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AN EXTENDED SINGLE-VALUED NEUTROSOPHIC AHP AND MULTIMOORA METHOD TO EVALUATE THE OPTIMAL TRAINING AIRCRAFT FOR FLIGHT TRAINING ORGANIZATIONS

Çağlar Karamaşa[1], Darjan Karabasevic[2], Dragisa Stanujkic[3], Alireza Rezanezhad Kookhdan[4], Arunodaya Raj Mishra[5], Mehmet Ertürk[6]

[1]Faculty of Business, Department of Business Administration, Anadolu University, Eskişehir, Turkey
[2]Faculty of Applied Management, Economics and Finance, University Business Academy in Novi Sad, Belgrade, Serbia
[3]Technical Faculty in Bor, University of Belgrade, Serbia
[4]Faculty of Management, Islamic Azad University Arak Branch, Arak
[5]Department of Mathematics, Govt College Jaitwara, Satna, India
[6]Faculty of Aviation and Aeronautical Sciences, Department of Civil Aviation Management, Özyeğin University, Istanbul, Turkey

Abstract. *Aircraft's training is crucial for a flight training organization (FTO). Therefore, an important decision that these organizations should wisely consider the choice of aircraft to be bought among many alternatives. The criteria for evaluating the optimal training aircraft for FTOs are collected based on the survey approach. Single valued neutrosophic sets (SVNS) have the degree of truth, indeterminacy, and falsity membership functions and, as a special case, neutrosophic sets (NS) deal with inconsistent environments. In this regard, this study has extended a single-valued neutrosophic analytic hierarchy process (AHP) based on multi-objective optimization on the basis of ratio analysis plus a full multiplicative form (MULTIMOORA) to rank the training aircraft as the alternatives. Moreover, a sensitivity analysis is performed to demonstrate the stability of the developed method. Finally, a comparison between the results of the developed approach and the existing approaches for validating the developed approach is discussed. This analysis shows that the proposed approach is efficient and with the other methods.*

Key Words: *Training Aircraft Selection, Neutrosophic Sets, Flight Training Organization, Civil Aviation, AHP, MULTIMOORA*

1. Introduction

Aircraft selection offers complex objectives that do not allow the decision-making approach to use only one variable [1-5]. Among other reasons, a multi-criteria approach becomes necessary when the number of objectives to be met is greater than or equal to two, and they are contradictory [6]. A good first training aircraft is vital for the success of flight training, so the performance of the first training aircraft is an important factor [7]. The selection of aircraft has historically been of great interest and considerable research effort [8]. For various reasons, most of the published reports have made a choice for military pilot training, although the entire military training is directly applicable to civil aviation [9]. In order to solve the aircraft type selection problem, the anticipated demand for the routes considered and operated by the same aircraft types is taken as input data [10]. The critical problem in this assessment is the selection of an aircraft, as this represents the main part of the required investment [11].

Airlines create much more value than other components of the airline industry as a growing service sector and have the lowest return on capital ratio. Airline companies are mostly affected by increased competition in the past decades. Generally, most aircraft are expected to have a service life of 30 years or more, but several uncertainties could affect the viability and applicability of the aircraft during its service life. For example, the price of fuel is always affected by the economic situation. The load factor changes throughout the year. Therefore, these economic uncertainties need to be taken into consideration when deciding to purchase new aircraft for an organization [12].

Aircraft selection can be taken as the most important investment decision for airline companies due to having an effect on the type and quality of services presented to customers [13]. Aircraft selection is a complex system engineering that includes aircraft parameters, engine performance, communication and navigation technology, flight dynamics, meteorology, art design, financial management, and corporate strategic planning [14]. Therefore, all these variables should be taken into consideration when selecting training aircraft. Neutrosophic Sets (NS) having the degree of truth, indeterminacy, and falsity membership functions as totally independent are introduced by Smarandache [15] for explaining decision-makers ambiguity and inconsistent judgments. Studies composed of neutrosophic sets based on multi-criteria decision-making methods have increased and gained importance in the last decades. The idea of the proposed method is to extend the Analytic Hierarchy Process (AHP) based Multi-Objective Optimization on the Basis of Ratio Analysis plus a full multiplicative form (MULTIMOORA) approach via single-valued neutrosophic sets and show the applicability on aircraft selection as a Multiple Criteria Decision Making (MCDM) problem.

Training plane assessment has always been a big issue for flight training academies. Right aircraft selection is very important for both organizations and practitioners. Although the selection of the optimal training aircraft for flight training organizations (FTOs) is a crucial concept, a few previous studies highlighted this issue in the literature. Therefore, a novel approach using AHP-MULTIMOORA is developed with SVNS and applied for aircraft selection problems by considering the decision-makers truth, indeterminacy, and falsity judgments in the real-life environment. Sensitivity analysis and comparison with previous methods are executed to show the strength of the approach. For this purpose, SVNS, as a case of NS is used with an integrated approach. In addition, an

aircraft selection problem is handled for showing the approach and presented the performance in practical MCDM problems. Sensitivity analysis is executed for the visual presentation of the outcome. Finally, a comparison is made for showing the strengths of the results. The major outcomes of the paper can be summarized as follows:

The rest of this study is organized in the following sections. In the first part information related to flight training organizations and the issue of optimal training aircraft selection is presented. Literature review related to training plane selection in terms of multi-criteria decision-making methods is expressed in the second section. A single-valued neutrosophic AHP and neutrosophic MULTIMOORA are stated under methodology in the third section. The results of the analysis and findings are presented in the fourth section. Finally, conclusions and future suggestions are given in the last section.

2. LITERATURE REVIEW

In past decades, several published papers in aircraft selection have used different decision-making approaches related to classical and fuzzy sets. Therefore, a detailed literature review related to the application of conventional and fuzzy decision-making methods in the area of aircraft selection is presented in Table 1.

AHP [30] and MULTIMOORA [31], as MCDM approaches have been widely applied to various realistic problems. The classical AHP and MULTIMOORA methods have been handled for overcoming MCDM problems in various environments. The summary of the available study on AHP and MULTIMOORA approaches is depicted in Table 2.

According to Tables 1 and 2, there is no study examining the decision problem by using AHP based MULTIMOORA method from single-valued neutrosophic sets. That shows the originality and novelty of this method for the application of training aircraft selection. Decision-makers can explain their indeterminate and uncertain judgments more flexibly and efficiently than classical, fuzzy, hesitant, and intuitionistic sets. AHP as a subjective weighting method is selected for prioritizing the importance values of criteria due to considering the inconsistency for decision-makers' judgments and presenting more realistic and practical results for real-world uncertain decision-making problems. MULTIMOORA as a robust alternative ranking method is handled because of making a decision based on the dominance of three approaches.

Fuzzy sets (FSs) doctrine originated by Zadeh [52], has widely been utilized to cope with the uncertainty that occurred in several fields. In recent times, several extensions of FSs such as interval-valued fuzzy sets (IVFSs) [53], intuitionistic fuzzy sets (IFSs) [54], Pythagorean fuzzy sets (PFSs) [55], and q-rung orthopair fuzzy sets (q-ROFSs) [56] have been introduced and implemented in the field of pattern recognition, decision-making, medical diagnosis, etc. [57-59]. However, the notions of FS and its generalizations can only handle incomplete and uncertain information but are unable to tackle the indeterminate and inconsistent information that arises in real-life issues. To handle this concern, Smarandache [15] pioneered the idea of neutrosophic set (NS) for describing incomplete, indeterminate and inconsistent information, which is a branch of philosophy as well as a mathematical tool for studying the origin, nature, and scope of neutralities. NS is characterized by the truth-membership, indeterminacy-membership and falsity-membership functions, which are totally independent and lying in $]0^-,1^+[$. For example,

Table 1 Outline of the relevant research studies on aircraft selection

Author(s)	Benchmark	Environment
See and Lewis [16]	Multiattribute Decision-Making methods	Classical sets
Wang and Chang [7]	The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method	Fuzzy Sets
Yeh and Chang [17]	A new method for modeling group subjective evaluation with absolute judgments	Fuzzy Sets
Özdemir et al. [18]	Analytic Network Process (ANP)	Classical sets
Dozic and Kalic [8]	AHP and sensitivity analysis	Classical Sets
Gomes et al. [11]	Novel Approach to Imprecise Assessment and Decision Environments (NAIADE) method	Fuzzy Sets
Bruno et al. [19]	AHP	Fuzzy Sets
Kannan et al. [20]	Novel framework using TOPSIS	Fuzzy Sets
Dozic and Kalic [10]	AHP and Even Swaps Method (ESM)	Classical set
Lozano et al. [21]	AHP and TOPSIS	Fuzzy Sets
Göleç et al. [22]	AHP, Simple Additive Weighting (SAW), ELimination and Choice Expressing REality (ELECTRE) and TOPSIS	Classical sets
Ozdemir and Basligil [23]	ANP and Generalized Choquet Integral	Fuzzy sets
Yurdusevimli and Ozger[24]	AHP and TOPSIS	Classical sets
Dozic et al. [1]	Fuzzy AHP and Logarithmic Fuzzy Preference Programming (LFPP)	Fuzzy Sets
Kiracı and Bakir[25]	AHP, Complex Proportional Assessment (COPRAS) and Multi-Objective Optimization Method by Ratio Analysis (MOORA)	Classical sets
Ilgın[13]	Linear Physical Programming	Classical sets
Maywald et al. [4]	Multi-step heuristic algorithm	Classical sets
Durmaz and Gencer[26]	SWARA and SMAA-2	Classical sets
Kiracı and Akan [27]	AHP and TOPSIS	Interval type-2 fuzzy sets
Sanchez-Lozano and Rodriguez [6]	AHP and Reference Ideal Method	Fuzzy sets
Ahmed et al. [28]	AHP and efficacy method	Fuzzy sets
Hoan and Ha [29]	ARAS and FUCOM	Classical sets

assume that 10 voters are taking part in a voting process. Suppose four votes are ''yes'', two votes are ''no'' and three are undecided. In neutrosophic sense, it can be expressed as (0.4, 0.3, 0.2), which is beyond the scope of IFS. According to Smarandache [60], it is the generalized concept of FS, IFS, IVIFS, PFS, q-ROFS, PiFS, Ternary fuzzy set (TFS), Spherical fuzzy set (SFS) and n-Hyper Spherical fuzzy set (n-HSFS). As the NS is a more suitable tool to capture the incomplete, indeterminate and inconsistent information, it has been widely utilized for several purposes [61-63].

