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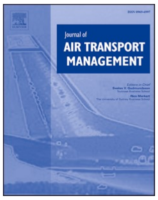

Aircraft selection by applying AHP and TOPSIS in interval type-2 fuzzy sets

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ABSTRACT

The selection of the appropriate aircraft can bring competitive advantages to airlines, however, there are a number of factors which introduce a degree of uncertainty to the selection process. By removing this uncertainty, airlines can increase their chances of achieving their long-term goals. New Multi-Criteria Decision Making (MCDM) methods provide decision-makers with a satisfactory solution for choosing suitable aircraft. Therefore, we focused on the multi-dimensional evaluation and selection of the most suitable commercial aircraft alternatives by using new MCDM method. This article provides decision support to airline planners on the selection of commercial aircraft under uncertainty. In the study, unlike other studies in the literature on aircraft selection, the model presented here uses an Interval Type-2 Fuzzy Analytical Hierarchy Process (IT2FAHP) and Interval Type-2 Fuzzy Technique for Order Preference by Similarity to an Ideal Solution (IT2FTOPSIS) hybrid methods. The proposed model for aircraft selection allows commercial airlines to evaluate the aircraft in terms of specific criteria: economic performance, technical performance, and environmental impact, and, as a result, it helps decision makers select appropriate aircraft in an uncertain environment. In addition to use by commercial airlines, the methods in the study can also be applied to the selection of training aircraft, cargo aircraft and military aircraft. Our findings show that the Airbus A321neo is the most suitable commercial aircraft in terms of technical aspects, economic aspects and environmental aspects for airlines.

1. Introduction

After the Second World War, the air transport sector entered an important development process thanks to the transfer of technology used in military aviation to civil aviation. In addition, the number of airlines and competition between the companies increased significantly thanks to the deregulation processes that started in 1978 in the USA. Deregulation has also enabled airlines to develop new business models to gain competitive advantage. As low-cost airlines (LCC) began to operate, ticket prices dropped and the demand for airlines increased significantly. The result of this is that airline companies' fleet planning and aircraft selection methods have become critical in order to gain further competitive advantage in the airline industry, which continues to have a high growth rate. Airline companies face many alternatives in fleet planning and aircraft selection. It is very important how airlines choose between aircraft alternatives to select the most suitable aircraft. Modern multi-criteria decision-making methods that help airline planners in choosing aircraft were developed in the 1950s (Köksalan et al., 2013).

Airline planners try to choose the best option among many aircraft alternatives. While this is sometimes easy for airline planners, sometimes many criteria need to be taken into account to make optimal decisions. Many methods are used in the evaluation process and multi-criteria decision making (MCDM) methods have been provided satisfactory solutions to airlines in selecting aircraft (Dožić et al., 2018). Airlines have different operational requirements according to their network structures and destinations. Airlines gain flexibility in fleet planning and operations by choosing the most appropriate aircraft for both themselves and passengers. In aircraft selection and fleet planning, aircraft are evaluated based on some their criteria. These criteria are; It can be listed as cost and operation-based criteria. In the selection of aircraft, many different criteria are taken into consideration and the most appropriate aircraft is selected for the fleet structure, planned schedule and company interests and, therefore, a holistic approach is needed for the most appropriate aircraft selection. We propose a novel model for aircraft evaluation and selection based on the interests of both the airlines and passengers. This model evaluates the planes in multiple dimensions (technical aspects, economic aspects and environmental

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aspects) to help airline planners when choosing appropriate aircraft type.

