \\ \vdots & \ddots & \vdots \\ x_{i1} & \cdots & x_{ij} \end{pmatrix}_{ixj} \end{array} \tag{12}$$

where $X_i = (x_1, x_2, ..., x_i)$ denote the set of all the alternatives under evaluation. Assume that the preference of the alternatives $(x_1, x_2, ..., x_i)$ with respect to a single criterion $g_j$ is completely known and measured explicitly.

Step 2: Normalize the decision matrix

$$n_{ij} = \frac{g_j(a_i)}{\sqrt{\sum_{i=1}^{I} g_j(a_i)^2}} \tag{13}$$

$$\begin{cases} i = 1, 2, ..., I \\ j = 1, 2, ..., J \end{cases} \tag{14}$$

where $g_j$ is deterministic value of alternative $i$ for criterion $g_j$. $n_{ij}$ is the normalized criteria values of alternatives.

Step 3: Calculate the weighted normalized decision matrix by multiplying the normalized decision matrix with its associated weights as:

$$u_{ij} = \omega_j n_{ij} \tag{15}$$

where $\omega_j$ is the weight of $j$th criterion $g_j$.

Step 4: Identify the optimal ideal solution ( $a^*$ ) vector.

$$a^* = \{u_1^*, ..., u_n^*\} = \{(\max_i u_{ij} \mid j \in I), (\min_i u_{ij} \mid j \in J)\} \tag{16}$$

Step 5: Determine the Euclidean distance of each alternative from the optimal ideal solutions.

$$D_i^* = \sqrt{\sum_{j=1}^{J} (u_j^* - u_{ij})^2} \tag{17}$$

Step 6: Rank the alternatives based on increasing values of $D_i^*$ ( $0 \le D_i^* \le 1$ ) and selecting the optimal one.

### C. *Objective Weighting Methods for Determination of Criteria Weights*

In this study, six objective weighting approaches were chosen to determine decision criteria weights.

#### *a. Mean Index*

The mean index requires minimal knowledge about priorities of criteria and minimal input of decision maker. Mean index is used in multiple criteria decision analysis when there is no information from decision maker or information is not sufficient to reach a decision. The criteria weights are represented as a uniform distribution on the unit.

$$\omega_j = \frac{1}{n}, \; j = 1, ..., n \tag{18}$$

$$\sum_{j=1}^{n} \omega_j = 1, \; \omega_j > 0, \; j = 1, ..., n \tag{19}$$

where $\omega_j$ is the objective weights of attributes which the mean weight method assigns.

#### *b. Variance Index*

The Variance is the average of the squared differences from the Mean ( $\mu_j$ ). The variance procedure determines the objective weights of the attributes. The objective weight ( $\omega_j$ ) of the $j$th criterion is obtained by statistical variance

$$\sigma_j^2 = \frac{1}{m-1} \sum_{i=1}^{m} (n_{ij} - \mu_j)^2 \tag{20}$$

$$\omega_j = \frac{\sigma_j^2}{\sum_{j=1}^{n} \sigma_j^2} \tag{21}$$

$$\sum_{j=1}^{n} \omega_j = 1, \; \omega_j > 0, \; j = 1, ..., n \tag{22}$$

where, $\sigma_j^2$ is the sample variance of the $j$th attribute, $n_{ij}$ is the normalized value of the $j$th attribute corresponding to the $i$th alternative, $m$ is the number of alternatives, $\mu_j$ is the mean value of normalized data $n_{ij}$ of the of the $j$th attribute, and $\omega_j$ is the objective weight of the $j$th criterion (attribute) which statistical variance assigns.

#### *c. Deviation Index*

The Standard Deviation ( $\sigma_j$ ) is the square root of the Variance ( $\sigma_j^2$ ). The standard deviation procedure determines the objective weights of the attributes. The objective weight ( $\omega_j$ ) of the $j$th criterion is obtained by standard deviation

$$\sigma_j = \frac{1}{m-1} \left[ \sum_{i=1}^{m} (n_{ij} - \mu_j)^2 \right]^{1/2} \tag{23}$$

$$\omega_j = \frac{\sigma_i}{\sum_{j=1}^{n} \sigma_j} \tag{24}$$

$$\sum_{j=1}^{n} \omega_j = 1, \; \omega_j > 0, \; j = 1, ..., n \tag{25}$$

where, $\sigma_j$ is the sample variance of the $j$th attribute, $n_{ij}$ is the normalized value of the $j$th attribute corresponding to the $i$th alternative, $m$ is the number of alternatives, $\mu_j$ is the mean value of normalized data $n_{ij}$ of the of the $j$th attribute, and $\omega_j$ is the objective weight of the $j$th criterion which standard deviation assigns.