However, without a specific description, it is difficult to implement the NSs to scientific and engineering problems as the truth-membership, indeterminacy-membership and falsity-membership functions lie in $]0^-,1^+[$.To overcome this limitation, Wang et al. [64] originated the doctrine of single-valued neutrosophic sets (SVNSs), whose values belong to [0, 1]. SVNSs can be considered as a subclass of NSs. It provides us an additional possibility to represent imprecise, incomplete, uncertain and inconsistent information, which exists in real-world. The notion of SVNS has been proven as one of

Table 2 Outline of several of the relevant research studies on AHP and MULTIMOORA methods

Author(s)	Benchmark	Application(s)
Brauers and Zavadskas [32]	MULTIMOORA method	Decide upon a bank loan to buy property
Balezentis and Zeng [33]	MULTIMOORA extended with type- 2 fuzzy sets	Personnel selection
Aksoy et al. [34]	AHP based MULTIMOORA and COPRAS	Evaluating the performance of Turkish Coal Enterprises
Hafezalkotob et al. [35]	Interval weighted MULTIMOORA	Materials selection of power gears
Karabasevic et al. [36]	MULTIMOORA and Step-wise Weight Assessment Ratio Analysis (SWARA)	Selection of a candidate for the position of the mining engineer for underground mining
Zavadskas et al. [37]	SWARA and MULTIMOORA with single-valued neutrosophic set	Selection of single-family house elements and materials
Fattahi and Khalilzadeh[38]	Failure mode and effects analysis (FMEA), MULTIMOORA, AHP under fuzzy environment	Risk evaluation of steel industries factory
Maghsoodi et al. [39]	MULTIMOORA integrated Shannon's entropy	Selection of the best performance appraisal methods
Wang et al. [40]	MULTIMOORA and Choquet integral with triangular fuzzy numbers	Fine-Kinney based risk evaluation of ballast tank maintenance
Zarch et al. [41]	SWARA based fuzzy MULTIMOORA method	Pharmacological therapy selection of type 2 diabetes
Liang et al. [42]	SWARA based MULTIMOORA with linguistic neutrosophic numbers	Mining method selection
Dorfeshan et al. [43]	MULTIMOORA, MOOSRA, and TPOP with interval type-2 fuzzy sets	Selection of project critical path for aircraft prototype batch and construction project
Liao et al. [44]	Unbalanced hesitant fuzzy linguistic MULTIMOORA	Investment selection case related to shared bicycles in China
Gündoğdu[45]	Spherical fuzzy MULTIMOORA	Personnel selection
Lin et al. [46]	Picture fuzzy MULTIMOORA	Site selection for car sharing stations in Beijing
Asante et al. [47]	MULTIMOORA-EDAS	Exploring and ranking the barriers to renewable energy adoption for Ghana
Rahimi et al. [48]	Fuzzy BWM, MULTIMOORA and GIS	Selecting sustainable landfill site for municipal solid waste in Iran
Tavana et al. [49]	FAHP, fuzzy MULTIMOORA	Assessing supply chain risk-benefit and supplier selection for a manufacturer of consumer electronic goods in New Jersey
Wu et al. [50]	Cloud model theory based MULTIMOORA	Determining the ranking order of engineering characteristics for electric vehicle manufacturing organization
Tanrıverdi and Lezki[51]	FAHP based FTOPSIS	Determining the best competition strategy for air cargo carriers

the flexible ways for solving group decision-making (GDM) problems. For instance, Liu et al. [63] suggested a novel GDM model based on DEMATEL approach with SVNSs for evaluating the transport service providers. Pamučar and Božanić [65] evaluated the location for the logistics center by employing single-valued neutrosophic MABAC model. Rani and Mishra [66] designed an integrated decision-making framework based on SWARA and VIKOR approaches with SVNSs and applied to deal with eco-industrial thermal power plants. Apart from these studies, several aggregation operators [67], information measures [68-69], and decision-making methods [70] have been developed in the context of SVNSs. However, there is no study in the literature regarding the evaluation of the optimal training aircraft for flight training organizations under SVNSs environment.

3. METHODOLOGY

3.1 Neutrosophic Set

The fuzzy sets, proposed by Zadeh [52], use the membership function for dealing with complex decision-making problems that are associated with inaccuracies and unreliability. Some limitations associated with the use of one membership function are eliminated by using two functions: the membership function and the non-membership function, which is considered in intuitionistic and bipolar fuzzy sets. Neutrosophic Sets (NS) are proposed by Smarandache [15] with the degree of truth, indeterminacy, and falsity membership functions that are independent. Neutrosophic sets use three membership functions that can be used for expressing accuracy, indeterminacy, and inaccuracy during the evaluation of alternatives in multiple criteria decision-making. Using these membership functions, neutrosophic sets provide an efficient and flexible approach for evaluating alternatives even if decision-making problems are related to uncertainty and predictions.

A universe of discourse can be symbolized as U and $x \in U$. N as an NS can be identified by a truth $T_N(x)$ an indeterminacy $I_N(x)$ and falsity membership functions $F_N(x)$, and is shown like $N=\{<x:T_N(x), I_N(x),F_N(x)>x \in U\}$. Also, the functions of $T_N(x), I_N(x)$ and $F_N(x)$ are real standard or real nonstandard subsets of $]0^-,1^+[$ and can be shown like $T,I,F:U \rightarrow]0^-,1^+[$. The sum of the functions of $T_N(x), I_N(x)$ and $F_N(x)$ can be written as $0^- \leq supT_N(x)+supI_N(x)+supF_N(x) \leq 3^+$.

The complement of an NS N is represented by N^C and described as below:

$$T_N^C(x) = 1^+ \ominus T_N(x), \tag{1}$$

$$I_N^C(x) = 1^+ \ominus I_N(x), \tag{2}$$

$$F_N^C(x) = 1^+ \ominus F_N(x) \text{ for all } x \in U. \tag{3}$$

N as NS is contained in other NS P represents, $N \subseteq P$ if and only if $infT_N(x) \leq infT_P(x)$, $supT_N(x) \leq supT_P(x)$, $infI_N(x) \geq infI_P(x)$, $supI_N(x) \geq supI_P(x)$, $infF_N(x) \geq infF_P(x)$, $supF_N(x) \geq supF_P(x)$ for all $x \in U$ [71].

3.2 Single valued neutrosophic sets (SVNS)

SVNS are proposed by Wang et al. [64] for solving real-life problems in an uncertain environment. The interval of [0,1] are considered for real-life applications rather than $]0^-,1^+[$. A universe of discourse can be symbolized as U and $x \in U$. A SVNS B in U can be identified by a truth $T_B(x)$, an indeterminacy $I_B(x)$ and falsity membership functions $F_B(x)$. A SVNS B can be shown as $B = \int_x < T_B(x), I_B(x), F_B(x) > / x : x \in U$ for continuous values of U. On the other hand, an SVNS B can be written as $B = \sum_{i=1}^{n} \int_x < T_B(x), I_B(x), F_B(x) > / x_i : x_i \in U$ for discrete values of U[72]. $T_B(x)$, $I_B(x)$ and $F_B(x)$ functions are real standard subsets of [0,1]that is $T_B(x):U \to [0,1]$, $I_B(x):U \to [0,1]$, and $F_B(x):U \to [0,1]$. Additionally, the sum of $T_B(x)$, $I_B(x)$ and $F_B(x)$, are in [0,3] and this can be written as $0 \le T_B(x) + I_B(x) + F_B(x) \le 3$ [73].