MCDM methods are important as the structure of the problem is evaluated by various perspectives based on a holistic approach (Roy, 2005). The human judgments in traditional MCDM problems are exact value numbers. Nevertheless, in some cases, decision makers might be unable to assign exact numerical value in the evaluation since the evaluation criteria may have a subjective and qualitative nature, and, as such, it is too difficult for decision makers to a make a decision to express preferences using exact numerical values (Tseng et al., 2008). Fuzzy set theory was specifically designed as important problem modelling and solution technique because it uses approximate information, and represents uncertainty and vagueness to generate decisions in decision-making problems. The knowledge can be stated in a more natural way by using fuzzy sets and the problems can be greatly simplified in many decisions making processes (Kahraman and Kaya, 2010). In type-1 fuzzy sets, each element has a degree of membership function in the interval [0, 1]. Even though type-1 fuzzy sets can overcome uncertainty, some imperfections are described in literature. Mendel and John (2002) defined the imperfections which are the usage of words, the group of experts, and the noisy data. Therefore, Zadeh (1975) proposed type-2 fuzzy sets having a fuzzy membership function in order to overcome these problems. In contrast to a type-1 fuzzy set, which has the membership grade as a crisp number, an interval type-2 fuzzy sets (IT2Fs) has membership functions which are also fuzzy numbers. Whilst type-1 fuzzy sets have membership function which are two-dimensional, type-2 fuzzy are three-dimensional. The third dimension provides additional degrees of freedom for possibility in models of uncertainty (Uçal Sari et al., 2013).

In the study, firstly, previous studies on aircraft selection were examined. The criteria and the sub-criteria used in the studies were collected into a pool. 3 main criteria groups were then determined by taking these criteria into consideration; technical criteria, economic criteria, and environmental effects criteria. Then 7 sub-criteria for technical criteria, 4 sub-criteria for economic criteria, and 2 sub-criteria for environmental effects criteria were defined. Since it is not possible to use all these sub-criteria in aircraft selection, the sub-criteria which were to be used were determined by taking expert opinions into account. The technical criteria and the economic criteria were separately evaluated by the IT2FAHP method. As a result, the highest-weight sub-criteria determined by decision-makers through the IT2FAHP method were used for aircraft selection. In the next stage, the model of aircraft selection was applied with a total of 8 criteria consisting of 4 technical criteria, 2 economic criteria and 2 environmental effects criteria. After this stage, the weights of these 8 criteria were calculated by using IT2FAHP on the equal comparisons. The weight of these criteria indicates which criteria have the most importance or weight in aircraft selection. In the last stage, the solution was reached by ranking the aircraft to be selected with the IT2FTOPSIS method.

In the literature, many studies have been carried out on aircraft selection using MCDM methods. Dožić (2019) classified the studies in the field of aviation using MCDM methods, however, it is seen that the number of aviation studies using IT2Fs MCDM methods is low. The studies conducted in the field of aviation using type-2 Fuzzy methods are as follows: Deveci et al. (2017) IT2Fs examined route choice using the FTOPSIS method. Görener et al. (2017) addressed the issue of supplier performance evaluation using IT2FFAHP and IT2FTOPSIS. Deveci et al. (2018), improving service quality using MCDM methods was examined. However, no studies have been conducted to investigate aircraft performance using IT2Fs MCDM methods. Although there are studies conducted by using MCDM methods in the aviation literature, it is not seen that the studies used by IT2FAHP and IT2FTOPSIS methods together. Therefore, this study is expected to contribute to the literature by using IT2Fs MCDM methods and focusing on aircraft performance.

2. Literature review

We can classify the conducted studies according to the method and the type of aircraft they examined. For example, Even Swaps Method (Dožić and Kalić, 2013), Roskam (1990) five-step approach method (Harasani, 2006), NAIADE Method (Gomes et al., 2014), AHP method (Dožić and Kalić, 2014; Teoh and Khoo, 2015), Fuzzy set theory method (Bruno et al., 2015), Fuzzy logic and Even Swaps Method (Dožić and Kalić, 2015a), ESM, Regression, Fuzzy logic Method (Dožić and Kalić, 2015b), AHP and Fuzzy Set Theory method (Bruno et al., 2015), FAHP and FANP method (Ozdemir and Basligil, 2016), TOPSIS method (Kiracı and Bakır, 2018b), AHP, COPRAS and MOORA method (Kiracı and Bakır, 2018a) and Linear Physical Programming method (Ilgın, 2019) have all been used for the selection, evaluation or ranking of aircraft types with different specifications and sizes.