### d. Standard Index

The Standard Index uses an objective standard deviation approach to determine criteria weights. The procedural steps of the diversity weight method are as follows:

Step 1: Determine the mean values of normalized performances in relation to each criterion in the initial decision matrix $X_i = [x_{ij}]_{mxn}$.

$$\mu_j = \frac{1}{m-1}\sum_{i=1}^{m} n_{ij} \tag{26}$$

Step 2: Determine the value of the deviation

$$\sigma_j = \frac{1}{m-1}\left[\sum_{i=1}^{m}(n_{ij}-\mu_j)^2\right]^{1/2} \tag{27}$$

Step 3: Determine the degree of diversity

$$\delta_j = 1-\sigma_j \tag{28}$$

Step 4: Determine the objective criteria weights

$$\omega_j = \frac{\delta_j}{\sum_{j=1}^{n}\delta_j} \tag{29}$$

$$\sum_{j=1}^{n}\omega_j = 1\ ,\ \omega_j > 0\ ,\quad j = 1,...,n \tag{30}$$

where, $\sigma_j$ is the sample standard deviation of the $j$th attribute, $n_{ij}$ is the normalized value of the $j$th attribute corresponding to the $i$th alternative, $m$ is the number of alternatives, $\mu_j$ is the mean value of normalized data $n_{ij}$ of the of the $j$th attribute, and $\omega_j$ is the objective weight of the $j$th criterion which standard index assigns.

### e. Correlation Index

Correlation index is objective method for determination of criteria weights which includes the intensity of the contrast and the conflict that is contained in the structure of the decision making problem. It belongs to the class of correlation methods and is based on the analytical examination of decision matrix to determine the information contained in the criteria by which the alternatives are evaluated. In addition to the contrast intensity of attribute datasets in the decision matrix, the higher the level of interdependency between attributes, the larger the ranking outcome error.

Correlation index is an objective weighting method which can consider correlations between all given criteria. The correlation analysis method also included the contrast intensities by means of standard deviations of criteria and combined them with the weights from correlations. To determine the criteria contrast, the standard deviation of normalized criterion values by columns and the correlation coefficients of all pairs of columns are used.

Consider an initial decision matrix, $X = \left[x_{ij}\right]_{mxn}$ , where $x_{ij}$ is the performance measure of $i$th alternative with respect to $j$th criterion, $m$ is the number of alternatives and $n$ is the number of criteria. The first step in the application of the correlation coefficients method is to normalize the initial decision matrix using the following equation:

$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \tag{31}$$

where $n_{ij}$ is the normalized criteria value.

In the process of criteria weights determination both standard deviation of the criterion and its correlation between other criteria are included. In this regard, the weight of the $j$th criterion $\omega_j$ is obtained. The objective weight ($\omega_j$) according to the correlation analysis method is expressed based on the characteristic conflict ($R_j$), the correlation of indicators ($\sigma_{jk}$), the amount of information ($C_j$), and the standard deviation ($\sigma_j$). The calculated formulae were as follows:

Step 1: Find the correlation coefficient

$\rho_{jk}$ calculated via the Pearson product-moments represents the correlation between the criteria $j$ and $k$.

$$\rho_{jk} = \frac{\sum_{i=1}^{m}(x_{ij}-\overline{x}_j)(x_{ik}-\overline{x}_k)}{\sqrt{\sum_{i=1}^{m}(x_{ij}-\overline{x}_j)^2\sum_{i=1}^{m}(x_{ik}-\overline{x}_k)^2}}\ ;\ j \text{ and } k = 1,...,n \tag{32}$$

where $m$, $\overline{x}_j$ and $\overline{x}_k$ are the number of alternatives and the average values of criteria $j$ and $k$, respectively. $\rho_{jk}$ close to +1 or -1 indicates highly correlated criteria, while $\rho_{jk}$ close to 0 indicates no correlation.