Let a single-valued neutrosophic triangular number $\tilde{a} = <(a_1, a_2, a_3); \alpha_{\tilde{a}}, \theta_{\tilde{a}}, \beta_{\tilde{a}}>$ is a special neutrosophic set on R. Additionally $\alpha_{\tilde{a}}, \theta_{\tilde{a}}, \beta_{\tilde{a}} \in [0,1]$ and $a_1, a_2, a_3 \in R$ where $a_1 \le a_2 \le a_3$. Truth, indeterminacy and falsity membership functions of this number can be computed as below [74-75]:

$$T_{\tilde{a}}(x) = \begin{cases} \alpha_{\tilde{a}} \left(\frac{x-a_1}{a_2-a_1} \right) & (a_1 \le x \le a_2) \\ \alpha_{\tilde{a}} & (x = a_2) \\ \alpha_{\tilde{a}} \left(\frac{a_3-x}{a_3-a_2} \right) & (a_2 < x \le a_3) \\ 0 & \text{otherwise} \end{cases} \tag{4}$$

$$I_{\tilde{a}}(x) = \begin{cases} \left(\frac{a_2-x+\theta_{\tilde{a}}(x-a_1)}{a_2-a_1} \right) & (a_1 \le x \le a_2) \\ \theta_{\tilde{a}} & (x = a_2) \\ \left(\frac{x-a_2+\theta_{\tilde{a}}(a_3-x)}{a_3-a_2} \right) & (a_2 < x \le a_3) \\ 1 & \text{otherwise} \end{cases} \tag{5}$$

$$F_{\tilde{a}}(x) = \begin{cases} \left(\frac{a_2-x+\beta_{\tilde{a}}(x-a_1)}{a_2-a_1} \right) & (a_1 \le x \le a_2) \\ \beta_{\tilde{a}} & (x = a_2) \\ \left(\frac{x-a_2+\beta_{\tilde{a}}(a_3-x)}{a_3-a_2} \right) & (a_2 < x \le a_3) \\ 1 & \text{otherwise} \end{cases} \tag{6}$$

According to the Eqs. (4-6) $\alpha_{\tilde{a}}$, $\theta_{\tilde{a}}$ and $\beta_{\tilde{a}}$ denote maximum truth, minimum indeterminacy and minimum falsity membership degrees, respectively.

Suppose $\tilde{a} = < (a_1, a_2, a_3); \alpha_{\tilde{a}}, \theta_{\tilde{a}}, \beta_{\tilde{a}} >$ and $\tilde{n} = < (n_1, n_2, n_3); \alpha_{\tilde{n}}, \theta_{\tilde{n}}, \beta_{\tilde{n}} >$ as two single-valued triangular neutrosophic numbers and $\lambda \neq 0$ as a real number. Considering the above-mentioned conditions addition of two single-valued triangular neutrosophic numbers are denoted as follows [74]:

$$\tilde{a} + \tilde{n} = \langle (a_1 + n_1, a_2 + n_2, a_3 + n_3); \alpha_{\tilde{a}} \wedge \alpha_{\tilde{n}}, \theta_{\tilde{a}} \vee \theta_{\tilde{n}}, \beta_{\tilde{a}} \vee \beta_n \rangle. \tag{7}$$

Subtraction of two single-valued triangular neutrosophic numbers is defined as Eq. (8):

$$\tilde{a} - \tilde{n} = \langle (a_1 - n_3, a_2 - n_2, a_3 - n_1); \alpha_{\tilde{a}} \wedge \alpha_{\tilde{n}}, \theta_{\tilde{a}} \vee \theta_{\tilde{n}}, \beta_a \vee \beta_{\tilde{n}} \rangle. \tag{8}$$

The inverse of a single-valued triangular neutrosophic number $(\tilde{a} \neq 0)$ can be denoted as below:

$$\tilde{a}^{-1} = \left\langle \left(\frac{1}{a_3}, \frac{1}{a_2}, \frac{1}{a_1}\right); \alpha_{\tilde{a}}, \theta_{\tilde{a}}, \beta_{\tilde{a}} \right\rangle. \tag{9}$$

Multiplication of a single-valued triangular neutrosophic number by a constant value is represented as follows:

$$\lambda\tilde{a} = \begin{cases} \langle(\lambda a_1, \lambda a_2, \lambda a_3); \alpha_{\tilde{a}}, \theta_{\tilde{a}}, \beta_{\tilde{a}}\rangle \ if \ (\lambda > 0) \\ \langle(\lambda a_3, \lambda a_2, \lambda a_1); \alpha_{\tilde{a}}, \theta_{\tilde{a}}, \beta_{\tilde{a}}\rangle \ if \ (\lambda < 0) \end{cases}. \tag{10}$$

Division of a single-valued triangular neutrosophic number by a constant value are denoted as Eq. (11):

$$\frac{\tilde{a}}{\lambda} = \begin{cases} \left\langle \left(\frac{a_1}{\lambda}, \frac{a_2}{\lambda}, \frac{a_3}{\lambda}\right); \alpha_{\tilde{a}}, \theta_{\tilde{a}}, \beta_{\tilde{a}} \right\rangle \ if \ (\lambda > 0) \\ \left\langle \left(\frac{a_3}{\lambda}, \frac{a_2}{\lambda}, \frac{a_1}{\lambda}\right); \alpha_{\tilde{a}}, \theta_{\tilde{a}}, \beta_{\tilde{a}} \right\rangle \ if \ (\lambda < 0) \end{cases}. \tag{11}$$

Multiplication of two single-valued triangular neutrosophic numbers can be seen as follows:

$$\tilde{a} . \tilde{n} = \begin{cases} \langle(b_1 c_1, b_2 c_2, b_3 c_3); \alpha_{\tilde{a}} \wedge \alpha_{\tilde{n}}, \theta_{\tilde{a}} \vee \theta_{\tilde{n}}, \beta_{\tilde{a}} \vee \beta_{\tilde{n}}\rangle \ if \ (b_3 > 0, c_3 > 0) \\ \langle(b_1 c_3, b_2 c_2, b_3 c_1); \alpha_{\tilde{a}} \wedge \alpha_{\tilde{n}}, \theta_{\tilde{a}} \vee \theta_{\tilde{n}}, \beta_{\tilde{a}} \vee \beta_{\tilde{n}}\rangle \ if \ (b_3 < 0, c_3 > 0) \\ \langle(b_3 c_3, b_2 c_2, b_1 c_1); \alpha_{\tilde{a}} \wedge \alpha_{\tilde{n}}, \theta_{\tilde{a}} \vee \theta_{\tilde{n}}, \beta_{\tilde{a}} \vee \beta_{\tilde{n}}\rangle \ if \ (b_3 < 0, c_3 < 0) \end{cases} \tag{12}$$

Division of two single-valued triangular neutrosophic numbers can be denoted as Eq. (13):

$$\frac{\tilde{a}}{\tilde{n}} = \begin{cases} \left\langle \left(\frac{a_1}{n_3}, \frac{a_2}{n_2}, \frac{a_3}{n_1}\right); \alpha_{\tilde{a}} \wedge \alpha_{\tilde{n}}, \theta_{\tilde{a}} \vee \theta_{\tilde{n}}, \beta_a \vee \beta_{\tilde{n}} \right\rangle \ if \ (a_3 > 0, n_3 > 0) \\ \left\langle \left(\frac{a_3}{n_3}, \frac{a_2}{n_2}, \frac{a_1}{n_1}\right); \alpha_{\tilde{a}} \wedge \alpha_{\tilde{n}}, \theta_{\tilde{a}} \vee \theta_{\tilde{n}}, \beta_{\tilde{a}} \vee \beta_{\tilde{n}} \right\rangle \ if \ (a_3 < 0, n_3 > 0) \\ \left\langle \left(\frac{a_3}{n_1}, \frac{a_2}{n_2}, \frac{a_1}{n_3}\right); \alpha_{\tilde{a}} \wedge \alpha_{\tilde{n}}, \theta_{\tilde{a}} \vee \theta_{\tilde{n}}, \beta_{\tilde{a}} \vee \beta_{\tilde{n}} \right\rangle \ if \ (a_3 < 0, n_3 < 0) \end{cases}. \tag{13}$$

Score function (s_a) for a single-valued triangular neutrosophic number $a=(a_1,a_2,a_3)$ can be found as below [76-77]:

$$s_a = (1 + a_1 - 2 * a_2 - a_3)/2, \tag{14}$$

where $s_a \in [-1, +1]$.

The maximum distance $e_{max}(a,n)$ between two single-valued triangular neutrosophic numbers such as $a = (a_1, a_2, a_3)$ and $n = (n_1, n_2, n_3)$ can be computed as follows [76]:

$$e_{max}(a, n) = \begin{cases} |a_1 - n_1| & a_1, n_1 \in \Omega_{max} \\ |a_3 - n_3| & a_3, n_3 \in \Omega_{min} \end{cases}. \tag{15}$$

3.3 Neutrosophic AHP

Steps of neutrosophic AHP can be explained as follows [74-75]:

1. Decision problem is constructed as a hierarchical view consisting of goal, criteria, sub-criteria and alternatives, respectively.

2. Pairwise comparisons are made to form a neutrosophic evaluation matrix composed of triangular neutrosophic numbers representing decision-makers' views. Neutrosophic pairwise evaluation matrix $(\tilde{O})$ is seen as below:

$$\tilde{O} = \begin{bmatrix} \tilde{1} & \tilde{o}_{12} & \cdots & \tilde{o}_{1n} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{o}_{n1} & \tilde{o}_{n2} & \cdots & \tilde{1} \end{bmatrix}. \tag{16}$$

According to Eq. (16), $\tilde{o}_{ji} = (\tilde{o}_{ij})^{-1}$ is valid.