In the studies conducted in the literature looking at aircraft selection, in addition to different types of method used, different criteria have also been employed. For instance, Multi-attribute methods were used by See and Lewis (2002) and See et al. (2004) with speed, max range, and number of passengers as criteria. Listes and Dekker (2005) compared 9 commercial aircraft types according to load factor, spill, revenues, operating costs, fleet cost, and profit. In the study, the scenario aggregation-based approach method was used. New Fuzzy multicriteria decision making (MCDM) approach used by Yeh and Chang (2009) with the level of technological advancement, social responsibility, and economic efficiency as criteria and 11 sub-criteria. Givoni and Rietveld (2010) compared 2 and 3 different commercial aircraft types according to air pollution and noise pollution criteria. Analytic Network Process (ANP) method used by Ozdemir et al. (2011) with cost, time, physical attributes and seven other criteria for appropriate aircraft selection. In Sun et al. (2011), max cruise speed, available seat mile, cabin volume per passenger and fuel consumption per seat mile criteria were used for appropriate aircraft selection. ELECTRE, SAW, TOPSIS, and the Taguchi loss function method were used in the study. Even Swaps and AHP methods used by Dožić and Kalić (2013) and Dožić and Kalić (2014) compared two medium-sized commercial aircraft types. Teoh and Khoo (2015) compared 3 commercial aircraft types for airline fleet planning decision-making. Load factor, passengers carried, RPK, ASK, fuel efficiency criteria were determined to evaluate aircraft. AHP and Fuzzy Set Theory methods were used in the study. AHP and Fuzzy Set Theory methods used by Bruno et al. (2015) with load factor, passengers carried, RPK, ASK, and fuel efficiency as criteria. Gomes et al. (2014) focused on the selection of aircraft for regional charter flights in Brazil. Financial, logistic, and 11 Quality Criteria were determined to evaluate aircraft. Cost, Time, Physical Attributes and 10 others criteria were determined. AHP, ESM Regression and Fuzzy logic methods used by Dožić and Kalić (2015a) and Dožić and Kalić (2015b) compared medium-sized commercial aircraft. Ozdemir and Basligil (2016) examined appropriate aircraft selection for Turkish Airlines using the FAHP, FANP and the Choquet integral method. Time, Cost and physical attributes criteria were used. In addition, Maywald et al. (2019) focused on the selection of cargo planes used by the military and developed a model for this. Fuzzy Reference Ideal Method (FRIM) used by Sánchez-Lozano and Rodriguez (2020) examined the appropriate military advanced training aircraft for Spain. Yeh and Chang (2009) evaluated 7 initial training aircraft according to 16 aircraft performance parameters. In the study, the FTOPSIS method was used. Park and O'Kelly (2018) focused on the choice of commercial cost-efficient aircraft fleets.

In literature, there are several AHP applications, but it was first proposed and developed by Saaty (1980). Some of these applications in literature are about FAHP which has the same calculation steps as crisp AHP, also fuzzy set theory has been used to contain linguistic variables for these methods. The FAHP, which is compared with triangular fuzzy membership functions, was first proposed by van Laarhoven and Pedrycz (1983), they developed Saaty's AHP method with fuzzy numbers logarithmic least square method could be used for providing fuzzy weight and fuzzy performance score. Buckley (1985), developed an extension of Saaty's AHP method with fuzzy numbers using the geometric mean method to provide fuzzy weights and performance score. Boender et al. (1989), modified Van Laarhoven and Pedrycz's method and offered a more powerful approach to normalization. Chang (1996), developed FAHP by using triangular fuzzy numbers in pairwise comparison with extent analysis method for synthetic extent value of pairwise comparison. Cheng (1997), built up fuzzy standards with membership function of judgment criteria, and calculated the grade of fuzzy membership function for the performance score. Zeng et al. (2007) proposed an arithmetic averaging method which used an extension of Saaty's AHP method with fuzzy numbers to obtain performance scores. Wang et al. (2019) stated the importance of FAHP.