Step 2: Calculating the characteristic conflict

$$R_j = \sum_{j=1}^{n}(1-\rho_{jk}) \tag{33}$$

Step 3: Calculating the amount of information

$C_j$ is the quantity of information contained in $j$th criterion

$$C_j = \sigma_j R_j = \sigma_j \sum_{j=1}^{n} (1-\rho_{jk}) \quad (34)$$

Step 4: Calculating the objective criteria weights

$$\omega_j = \frac{C_j}{\sum_{j=1}^{n} C_j} \quad (35)$$

$$\omega_j = \frac{C_j}{\sum_{j=1}^{n} C_j} = \frac{\sigma_j \sum_{k=1}^{n} (1-\rho_{jk})}{\sum_{j=1}^{n} (\sigma_j \sum_{k=1}^{n} (1-\rho_{jk}))}; \; j \text{ and } k = 1,\dots,n \quad (36)$$

The objective weight of the $j$th criterion ($\omega_j$) is obtained.

*f. Entropy Index*

In multiple criteria decision analysis, entropy relates to the degree of diversity within an attribute dataset. The greater the degree of the diversity, the higher the weight of that attribute.

In another words, the smaller the entropy within the data associated to an attribute, the greater the discrimination power of the attribute in changing ranks of alternatives. Entropy relates to incomplete information because it relates to the number of possible alternative results for a physical system after all the macroscopically observable information is recorded. The procedural steps for calculation of Entropy weights are as follows.

Step 1: Normalizing the decision matrix

Since measured data under different criteria can be of different units or scales, a given decision matrix should be first transformed into a dimensionless space:

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}}, \; i = 1,2,\dots,m, \; j = 1,\dots,n \quad (37)$$

where $x_{ij}$ is an element of the decision matrix corresponding to the $i$th alternative and the $j$th criterion. $m$ is the total number of alternatives, and $n$ is the number of criteria.

Step 2: Calculation of the entropy ($e_j$) and the degree of diversity ($d_j$)

Entropy within the datasets of the normalized decision matrix for the $j$th criterion can be calculated

$$e_j = -\frac{1}{\ln(m)} \sum_{i=1}^{m} p_{ij} \ln p_{ij} \quad (38)$$

The degree of diversity ($d_j$) is then calculated as

$$d_j = 1 - e_j \quad (39)$$

Step 3: Calculation of objective weights ($\omega_j$)

The linear normalization of $d_j$ to find the relative objective weight of each criterion:

$$\omega_j = \frac{d_i}{\sum_{j=1}^{n} d_j} \quad (40)$$

$$\sum_{j=1}^{n} \omega_j = 1, \; \omega_j > 0, \; j = 1,\dots,n \quad (41)$$

where $\omega_j$ is the objective weight of the $j$th criterion which entropy method assigns.

## III. Application

In this section, to demonstrate the applicability of the multiple criteria decision analysis technique on fighter aircraft selection problem, six objective weighting procedures (Mean Index (MI), Variance Index (VI), Deviation Index (DI), Standard Index (SI), Correlation Index (CI), and Entropy Index (EI)) are considered to conduct the sensitivity analysis.

Six decision attributes ($g_1$, $g_2$, $g_3$, $g_4$, $g_5$, $g_6$) are the beneficial criteria where higher values are desirable. Considering these evaluation criteria, the decision problem determines the optimum alternative from the selected three alternatives.

When purchasing fighter aircraft according to the following decision criteria a) maximum speed (Mach number) ($g_1$); b) service ceiling (km) ($g_2$); c) combat range (km) ($g_3$); d) maximum takeoff weight (kg.) ($g_4$); d) reliability (linguistic variable (high-low)) ($g_5$) and f) maneuverability (linguistic variable (high-low)) ($g_6$) for the protection of a country, it is considered to select the best. The definitions of fighter aircraft decision criteria are given in Table 1.

Based on these decision criteria, three models of fighter aircraft such as a) Su-35 ($a_1$), b) F-35 ($a_2$), and c) TF-X (MMU) ($a_3$) were evaluated with respect to two test aircraft $a^*$ (best) and $a^{**}$ (worst) as shown in Table 2. Acquisition cost was excluded from the evaluation criteria set as it is frequently subject to changing global military aviation market conditions.