3. Neutrosophic pairwise evaluation matrix is constructed by using scale arranged for the neutrosophic environment such as Table 3:

Table 3 AHP scale transformed for neutrosophic triangular numbers

Value	Explanation	Neutrosophic triangular scale
1	Equally influential	$\tilde{1} = \langle(1,1,1); 0.5,0.5,0.5\rangle$
3	Slightly influential	$\tilde{3} = \langle(2,3,4); 0.3,0.75,0.7\rangle$
5	Strongly influential	$\tilde{5} = \langle(4,5,6); 0.8,0.15,0.2\rangle$
7	Very strongly influential	$\tilde{7} = \langle(6,7,8); 0.9,0.1,0.1\rangle$
9	Absolutely influential	$\tilde{9} = \langle(9,9,9); 1,0,0\rangle$
2		$\tilde{2} = \langle(1,2,3); 0.4,0.65,0.6\rangle$
4	Intermediate values between two close	$\tilde{4} = \langle(3,4,5); 0.6,0.35,0.4\rangle$
6	scales	$\tilde{6} = \langle(5,6,7); 0.7,0.25,0.3\rangle$
8		$\tilde{8} = \langle(7,8,9); 0.85,0.1,0.15\rangle$

4. Neutrosophic pairwise evaluation matrix is changed to deterministic pairwise evaluation matrix for obtaining the weights of criterion as follows:

Let $\tilde{o}_{ij} = \langle(d_1, e_1, f_1); \alpha_{\tilde{o}}, \theta_{\tilde{o}}, \beta_{\tilde{o}}\rangle$ be a single-valued neutrosophic number, then the score and accuracy degrees of $\tilde{o}_{ij}$ are computed as the following equations:

$$S(\tilde{o}_{ij}) = \frac{1}{16}[d_1 + e_1 + f_1]x(2 + \alpha_{\tilde{o}} - \theta_{\tilde{o}} - \beta_{\tilde{o}}), \tag{17}$$

$$A(\tilde{o}_{ij}) = \frac{1}{16}[d_1 + e_1 + f_1]x(2 + \alpha_{\tilde{o}} - \theta_{\tilde{o}} + \beta_{\tilde{o}}). \tag{18}$$

In order to obtain the score and accuracy degree of $\tilde{o}_{ij}$, the following equations are used.

$$S(\tilde{o}_{ji}) = 1/S(\tilde{o}_{ij}), \tag{19}$$

$$A(\tilde{o}_{ji}) = 1/A(\tilde{o}_{ij}). \tag{20}$$

The deterministic pairwise evaluation matrix is constructed with compensation by score value in the neutrosophic pairwise evaluation matrix. The obtained deterministic matrix can be seen as follows:

$$O = \begin{bmatrix} 1 & o_{12} & \cdots & o_{1n} \\ \vdots & \vdots & \vdots & \vdots \\ o_{n1} & o_{n2} & \cdots & 1 \end{bmatrix}. \tag{21}$$

Ranking of priorities as eigenvector X is obtained according to the following steps:

a) Firstly column entries are normalized by dividing each entry to the sum of column

b) Then row averages are summed.

5. Consistency index *(CI)* and consistency ratio *(CR)* values are computed for measuring the inconsistency for decision-makers' judgments in the entire pairwise evaluation matrix. If *CR* is greater than 0.1, the process should be repeated due to unreliable decision-makers' judgments.

CI is computed according to the following steps:

a) Each value in the first column of the pairwise evaluation matrix is multiplied by the priority of the first criterion and this process is applied for all columns. Values are summed across the rows to construct the weighted sum vector.

b) The elements of the weighted sum vector are divided by corresponding to the priority of each criterion. Then the average of values are acquired and represented by λ_{max}.

c) The value of *CI* is calculated as Eq. (22):

$$CI = \frac{\lambda_{max} - n}{n-1}. \tag{22}$$

According to Eq. (7), the number of elements being compared is denoted by n.

After the value of *CI* is found, *CR* is computed as follows:

$$CR = \frac{CI}{RI} \tag{23}$$

where *RI* denotes the consistency index for randomly generated pairwise evaluation matrix and can be shown as Table 4.

Table 4 RI table used for computing CR value

Order of random matrix (n)	1	2	3	4	5	6	7	8	9	10
Related *RI* value	0	0	0.58	0.9	1.12	1.24	1.32	1.4	1.45	1.49

6. Overall priority values for each alternative are computed and the ranking process is applied.

3.4 MULTIMOORA method

The MULTIMOORA method developed by Brauers and Zavadskas [31] includes three approaches for ranking alternatives. These approaches are Ratio System (RS), Reference Point (RF), and the Full Multiplicative Form (FMF), respectively. The decision about selecting the best alternative is made according to the theory of dominance for three approaches [78-81].

The overall importance of alternative i in ratio system approach is given as [76]:

$$z_i = z_i^+ - z_i^-, \tag{24}$$

$$z_i^+ = \sum_{j \in \Omega_{max}} w_j\, p_{ij} \tag{25}$$

$$z_i^- = \sum_{j \in \Omega_{min}} w_j\, p_{ij}, \tag{26}$$

$$p_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^2}}. \tag{27}$$

According to Eqs. (24)-(27) z_i^+ and z_i^- show overall importance of alternative i acquired for benefit and cost criteria; p_{ij} describes the normalized performance of alternative i in terms of criterion j; x_{ij} shows the performance of alternative i related with criterion j; sets of benefit and cost criteria are represented by Ω_{max} and Ω_{min}; the weight of criterion j is denoted by w_j. In terms of ratio system, approach alternatives are ranked in terms of decreasing z_i values.

According to the reference point approach optimization is shown as Eq. (28):

$$e_i^{max} = \max_j \left(w_j \left| p_j^* - p_{ij} \right| \right). \tag{28}$$

The maximum distance of alternative i to the reference point is shown by e_{max}^i and the coordinate j of the reference point is denoted by p_j^* and obtained as below:

$$p_j^* = \begin{cases} \max\limits_i p_{ij} & j \in \Omega_{max} \\ \min\limits_i p_{ij} & j \in \Omega_{min} \end{cases}. \tag{29}$$

In terms of reference point, approach alternatives are ranked according to increasing e_{max}^i values.

The overall utility of the alternative in the full multiplicative form is obtained as:

$$ou_i = \frac{c_i}{d_i}, \tag{30}$$

$$c_i = \prod_{j \in \Omega_{max}} w_j p_{ij}, \tag{31}$$

$$d_i = \prod_{j \in \Omega_{min}} w_j p_{ij}. \tag{32}$$

According to Eqs. (30-32) while the product of the weighted performance ratings of benefit criteria for alternative i is represented by c_i, d_i can be used for cost criteria. In terms of full multiplicative form approach alternatives are ranked in terms of decreasing ou_i values.

The ranking list related to three approaches is constructed and the decision is made by considering the theory of dominance [32, 82-85].

3.5 Single Valued Neutrosophic Sets Based MULTIMOORA Method

SVNS based MULTIMOORA method can be applied for decision problems consisting of m alternatives and n criteria, and the performances of alternatives are considered by using SVNS. Steps of SVNS based MULTIMOORA method for ratio system approach are expressed as below [76]:

1. By using a single-valued neutrosophic weighted average operator the values of Z_i^+ and Z_i^- are computed as below:

$$Z_i^+ = \left(1 - \prod_{j \in \Omega_{max}} \left(1 - t_j \right)^{w_j}, \prod_{j \in \Omega_{max}} \left(i_j \right)^{w_j}, \prod_{j \in \Omega_{max}} \left(f_j \right)^{w_j} \right), \tag{33}$$

$$Z_i^- = \left(1 - \prod_{j \in \Omega_{min}} \left(1 - t_j \right)^{w_j}, \prod_{j \in \Omega_{min}} \left(i_j \right)^{w_j}, \prod_{j \in \Omega_{min}} \left(f_j \right)^{w_j} \right). \tag{34}$$

The importance of alternative i acquired for benefit and cost criteria are represented by Z_i^+ and Z_i^- as single-valued neutrosophic numbers.

2. Then the values of z_i^+ and z_i^- are computed via score function as Eqs. (35) and (36):

$$z_i^+ = s(Z_i^+), \tag{35}$$

$$z_i^- = s(Z_i^-). \tag{36}$$

3. The overall importance for each alternative is obtained as below:

$$z_i = z_i^+ - z_i^-. \tag{37}$$

4. Alternatives are ranked in terms of decreasing z_i values.

The steps of SVNS based MULTIMOORA method for reference point approach are stated as below [76]:

1. As a single-valued neutrosophic number each coordinate of the reference point is written by $p^* = \{p_1^*, p_2^*, ..., p_n^*\}$ and $p_j^* = \langle t_j^*, i_j^*, f_j^* \rangle$ values are acquired as Eq. (38):

$$p_j^* = \begin{cases} \langle \max_i t_{ij}, \min_i i_{ij}, \min_i f_{ij} \rangle & j \in \Omega_{max} \\ \langle \min_i t_{ij}, \min_i i_{ij}, \max_i f_{ij} \rangle & j \in \Omega_{min} \end{cases}. \tag{38}$$

Coordinate j of the reference point can be written as p_j^*:

$$p_j^* = \begin{cases} \langle 1,0,0 \rangle & j \in \Omega_{max} \\ \langle 0,0,1 \rangle & j \in \Omega_{min} \end{cases}. \tag{39}$$

2. Maximum distance from each alternative to all coordinates of the reference point is calculated by using Eq. (40):

$$e_{ij}^{max} = e_{max}(p_{ij}, p_j^*) w_j. \tag{40}$$

3. Maximum distance of each alternative is computed via Eq. (41):

$$e_i^{max} = \max_j e_{ij}^{max}. \tag{41}$$

Then alternatives are ranked in terms of increasing I_{MAX} values.