Table 1. Definitions of Fighter Aircraft Decision Criteria

| Decision Criteria | Definition |
|---|---|
| Maximum speed ( $g_1$ ) | Maximum speed is the maximum operating speed of aircraft in Mach number. |
| Service ceiling ( $g_2$ ) | Service ceiling (km) means the maximum height at which a particular type of aircraft can sustain a specified rate of climb. |
| Combat range ( $g_3$ ) | Combat range (km) refers to the maximum distance an aircraft can travel away from its base along a given course with normal load and return without refueling. Combat range is always smaller than maximum range. |
| Maximum takeoff weight (MTOW) ( $g_4$ ) | Maximum takeoff weight (MTOW) (kg) is the maximum weight allowed to attempt to take off, due to structural or other limits. |
| Reliability ( $g_5$ ) | Aircraft reliability is the ability to perform a required function under given conditions for a given time interval. |
| Maneuverability ( $g_6$ ) | Maneuverability is defined as the ability to change the speed and flight direction of a military fighter aircraft. |

Table 2. Decision Matrix of the Fighter Aircraft Selection Problem

| | Criteria | $g_1$ | $g_2$ | $g_3$ | $g_4$ | $g_5$ | $g_6$ |
|---|---|---|---|---|---|---|---|
| | Optimization | max | max | max | max | max | max |
| Fighter Aircraft | $a_1$ | 2,25 | 18000 | 1600 | 34500 | H | VH |
| | $a_2$ | 1,6 | 15000 | 1093 | 31751 | VH | H |
| | $a_3$ | 1,8 | 17000 | 1100 | 27215 | VH | VH |
| | $a^*$ | 2,5 | 20000 | 1700 | 35000 | EH | EH |
| | $a^{**}$ | 1,5 | 14500 | 1000 | 25000 | EL | EL |

The linguistic variable ratings of reliability and maneuverability criteria were converted from linguistic variables to crisp values using corresponding conversion values in Table 3.

Table 3. Conversion of linguistic variables to crisp values

| Linguistic Variable | Crisp Value |
|---|---|
| Extremely Low, EL | 1 |
| Very Low, VL | 2 |
| Low, L | 3 |
| Average, A | 4 |
| High, H | 5 |
| Very High, VH | 6 |
| Extremely High, EH | 7 |

The objective weights of the decision criteria with respect to each related performance measurement were calculated by each weighting approach and the obtained results are illustrated in Table 4 to use in the MCDMA technique steps. The decision criteria weights determined by the six objective weighting methods are given in Fig. 1.

Table 4. Objective Weights of Evaluation Criteria

| Method | $g_1$ | $g_2$ | $g_3$ | $g_4$ | $g_5$ | $g_6$ |
|---|---|---|---|---|---|---|
| Optimization | max | max | max | max | max | max |
| Mean Index (MI) | 1/6 | 1/6 | 1/6 | 1/6 | 1/6 | 1/6 |
| Variance Index (VI) | 0,0917 | 0,0336 | 0,1149 | 0,0395 | 0,3601 | 0,3601 |
| Deviation Index (DI) | 0,1362 | 0,0824 | 0,1524 | 0,0894 | 0,2698 | 0,2698 |
| Standard Index (SI) | 0,1708 | 0,1781 | 0,1686 | 0,1772 | 0,1527 | 0,1527 |
| Correlation Index (CI) | 0,1339 | 0,1406 | 0,1563 | 0,1720 | 0,2396 | 0,1576 |
| Entropy Index (EI) | 0,0664 | 0,0239 | 0,0835 | 0,0288 | 0,3987 | 0,3987 |

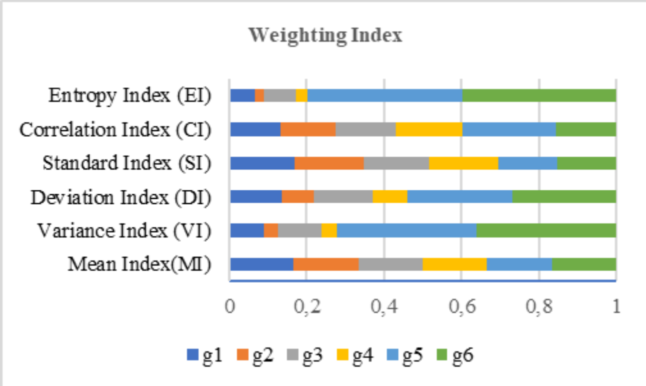


Fig. 1 Decision criteria weights determined by the weighting methods

Following the application of the proposed method to the fighter aircraft selection problem, the final ranking results obtained using the multiple criteria decision making analysis technique with TOPSIS MCDMA model, Euclidean Distance MCDMA model, Additive MCDMA model, and Multiplicative MCDMA model, and the six weighting methods are given in Table 5-Table 8, respectively.

The ranking results given in Table 5-Table 8 also reflect the rankings of the alternatives when the proposed method and the weights obtained according to different weight determination methods are used.

Table 5. Final Ranking Order of the Fighter Aircraft TOPSIS MCDMA Model

| Ranking Order in Weighting Index | | | | | | | |
|---|---|---|---|---|---|---|---|
| Weighting Index | MI | 2 | 4 | 3 | 1 | 5 | Ranking Order |
| | VI | 3 | 4 | 2 | 1 | 5 | |
| | DI | 3 | 4 | 2 | 1 | 5 | |
| | SI | 2 | 4 | 3 | 1 | 5 | |
| | CI | 2 | 4 | 2 | 1 | 5 | |
| | EI | 3 | 4 | 2 | 1 | 5 | |
| Fighter Aircraft | | $a_1$ | $a_2$ | $a_3$ | $a^*$ | $a^{**}$ | |

Table 6. Final Ranking Order of the Fighter Aircraft
Euclidean Distance MCDMA Model

| Weighting Index | Ranking Order in Weighting Index | | | | | Ranking Order |
|---|---|---|---|---|---|---|
| MI | 2 | 4 | 3 | 1 | 5 | |
| VI | 3 | 4 | 2 | 1 | 5 | |
| DI | 3 | 4 | 2 | 1 | 5 | |
| SI | 2 | 4 | 3 | 1 | 5 | |
| CI | 2 | 4 | 2 | 1 | 5 | |
| EI | 3 | 4 | 2 | 1 | 5 | |
| Fighter Aircraft | $a_1$ | $a_2$ | $a_3$ | $a^*$ | $a^{**}$ | |

Table 7. Final Ranking Order of the Fighter Aircraft
Additive MCDMA Model

| Weighting Index | Ranking Order in Weighting Index | | | | | Ranking Order |
|---|---|---|---|---|---|---|
| MI | 2 | 4 | 3 | 1 | 5 | |
| VI | 2 | 4 | 3 | 1 | 5 | |
| DI | 2 | 4 | 3 | 1 | 5 | |
| SI | 2 | 4 | 3 | 1 | 5 | |
| CI | 2 | 4 | 3 | 1 | 5 | |
| EI | 3 | 4 | 2 | 1 | 5 | |
| Fighter Aircraft | $a_1$ | $a_2$ | $a_3$ | $a^*$ | $a^{**}$ | |

Table 8. Final Ranking Order of the Fighter Aircraft
Multiplicative MCDMA Model

| Weighting Index | Ranking Order in Weighting Index | | | | | Ranking Order |
|---|---|---|---|---|---|---|
| MI | 2 | 4 | 3 | 1 | 5 | |
| VI | 2 | 4 | 3 | 1 | 5 | |
| DI | 2 | 4 | 3 | 1 | 5 | |
| SI | 2 | 4 | 3 | 1 | 5 | |
| CI | 2 | 4 | 3 | 1 | 5 | |
| EI | 3 | 4 | 2 | 1 | 5 | |
| Fighter Aircraft | $a_1$ | $a_2$ | $a_3$ | $a^*$ | $a^{**}$ | |

In terms of sensitivity analysis, the ranking results from TOPSIS MCDMA Model (Table 5), and Euclidean Distance MCDMA Model (Table 6) were the same due to the similar distance algorithms. As expected, the best $a^*$ and worst $a^{**}$ test fighter aircraft got the first ranking order, and last ranking order in the multiple criteria analysis. However, alternative $a_2$, F-35, got the worst ranking order in the real fighter aircraft set.