The steps of SVNS based MULTIMOORA method for a full multiplicative form approach are explained as follows [76]:

1. The values of C_i and D_i are calculated as follows:

$$C_i = \left(\prod_{j \in \Omega_{max}} (t_j)^{w_j}, 1 - \prod_{j \in \Omega_{max}} (1 - i_j)^{w_j}, 1 - \prod_{j \in \Omega_{max}} (1 - f_j)^{w_j} \right), \tag{42}$$

$$D_i = \left(\prod_{j \in \Omega_{min}} (t_j)^{w_j}, 1 - \prod_{j \in \Omega_{min}} (1 - i_j)^{w_j}, 1 - \prod_{j \in \Omega_{min}} (1 - f_j)^{w_j} \right). \tag{43}$$

As single-valued neutrosophic numbers C_i and D_i can be written as $C_i = \langle t_{Ci}, i_{Ci}, f_{Ci} \rangle$ and $D_i = \langle t_{Di}, i_{Di}, f_{Di} \rangle$, respectively.

2. The values of c_i and d_i are computed via score function as Eqs. (44) and (45):

$$c_i = s(C_i), \tag{44}$$

$$d_i = s(D_i). \tag{45}$$

3. The overall utility for each alternative is obtained as below:

$$ou_i = \frac{c_i}{d_i}. \tag{46}$$

Alternatives are ranked in terms of decreasing ou_i values and final ranking related to alternatives are made via the theory of dominance in terms of MULTIMOORA method.

4. CASE STUDY AND RESULTS

In this study, nine criteria for choosing the optimal training aircraft for FTOs are determined according to literature review [7, 8, 18] and experts' opinions. Additionally, they are weighted via single-valued neutrosophic AHP firstly. For this purpose evaluations of 10 decision-makers related to the selection of training aircraft are considered in terms of the group decision-making (GDM) process. The required criteria are: runway length, capable of IFR/VFR operations, reliability/security, purchasing cost, maintenance cost, operational cost, certified staff number, availability of facilities and ease of finding spare part, respectively. While some of the criteria are common (purchasing cost, maintenance cost, operational cost, reliability/security) , the other criteria are specified and diversified according to the purpose and mission for military, commercial, passenger and cargo aircraft types.

The neutrosophic evaluation matrix in terms of the criteria considered for the selection of training aircraft is constructed through decision-makers' linguistic judgments which are seen as Table 3. A part of the neutrosophic evaluation matrix for the criteria are shown in Appendix 1.

After that, the neutrosophic evaluation matrix is transformed into a crisp one by using Eq. (17) and taking the geometric means of 10 decision-makers' judgments. The crisp evaluation matrix for criteria is shown in Table 5.

Table 5 The crisp evaluation matrix for criteria

Criteria	Required runway length	Capable of IFR/VFR operations	Reliability/ safety	Purchasing cost	Maintenance cost	Operational cost	Certified staff number	Availability of facilities	Ease of finding spare part
Required runway length	1	0.773	1.0200	0.8695	1.1133	1.2563	0.4357	0.8855	0.591
Capable of IFR/VFR operations	1.2922	1	1.1298	2.0885	2.0296	1.2228	1.3450	0.9182	0.715
Reliability/ safety	0.9803	0.8850	1	1.5795	1.0079	0.8103	0.3959	0.5376	0.663
Purchasing cost	1.1500	0.4787	0.6330	1	0.6413	0.9892	0.8545	0.5830	1.247
Maintenance cost	0.8981	0.4926	0.9921	1.5592	1	0.9243	0.8374	0.6753	0.793
Operational cost	0.7959	0.8177	1.2340	1.0108	1.0818	1	1.0153	0.5583	1.428
Certified staff number	2.2947	0.743	2.5254	1.1702	1.194	0.9849	1	0.7840	1.288
Availability of facilities	1.1292	1.0890	1.8600	1.7149	1.4807	1.7909	1.2754	1	1.256
Ease of finding spare part	1.6901	1.3967	1.5077	0.8015	1.2599	0.7000	0.7759	0.7956	1

The normalized evaluation matrix for criteria is formed as Table 6.

Table 6 The normalized evaluation matrix for criteria

Criteria	Required runway length	Capable of IFR/VFR operations	Reliability/safety	Purchasing cost	Maintenance cost	Operational cost	Certified staff number	Availability of facilities	Ease of finding spare part
Required runway length	0.0890	0.1007	0.0857	0.0737	0.1030	0.1298	0.0549	0.1314	0.065
Capable of IFR/VFR operations	0.1150	0.1302	0.0949	0.1770	0.1877	0.1263	0.1695	0.1362	0.079
Reliability/safety	0.0872	0.1152	0.0840	0.1339	0.093	0.0837	0.0498	0.0797	0.073
Purchasing cost	0.1024	0.0623	0.0531	0.0847	0.0593	0.1022	0.1076	0.086	0.138
Maintenance cost	0.0799	0.0641	0.0833	0.1322	0.0925	0.0954	0.1055	0.1002	0.088
Operational cost	0.070	0.1065	0.1036	0.0857	0.1000	0.1033	0.1279	0.0828	0.158
Certified staff number	0.2043	0.0968	0.2121	0.099	0.1104	0.1017	0.1260	0.116	0.143
Availability of facilities	0.1005	0.1418	0.1562	0.1454	0.1369	0.1850	0.1607	0.1484	0.139
Ease of finding spare part	0.1504	0.1819	0.1266	0.0679	0.1165	0.0723	0.0977	0.1180	0.111

Finally, the priorities for the criteria as eigenvector *X* can be calculated by taking the overall row averages and seen as below:

$$X = \begin{bmatrix} 0.092695 \\ 0.13521 \\ 0.088997 \\ 0.088593 \\ 0.093533 \\ 0.104439 \\ 0.134509 \\ 0.146125 \\ 0.1159 \end{bmatrix}$$

According to eigenvector *X,* while the number of maintenance facilities was found as the most important criterion having a value of 0.146125, the historical cost was obtained as the least important one having a value of 0.088593.

Then the consistency of decision-makers' judgments is checked by computing *CI* and *CR* values. *CI* value is found as 0.037 and by using Eq. (23) *CR* value is acquired as 0.025. Decision-makers' evaluations are consistent because of having *CR* value smaller than 0.1.

After obtaining the criteria weights, alternatives have been chosen among the most commonly used aircraft by FTOs in Turkey. Besides, ninety percent of aircraft used for flight training is of a single-engine type [86]. Therefore, only six single-engine type aircraft (Diamond 40, Evektor, The Tecnam, Pipera, Diamond 20 and Cessna 172) have been included as alternatives in the research according to the experts' views in terms of

training aircrafts. Alternatives are ranked via single-valued neutrosophic sets based on MULTIMOORA method.

Firstly neutrosophic evaluations of six training aircraft obtained by taking the geometric means of 10 decision-makers' judgments are presented in Appendix 2.

Then in terms of ratio system approach the values of $Z_i^+, Z_i^-, z_i^+, z_i^-$ and z_i are computed and training planes are ranked as seen in Table 7.

Table 7 Ranking of training aircraft according to the ratio system approach

	Z_i^+	Z_i^-	z_i^+	z_i^-	z_i	Ranking
Diamond 40	(0.63,0.35,0.37)	(0.33,0.66,0.67)	0.273404	-0.33757	0.610969	3
Evektor	(0.62,0.37,0.38)	(0.32,0.66,0.68)	0.242802	-0.33344	0.576242	5
The tecnam	(0.67,0.31,0.33)	(0.33,0.65,0.67)	0.360386	-0.31666	0.677044	2
Pipera	(0.63,0.33,0.37)	(0.34,0.64,0.66)	0.298661	-0.30727	0.605931	4
Diamond 20	(0.47,0.5,0.53)	(0.25,0.72,0.75)	-0.02318	-0.47464	0.451462	6
Cessna 172	(0.63,0.34,0.37)	(0.29,0.68,0.71)	0.298632	-0.38994	0.688570	1

According to Table 7 ranking of training aircraft is Cessna 172 > The tecnam > Diamond 40 > Pipera > Evektor > Diamond 20 in terms of ratio system approach.

In addition, the ranking of training aircraft is presented in Table 8 in terms of the reference point approach.

Table 8 Ranking of training aircraft according to the reference point approach

	p_1^*	p_2^*	p_3^*	p_4^*	p_5^*	p_6^*	p_7^*	p_8^*	p_9^*	e_i^{max}	Ranking
Diamond 40	0.02	0.033	0.020	0.069	0.074	0.06	0.030	0.052	0.01	0.07	1
Evektor	0.02	0.023	0.040	0.067	0.063	0.08	0.053	0.029	0.02	0.08	4
The tecnam	0.02	0.031	0.019	0.068	0.065	0.08	0.020	0.054	0.01	0.08	5
Pipera	0.03	0.040	0.017	0.071	0.060	0.08	0.030	0.036	0.02	0.08	6
Diamond 20	0.02	0.050	0.036	0.052	0.061	0.06	0.073	0.080	0.03	0.08	3
Cessna 172	0.02	0.0360	0.0217	0.0623	0.0645	0.07	0.028	0.040	0.02	0.07	2

According to Table 8, the ranking of training aircraft is Diamond 40 > Cessna 172 > Diamond 20 > Evektor > The tecnam > Pipera in terms of reference point approach.

In terms of the full multiplicative form approach the values of C_i, D_i, c_i, d_i and ou_i are computed and training aircraft are ranked seen as Table 9.

Table 9 Ranking of training aircraft according to the full multiplicative form approach

	C_i	D_i	c_i	d_i	ou_i	Ranking
Diamond 40	(0.8,0.18,0.2)	(0.92,0.08,0.08)	0.621453	0.836481	0.742937	4
Evektor	(0.79,0.21,0.21)	(0.92,0.07,0.08)	0.580427	0.842982	0.688540	5
The tecnam	(0.83,0.16,0.17)	(0.92,0.07,0.08)	0.668086	0.851028	0.785034	2
Pipera	(0.81,0.16,0.19)	(0.92,0.07,0.08)	0.650124	0.84683	0.767714	3
Diamond 20	(0.67,0.32,0.33)	(0.88,0.11,0.12)	0.347624	0.768949	0.452076	6
Cessna 172	(0.82,0.16,0.18)	(0.9,0.08,0.1)	0.656703	0.819214	0.801625	1

According to Table 9, ranking of training aircraft is Cessna 172 > The tecnam > Pipera > Diamond 40 > Evektor > Diamond 20 in terms of a full multiplicative form approach.

The final ranking of training aircraft according to the SVNS based MULTIMOORA method by considering three different approaches is presented in Table 10.

Table 10 The final ranking of training aircraft according to the single-valued neutrosophic sets based MULTIMOORA method

	Ranking for ratio system approach	Ranking for reference point approach	Ranking for a full multiplicative form approach	Final ranking based on dominance theory
Diamond 40	3	1	4	3
Evektor	5	4	5	5
The tecnam	2	5	2	2
Pipera	4	6	3	4
Diamond 20	6	3	6	6
Cessna 172	1	2	1	1

According to Table 10, three different approaches give different ranking results and the final ranking for dominance theory is Cessna 172 > The tecnam > Diamond 40 > Pipera > Evektor > Diamond 20 like ratio system approach.

5. COMPARISON AND SENSITIVITY ANALYSIS

In this section, the results of the proposed approach are analyzed based on a comparison and a sensitivity analysis.

5.1 Comparison with the neutrosophic AHP-TOPSIS method

Here, a comparison was performed between the results attained from the neutrosophic AHP-MULTIMOORA method and those of another approach. To show the efficiency and display the irreplaceable merits of the neutrosophic AHP-MULTIMOORA method, the AHP-TOPSIS method [87] is implemented to handle the decision making problem.

Let p_{ij} be the neutrosophic number that describes the normalized performance of alternative i in terms of criterion j; sets of benefit and cost criteria are represented by Ω_{max} and Ω_{min}; weight of criterion j is denoted by w_j. In the AHP-TOPSIS approach, the computation of an ideal solution (IS) and anti-ideal solution (A-IS) of each criterion are important concerns for DEs. At this time, IS and A-IS are computed with reference to the

neutrosophic fuzzy IS (NF-IS) and A-IS (NFA-IS). Let p_j^+ and p_j^- denote the NF-IS and NFA-IS and are calculated using the following formula

$$p_j^+ = (t_{ij}^+, i_{ij}^+, f_{ij}^+) = \begin{cases} \langle \max_i t_{ij}, \min_i i_{ij}, \min_i f_{ij} \rangle & j \in \Omega_{max} \\ \langle \min_i t_{ij}, \min_i i_{ij}, \max_i f_{ij} \rangle & j \in \Omega_{min} \end{cases}, \quad (47)$$

$$p_j^- = (t_{ij}^-, i_{ij}^-, f_{ij}^-) = \begin{cases} \langle \min_i t_{ij}, \min_i i_{ij}, \max_i f_{ij} \rangle & j \in \Omega_{max} \\ \langle \max_i t_{ij}, \min_i i_{ij}, \min_i f_{ij} \rangle & j \in \Omega_{min} \end{cases}. \quad (48)$$

Next, calculate the distance measures with the Euclidean distance [87]. The separation to the ideal alternative and distance to the anti-ideal alternative are denoted by

$$d(p_{ij}, p_j^+) = \frac{1}{3} \sum_{j=1}^n w_j [|t_{ij} - t_{ij}^+| + |i_{ij} - i_{ij}^+| + |f_{ij} - f_{ij}^+|], \quad (49)$$

$$(p_{ij}, p_j^-) = \frac{1}{3} \sum_{j=1}^n w_j [|t_{ij} - t_{ij}^-| + |i_{ij} - i_{ij}^-| + |f_{ij} - f_{ij}^-|]. \quad (50)$$

Now, compute the relative closeness to the ideal alternative and rank the preference order. The relative closeness of the ith to the ideal alternative concerning the ideal alternative is as follows:

$$C_i = \frac{d(p_{ij}, p_j^-)}{d(p_{ij}, p_j^-) + d(p_{ij}, p_j^+)}; C_i \in [0, 1]. \quad (51)$$

A set of alternatives that can be preference are ranked according to the descending order of $C_i \in [0,1]$; then larger means a better alternative.

From **Appendix 2** and Eqs. (47)-(48), NF-IS and NFA-IS are evaluated. Now, the whole computational results of neutrosophic AHP-TOPSIS [86] method are depicted in Table 11.

**Table 11** Ranking of training aircraft according to AHP-TOPSIS method

	$d(p_{ij}, p_j^+)$	$d(p_{ij}, p_j^-)$	C_i	Ranking
Diamond 40	0.081	0.123	0.602	4
Evektor	0.088	0.117	0.571	5
The tecnam	0.070	0.124	0.639	2
Pipera	0.073	0.116	0.613	3
Diamond 20	0.175	0.112	0.389	6
Cessna 172	0.063	0.131	0.673	1

Next, to illustrate the advantages of our proposed neutrosophic AHP-MULTIMOORA, a comparative analysis is conducted with AHP-TOPSIS [86] model. Fig.1 displays the ranking results of the six training aircraft for flight training organizations alternative as yielded using the mentioned methods. From Fig.1, we can observe that given methods suggest Cessna 172 as the first choice for the considered training aircraft for flight training organizations. Moreover, the ranking orders of the six training aircraft for flight training determined by the proposed method are exactly matched with those derived by the neutrosophic AHP-TOPSIS method. This

demonstrates the validity of the proposed decision-making framework. By comparison, the MULTIMOORA utilized in our proposed method is more comprehensive in dealing with training aircraft for flight training problems as it utilizes the ratio system, the reference point approach, and the full multiplicative form. Therefore, the reliability and veracity of the decision-making results would be improved greatly by using the proposed neutrosophic AHP-MULTIMOORA model.

Compared with the neutrosophic AHP-TOPSIS method in the literature, the AHP-MULTIMOORA method developed in this study has the following attractions:

- The SVNSs improve the elicitation of linguistic information when a decision-maker hesitates among several values to assess a training aircraft for flight training problems. The use of SVNSs provides a more flexible way to represent decision-makers' evaluations. So, an organized method is given to combine expert knowledge and experience for use in selecting the optimal training aircraft for flight training organizations.

- The AHP method for importance coefficients of criteria is taken into account in the process of training aircraft for flight training evaluation and selection, which makes the proposed decision-making model more realistic, more practical, and more flexible.

- The MULTIMOORA method is used for the prioritization of training aircraft for flight training alternatives, which is a robust and powerful MCDM method and is easily implemented relative to other methods such as the TOPSIS and the VIKOR methods. Hence, the proposed method more effectively conducts robust evaluation for a particular manufacturing environment.
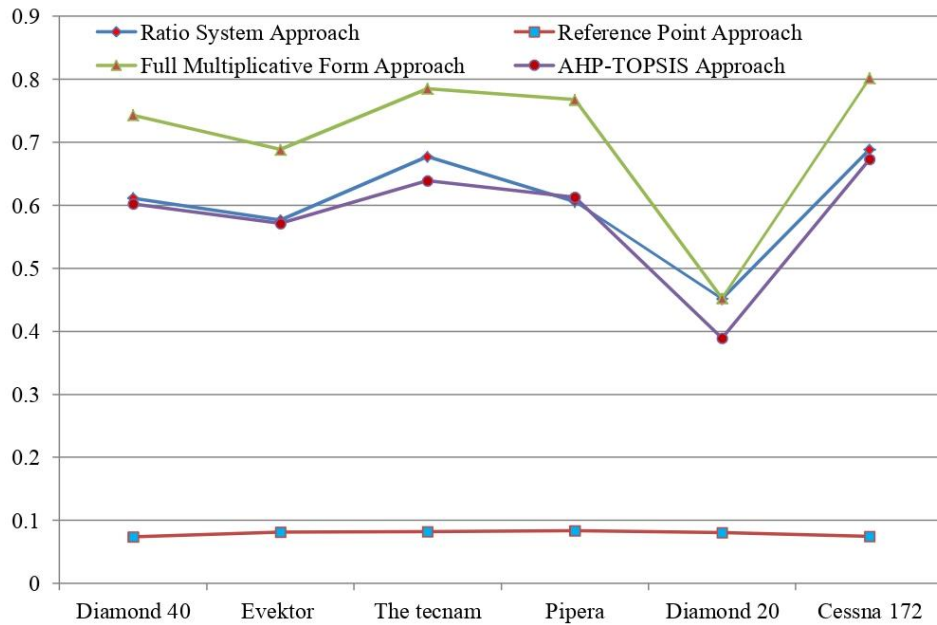
Fig. 1 Comparison of preference order of training aircraft derived by the different methods

5.2 Sensitivity analysis

The aim of the sensitivity analysis is to investigate the impact of various settings of criteria weights over different weight sets. In this paper, a sensitivity analysis was done to investigate the proposed approach behavior. Nine different criteria weight sets are taken and depicted in Table 12. In this table, for every set, one of the criteria has the maximum weight, while the other ones have lower weights. By applying this process, the ample scope of criteria weights was created to investigate the sensitivity of the developed approach to variation of the criteria weights.