Also, it is worth mentioning that VI, DI, and EI weighting indices favored $a_3$ the optimal fighter aircraft, whilst MI, SI, and CI weighting indices favored $a_1$ as the optimal fighter aircraft as given in Table 5 and Table 6 respectively. This effect of the weighting indices in the sensitivity analysis procedure is given in Table 9, using correlation analysis for the Pearson correlation coefficient / the Spearman rank correlation coefficient.

Table 9. Correlation Analysis for the Pearson Correlation Coefficient / the Spearman Rank Correlation Coefficient

| | *MI* | *VI* | *DI* | *SI* | *CI* | *EI* |
|---|---|---|---|---|---|---|
| MI | 1 | | | | | |
| VI | 0,9 | 1 | | | | |
| DI | 0,9 | 1 | 1 | | | |
| SI | 1 | 0,9 | 0,9 | 1 | | |
| CI | 0,96 | 0,96 | 0,96 | 0,96 | 1 | |
| EI | 0,9 | 1 | 1 | 0,9 | 0,96 | 1 |

By the same token, the ranking results from Additive MCDMA Model (Table 7), and Multiplicative MCDMA Model (Table 8) were the same but yielded different ranking results from the TOPSIS MCDMA Model (Table 5), and Euclidean Distance MCDMA Model (Table 6). Again, as expected, the best $a^*$ and worst $a^{**}$ test fighter aircraft got the first ranking order, and last ranking order in the multiple criteria analysis. However, alternative $a_2$, F-35, got the worst ranking order in the real fighter aircraft set. Alternative $a_1$, Su-35, the got the optimal ranking order, whilst alternative $a_3$, TF-X (MMU), got the second ranking order, in the real fighter aircraft set.

Consequently, this effect of the weighting indices in the sensitivity analysis procedure is also given in Table 10, using correlation analysis for the Pearson correlation coefficient / the Spearman rank correlation coefficient.

Table 10. Correlation Analysis for the Pearson Correlation Coefficient / the Spearman Rank Correlation Coefficient

| | *MI* | *VI* | *DI* | *SI* | *CI* | *EI* |
|---|---|---|---|---|---|---|
| MI | 1 | | | | | |
| VI | 1 | 1 | | | | |
| DI | 1 | 1 | 1 | | | |
| SI | 1 | 1 | 1 | 1 | | |
| CI | 1 | 1 | 1 | 1 | 1 | |
| EI | 0,9 | 0,9 | 0,9 | 0,9 | 0,9 | 1 |

## IV. Conclusion

Multiple criteria decision making analysis is a well-established, and defined as the scientific process of transforming data into insights to making better decisions in operations research. In this study, a comprehensive MCDMA method was employed to determine the best fighter aircraft among a set of alternatives for the Air Force. The proposed method has advantages over other MCDMA techniques because it requires a lesser of computational complexity, and the result obtained is more consistent.

The literature review determined six decision criteria to evaluate fighter aircraft, and six objective weighting methods were used throughout as decision making process to acquire the final objective weight values of the criteria, while the reliable MCDMA method was used to derive the final ranking of fighter aircrafts with respect to criteria.

Sensitivity analysis was conducted, and the result was compared with the other MCDMA methods to endorse the robustness of the proposed method. Also, it was demonstrated that the proposed method provided reliable ranking results.

As a given result of the decision making analysis process, the Su-35 was the best suitable solution, followed closely by TF-X (MMU). The Su-35 ranks higher than both the F-35 and TF-X (MMU) in some technical parameters. Therefore, the Su-35 can be considered a more suitable fighter aircraft, as it meets the technical requirements, and real-life Air Force conditions.

In this study, the MCDMA model was presented to compare performance among three alternatives under six decision criteria. This method allows finding the ranking order of alternatives ranging from the best to the worst.

To illustrate the proposed method a realistic case involving fighter aircraft selection problem is presented. The ranking results show the effectiveness of the method. In terms of computational burden, the MCDMA model consists of a reliable computation procedure, which encourages researcher in different areas of knowledge to use it. It is important to note that the MCDMA model is a well-stablished and reliable method. For the future research, the problem can be solved by other MCDMA techniques, and the solutions can be compared. This MCDMA study can be considered as a reference for future studies on determining the efficiency of the fighter aircraft selection model.