**Table 12** Different criteria weight sets for ranking of training aircraft

	Required runway length	Capable of IFR/VFR operations	Reliability/ safety	Purchasing cost	Maintenance cost	Operational cost	Certified staff number	Availability of facilities	Ease of finding spare part
Set-1	0.0926	0.1352	0.0889	0.0885	0.0935	0.1044	0.1345	0.1461	0.1159
Set-2	0.135	0.0889	0.0885	0.0935	0.1044	0.1345	0.1461	0.1159	0.0926
Set-3	0.0889	0.0885	0.0935	0.1044	0.1345	0.1461	0.1159	0.0926	0.1352
Set-4	0.0885	0.0935	0.1044	0.1345	0.1461	0.1159	0.0926	0.135	0.0889
Set-5	0.0935	0.1044	0.1345	0.1461	0.1159	0.0926	0.1352	0.0889	0.0885
Set-6	0.1044	0.1345	0.1461	0.1159	0.0926	0.1352	0.0889	0.0885	0.0935
Set-7	0.1345	0.1461	0.1159	0.0926	0.1352	0.0889	0.0885	0.0935	0.1044
Set-8	0.1461	0.1159	0.0926	0.1352	0.0889	0.0885	0.0935	0.1044	0.1345
Set-9	0.1159	0.0926	0.1352	0.0889	0.0885	0.0935	0.1044	0.1345	0.1461

Table 13 Overall utility degree for each training aircraft with different values of weight sets

Sets	Diamond 40	Evektor	The tecnam	Pipera	Diamond 20	Cessna 172
Set-1	0.7427	0.6865	0.7866	0.7661	0.4548	0.8019
Set-2	0.7928	0.7133	0.8384	0.8032	0.5357	0.8629
Set-3	0.8750	0.7785	0.9147	0.8818	0.6441	0.9294
Set-4	0.8483	0.8006	0.8937	0.8907	0.6364	0.9375
Set-5	0.8184	0.7102	0.8740	0.8403	0.5794	0.8900
Set-6	0.8200	0.7113	0.8489	0.8146	0.5974	0.8701
Set-7	0.7711	0.7186	0.8303	0.7973	0.5678	0.8403
Set-8	0.7668	0.7165	0.8236	0.7773	0.5714	0.8370
Set-9	0.7310	0.6474	0.7812	0.7578	0.4715	0.7899

The sensitivity analysis results described in Table 13 and Fig. 2 show that the overall utility degree could change over different criteria weight sets and the rank of training aircraft alternative. For example, when decision experts (DEs) give the different criteria weight sets-1 to 9, the ranking of training aircraft alternative is Cessna 172 ≻ The tecnam ≻ Diamond 40 ≻ Pipera ≻ Evektor ≻ Diamond 20. And Cessna 172 is the optimal alternative. We can observe that in each criterion weight set, Cessna 172 is the best

option rank but the preference order of training aircraft alternative is also identical, which includes the experiments to manipulate factors and see how outcomes change, sensitivity analysis of a mathematical model reveals how outcomes respond to variate the criteria weight settings.
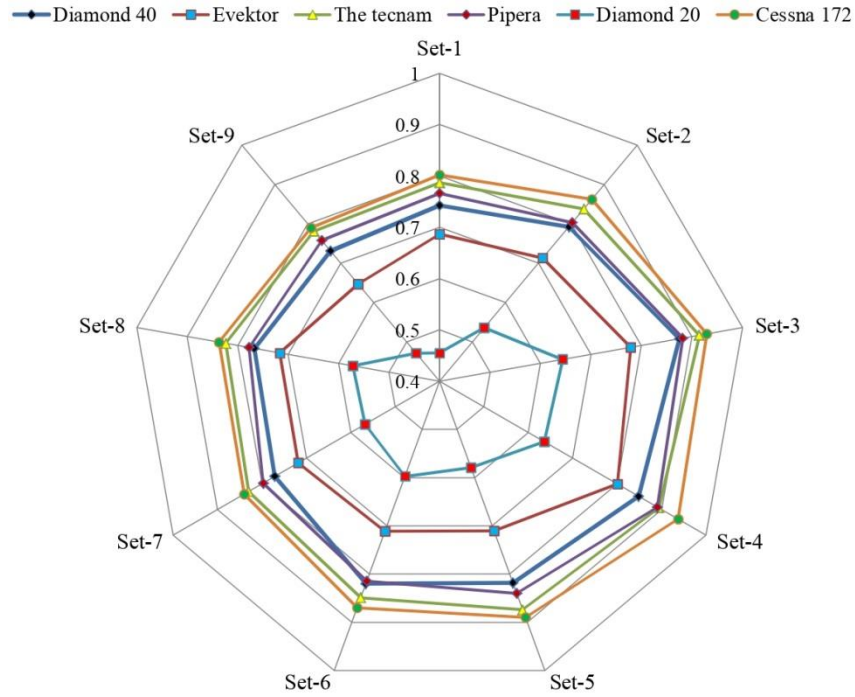
Fig. 2 Ranking of overall utility for each alternative with different values of weight sets

From the above discussion, it is concluded that the training aircraft alternative selection is dependent on and sensitive to these criteria weight sets. Therefore, the proposed approach has acceptable stability with different weight sets.

5. CONCLUSION

In this study, training aircraft are ranked by using a neutrosophic AHP based neutrosophic Multimoora approach. For this aim firstly criteria for selecting the training aircraft are determined according to the depth literature review process and weighted via SVNS based AHP approach. Then the six training aircraft as alternatives are ranked by using SVNS based Multimoora method. SVNS are preferred compared to crisp, fuzzy, interval-valued, and intuitionistic sets due to efficiency, flexibility, and easiness for explaining decision-makers' indeterminate judgments. Furthermore, the selection of training aircraft as a complex real-world decision-making problem can be efficiently solved under neutrosophic sets based environment.

For further research studies criteria related to training aircraft selection can be expanded and results can be compared to different multi-criteria decision-making methods. A sensitivity analysis has also been performed with different criteria weights sets to represent the stability of the proposed approach. The analyses of the results show that the proposed approach has good efficiency and stability, and is well consistent with the other methods. Besides, alpha-Discounting method which was proposed by [59] can be used as an alternative to AHP for prioritizing criteria and obtaining consistent outputs with pairwise comparisons. It works for any number of preferences that can be transformed into a system of homogeneous (and/or non-homogeneous) linear (and/or non-linear) equations (and/or inequalities) and useful for avoiding the rank reversal produced by AHP. Also, various hybrid techniques can be proposed and applied to real-world complex decision-making problems.

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APPENDICES

Appendix 1. Neutrosophic evaluation matrix for criteria

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
C_1	$\langle (1,1,1); 0.5,0.5,0.5 \rangle$	$\langle (2,3,4); 0.3,0.75,0.7 \rangle$	$\langle (4,5,6); 0.8,0.15,0.2 \rangle$	$\langle (2,3,4); 0.3,0.75,0.7 \rangle$	$\langle (2,3,4); 0.3,0.75,0.7 \rangle$	$\langle (6,7,8); 0.9,0.1,0.1 \rangle$	$\langle (1,1,1); 0.5,0.5,0.5 \rangle$	$\langle (4,5,6); 0.8,0.15,0.2 \rangle$	$\langle (1,2,3); 0.4,0.65,0.6 \rangle$
C_2	$\langle \left(\frac{1}{4},\frac{1}{3},\frac{1}{2}\right); 0.3,0.75,0.7 \rangle$	$\langle (1,1,1); 0.5,0.5,0.5 \rangle$	$\langle (9,9,9); 1,0,0 \rangle$	$\langle (6,7,8); 0.9,0.1,0.1 \rangle$	$\langle (6,7,8); 0.9,0.1,0.1 \rangle$	$\langle (6,7,8); 0.9,0.1,0.1 \rangle$	$\langle (6,7,8); 0.9,0.1,0.1 \rangle$	$\langle (1,1,1); 0.5,0.5,0.5 \rangle$	$\langle (6,7,8); 0.9,0.1,0.1 \rangle$
C_3	$\langle \left(\frac{1}{6},\frac{1}{5},\frac{1}{4}\right); 0.8,0.15,0.2 \rangle$	$\langle \left(\frac{1}{9},\frac{1}{9},\frac{1}{9}\right); 1,0,0 \rangle$	$\langle (1,1,1); 0.5,0.5,0.5 \rangle$	$\langle (6,7,8); 0.9,0.1,0.1 \rangle$	$\langle (2,3,4); 0.3,0.75,0.7 \rangle$	$\langle (1,1,1); 0.5,0.5,0.5 \rangle$	$\langle (1,1,1); 0.5,0.5,0.5 \rangle$	$\langle (1,2,3); 0.4,0.65,0.6 \rangle$	$\langle (9,9,9); 1,0,0 \rangle$
C_4	$\langle \left(\frac{1}{4},\frac{1}{3},\frac{1}{2}\right); 0.3,0.75,0.7 \rangle$	$\langle \left(\frac{1}{8},\frac{1}{7},\frac{1}{6}\right); 0.9,0.1,0.1 \rangle$	$\langle \left(\frac{1}{8},\frac{1}{7},\frac{1}{6}\right); 0.9,0.1,0.1 \rangle$	$\langle (1,1,1); 0.5,0.5,0.5 \rangle$	$\langle (4,5,6); 0.8,0.15,0.2 \rangle$	$\langle (4,5,6); 0.8,0.15,0.2 \rangle$	$\langle (1,1,1); 0.5,0.5,0.5 \rangle$	$\langle (2,3,4); 0.3,0.75,0.7 \rangle$	$\langle (2,3,4); 0.3,0.75,0.7 \rangle$
C_5	$\langle \left(\frac{1}{4},\frac{1}{3},\frac{1}{2}\right); 0.3,0.75,0.7 \rangle$	$\langle \left(\frac{1}{8},\frac{1}{7},\frac{1}{6}\right); 0.9,0.1,0.1 \rangle$	$\langle \left(\frac{1}{4},\frac{1}{3},\frac{1}{2}\right); 0.3,0.75,0.7 \rangle$	$\langle \left(\frac{1}{6},\frac{1}{5},\frac{1}{4}\right); 0.8,0.15,0.2 \rangle$	$\langle (1,1,1); 0.5,0.5,0.5 \rangle$	$\langle (6,7,8); 0.9,0.1,0.1 \rangle$	$\langle (1,1,1); 0.5,0.5,0.5 \rangle$	$\langle (6,7,8); 0.9,0.1,0.1 \rangle$	$\langle (4,5,6); 0.8,0.15,0.2 \rangle$
C_6	$\langle \left(\frac{1}{8},\frac{1}{7},\frac{1}{6}\right); 0.9,0.1,0.1 \rangle$	$\langle \left(\frac{1}{8},\frac{1}{7},\frac{1}{6}\right); 0.9,0.1,0.1 \rangle$	$\langle (1,1,1); 0.5,0.5,0.5 \rangle$	$\langle \left(\frac{1}{6},\frac{1}{5},\frac{1}{4}\right); 0.8,0.15,0.2 \rangle$	$\langle \left(\frac{1}{8},\frac{1}{7},\frac{1}{6}\right); 0.9,0.1,0.1 \rangle$	$\langle (1,1,1); 0.5,0.5,0.5 \rangle$	$\langle (5,6,7); 0.7,0.25,0.3 \rangle$	$\langle (4,5,6); 0.8,0.15,0.2 \rangle$	$\langle (5,6,7); 0.7,0.25,0.3 \rangle$
C_7	$\langle (1,1,1); 0.5,0.5,0.5 \rangle$	$\langle \left(\frac{1}{8},\frac{1}{7},\frac{1}{6}\right); 0.9,0.1,0.1 \rangle$	$\langle (1,1,1); 0.5,0.5,0.5 \rangle$	$\langle (1,1,1); 0.5,0.5,0.5 \rangle$	$\langle (1,1,1); 0.5,0.5,0.5 \rangle$	$\langle \left(\frac{1}{7},\frac{1}{6},\frac{1}{5}\right); 0.7,0.25,0.3 \rangle$	$\langle (1,1,1); 0.5,0.5,0.5 \rangle$	$\langle (4,5,6); 0.8,0.15,0.2 \rangle$	$\langle (6,7,8); 0.9,0.1,0.1 \rangle$
C_8	$\langle \left(\frac{1}{6},\frac{1}{5},\frac{1}{4}\right); 0.8,0.15,0.2 \rangle$	$\langle (1,1,1); 0.5,0.5,0.5 \rangle$	$\langle \left(\frac{1}{3},\frac{1}{2},1\right); 0.4,0.65,0.6 \rangle$	$\langle \left(\frac{1}{4},\frac{1}{3},\frac{1}{2}\right); 0.3,0.75,0.7 \rangle$	$\langle \left(\frac{1}{8},\frac{1}{7},\frac{1}{6}\right); 0.9,0.1,0.1 \rangle$	$\langle \left(\frac{1}{6},\frac{1}{5},\frac{1}{4}\right); 0.8,0.15,0.2 \rangle$	$\langle \left(\frac{1}{6},\frac{1}{5},\frac{1}{4}\right); 0.8,0.15,0.2 \rangle$	$\langle (1,1,1); 0.5,0.5,0.5 \rangle$	$\langle (4,5,6); 0.8,0.15,0.2 \rangle$
C_9	$\langle \left(\frac{1}{3},\frac{1}{2},1\right); 0.4,0.65,0.6 \rangle$	$\langle \left(\frac{1}{8},\frac{1}{7},\frac{1}{6}\right); 0.9,0.1,0.1 \rangle$	$\langle \left(\frac{1}{9},\frac{1}{9},\frac{1}{9}\right); 1,0,0 \rangle$	$\langle \left(\frac{1}{4},\frac{1}{3},\frac{1}{2}\right); 0.3,0.75,0.7 \rangle$	$\langle \left(\frac{1}{6},\frac{1}{5},\frac{1}{4}\right); 0.8,0.15,0.2 \rangle$	$\langle \left(\frac{1}{7},\frac{1}{6},\frac{1}{5}\right); 0.7,0.25,0.3 \rangle$	$\langle \left(\frac{1}{8},\frac{1}{7},\frac{1}{6}\right); 0.9,0.1,0.1 \rangle$	$\langle \left(\frac{1}{6},\frac{1}{5},\frac{1}{4}\right); 0.8,0.15,0.2 \rangle$	$\langle (1,1,1); 0.5,0.5,0.5 \rangle$

Appendix 2. Neutrosophic evaluation matrix for six training aircraft obtained from 10 decision makers

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
Diamond 40	⟨0.68,0.3, 0.32⟩	⟨0.75,0.22, 0.25⟩	⟨0.77,0.21, 0.23⟩	⟨0.79,0.2, 0.21⟩	⟨0.79,0.19, 0.21⟩	⟨0.65,0.34, 0.35⟩	0.78, ⟨0.21,⟩ 0.22	⟨0.64,0.36, 0.36⟩	0.84, ⟨0.15,⟩ 0.16
Evektor	⟨0.75,0.24, 0.25⟩	⟨0.82,0.17, 0.18⟩	⟨0.54,0.47, 0.46⟩	⟨0.77,0.21, 0.23⟩	⟨0.67,0.29, 0.33⟩	⟨0.78,0.2, 0.22⟩	⟨0.6,0.38, 0.4⟩	⟨0.8,0.19, 0.2⟩	0.76, ⟨0.22,⟩ 0.24
The tecnam	⟨0.74,0.21, 0.26⟩	⟨0.76,0.23, 0.24⟩	⟨0.78,0.2, 0.22⟩	⟨0.77,0.21, 0.23⟩	⟨0.7,0.28, 0.3⟩	⟨0.78,0.19, 0.22⟩	⟨0.85,0.14, 0.15⟩	⟨0.63,0.35, 0.37⟩	⟨0.89,0.1, 0.11⟩
Pipera	⟨0.66,0.3, 0.34⟩	⟨0.7,0.25, 0.3⟩	⟨0.8,0.18, 0.2⟩	⟨0.81,0.17, 0.19⟩	⟨0.64,0.34,0.36⟩	⟨0.8,0.17, 0.2⟩	⟨0.77,0.2, 0.23⟩	⟨0.75,0.22, 0.25⟩	⟨0.81,0.17, 0.19⟩
Diamond 20	⟨0.75,0.21, 0.25⟩	⟨0.62,0.33, 0.38⟩	⟨0.59,0.38, 0.41⟩	⟨0.59,0.38, 0.41⟩	⟨0.66,0.29, 0.34⟩	⟨0.64,0.31, 0.36⟩	⟨0.46,0.56, 0.54⟩	⟨0.45,0.57, 0.55⟩	⟨0.7,0.25, 0.3⟩
Cessna 172	⟨0.77,0.2, 0.23⟩	⟨0.73,0.25, 0.27⟩	⟨0.76,0.21, 0.24⟩	⟨0.7,0.26, 0.3⟩	⟨0.69,0.28, 0.31⟩	⟨0.71,0.26, 0.29⟩	⟨0.78,0.19, 0.22⟩	⟨0.72,0.24, 0.28⟩	⟨0.77,0.2, 0.23⟩