## References

[1] Ardil, C., Bilgen, S. (2017) Online Performance Tracking. SocioEconomic Challenges, 1(3), 58-72.

[2] Ardil, C. (2018) Multidimensional Performance Tracking. International Journal of Computer and Systems Engineering, Vol:12, No:5,320-349

[3] Ardil, C. (2018) Multidimensional Compromise Optimization for Development Ranking of the Gulf Cooperation Council Countries and Turkey. International Journal of Mathematical and Computational Sciences Vol:12, No:6, 131-138.

[4] Ardil, C. (2018) Multidimensional Compromise Programming Evaluation of Digital Commerce Websites. International Journal of Computer and Information Engineering Vol:12, No:7, 556-563.

[5] Ardil, C. (2018) Multicriteria Decision Analysis for Development Ranking of Balkan Countries. International Journal of Computer and Information Engineering Vol:12, No:12, 1118-1125.

[6] Ardil, C. (2019) Scholar Index for Research Performance Evaluation Using Multiple Criteria Decision Making Analysis. International Journal of Educational and Pedagogical Sciences, Vol:13, No:2, 93-105.

[7] Ardil, C. (2019) Military Fighter Aircraft Selection Using Multiplicative Multiple Criteria Decision Making Analysis Method. International Journal of Mathematical and Computational Sciences, 13(9), 184 - 193.

[8] Velasquez, M., Hester, P. T. (2013) An Analysis of Multi-Criteria Decision Making Methods. International Journal of Operations Research Vol. 10, No. 2, p.56-66.

[9] Mardani, A., Jusoh, A., Nor, K. MD., Khalifah, Z., Zakwan, N., Valipour, V. (2015) Multiple criteria decision-making techniques and their applications – a review of the literature from 2000 to 2014. Economic Research-Ekonomska Istraživanja, 28:1, p. 516-571.

[10] Mardani, A., Zavadskas, E. K., Khalifah, Z., Jusoh, A., Nor, K. MD. (2016) Multiple criteria decision-making techniques in transportation systems: a systematic review of the state of the art literature, Transport, 31:3, p.359-385.

[11] Wang Tien-Chin, Chang Tsung-Han (2007) Application of TOPSIS in evaluating initial training aircraft under a fuzzy environment. Expert Systems with Applications, 33, 870–880.

[12] Sánchez-Lozano, J.M., Serna, J., Dolón-Payán, A. (2015) Evaluating military training aircrafts through the combination of multi-criteria decision making processes with fuzzy logic. A case study in the Spanish Air Force Academy. Aerospace Science and Technology, 42, 58-65.

[13] Ali, Y., Muhammad, N., Salman, A. (2017) Selection of a fighter aircraft to improve the effectiveness of air combat in the war on terror: Pakistan air force - a case in point. International Journal of the Analytic Hierarchy Process, 9(2). https://doi.org/10.13033/ijahp.v9i2.489

[14] Hwang, C.L., Yoon, K. (1981) Multiple Attribute Decision Making: Methods and Applications, Springer-Verlag, Heidelberg.

[15] Lai, Y.J., Hwang, C.L. (1994) Fuzzy Multiple Objective Decision Making: Methods and Applications. Springer-Verlag, Berlin.

[16] Lai, Y., Liu, T., Hwang, C. (1994) TOPSIS for MODM. European Journal of Operational Research, 76, 486-500.

[17] Chris Tofallis (2014) Add or Multiply? A Tutorial on Ranking and Choosing with Multiple Criteria. INFORMS Transactions on Education 14(3):109-119. https://doi.org/10.1287/ited.2013.0124

[18] Choo, E., Schoner, B., Wedley, W. (1999) Interpretation of criteria weights in multicriteria decision making. Computers & Industrial Engineering, 37, 527-541.

[19] Vafaei, N., Ribeiro, R.A.,Camarinha-Matos, L. (2018) Data normalisation techniques in decision making: case study with TOPSIS method. Int. J. Inf. Decis. Sci., 10, 19-38.

[20] Zavadskas, E., Turskis, Z. (2008) A New Logarithmic Normalization Method in Games Theory. Informatica, 19, 303-314.

[21] Yager, R. (2004) Decision making using minimization of regret. Int. J. Approx. Reason., 36, 109-128.