2.1. Interval Type-2 Fuzzy Analytic Hierarchy Process

Classic AHP is used in a wide range of aircraft selection studies. Nevertheless, IT2FAHP has been used in literature in MCDM. Uçal Sari et al. (2013), which was one of the first studies on this subject, studied a potential application of IT2FS for warehouse selection. Kahraman et al. (2014) developed an IT2FAHP method along with a new ranking method for IT2FS and solved a problem of supplier selection with Buckley's type-1 and IT2FAHP. Both results had the same ranking solutions. Nevertheless, it was concluded that IT2FAHP allowed for wider flexibility in the definition of membership functions. Abdullah and Najib (2014) suggested a new linguistic variable with a ranking approach for IT2FAHP and also compared classic AHP with FAHP. In the results, rankings were consistent while the weights were different in three methods. Celik et al. (2013) set down and evaluated the critical performance factors of humanitarian relief logistics. The proposed method was based on IT2FAHP in setting down the critical performance criteria, some of criteria, such as the management, planning, transportation, and distribution, were found to be more important than others. Oztaysi (2015) suggested a selection method for enterprise information systems. The proposed model was based on IT2FAHP with group decision and was applied on the selection of Enterprise Resource Planning (ERP). It was stated in the study that IT2FNs were more efficient than type 1 fuzzy sets. Ayodele et al. (2018) proposed a method for a geographic information system using IT2FAHP in order to determine the most suitable location of a wind farm for wind farm projects in Nigeria. The model focused on using fuzzy set linguistic judgment. The criteria used were evaluated as economic, social or environmental.

2.2. Interval Type-2 fuzzy TOPSIS

The IT2FTOPSIS method based on interval type-2 fuzzy from TOPSIS has been developed (Ashtiani et al., 2009; Chen and Lee, 2010; Lee and Chen, 2008). Liao (2015) applied IT2FTOPSIS to material selection. Abdullah and Otheman (2013) applied IT2FTOPSIS to supplier selection. Celik et al. (2013) used an integrated novel IT2FTOPSIS method to improve customer satisfaction in public transportation. Chen (2012) applied a comparative study between SAT and TOPSIS in interval type-2 fuzzy environment and found that similarities exist between IT2FSAW and IT2FTOPSIS. Deveci et al. (2018) developed an application of a new route selection for and airline based on IT2FTOPSIS. Dymova et al. (2015) developed a new method of an interval type-2 fuzzy extension of the TOPSIS using alpha cuts. Cevik Onar et al. (2014) presented a method for strategic decision making using IT2FAHP and hesitant TOPSIS methods.

2.3. Interval Type-2 fuzzy hybrid methods

These researches are related to the single models in literature. In addition, some applications based on MCDM methods are used with IT2FAHP such as in the following hybrid study: Kiliç and Kaya (2015), proposed a model based on IT2FAHP and IT2FTOPSIS in order to evaluate an investment projects. They concluded that the presented model was effective to evaluate alternatives in MCDM problems. Also, it provided a wide range of perspective for making a decision. Kiliç and Kaya (2016), proposed a new city-ranking model, based on IT2FAHP and IT2FTOPSIS, in order to evaluate development agencies operating in Turkey. Four different provinces were evaluated by decision makers with linguistic variables for 26 criteria, as a result of the evaluation, the provinces were ranked by scores. Erdogan and Kaya (2016) presented an MCDM methodology based on IT2FSs in the energy sector. They concluded that the methodology gave a perspective for the energy policy of Turkey. Wu et al. (2019b) proposed MCDM based on IT2FAHP and IT2FTOPSIS for the performance assessment of wind power coupling hydrogen storage projects from the point of view of sustainability. Wu et al. (2019a) presented an MCDM based on IT2FAHP in order to optimize renewable energy projects from the perspective of sustainability. Alegoz and Yapicioglu (2019) proposed a MCDM method with IT2FAHP, using TOPSIS and goal programming for supplier selection. In addition to these articles, studies on unmanned aerial vehicles (UAV) have also been conducted (Bravo-Mosquera et al., 2019; Bravo-Mosquera et al., 2017). Schwening and Abdalla (2014) proposed selection of agricultural aircraft based on Fuzzy AHP and Fuzzy TOPSIS. As a result, the MCDM methods can be not only contributed to passenger aircraft selection but also, can be used for other fields in aviation in view of the holistic such as UAV, war aircraft, conceptual design, choosing aircraft configurations and the creation of multidisciplinary optimization etc.

3. Methodology

In this section, we will introduce Interval Type-2 Fuzzy Sets, Interval Type-2 Fuzzy Analytic Hierarchy Process and Interval Type-2 Fuzzy TOPSIS methods used in the study.

3.1. Interval Type-2 fuzzy sets

IT2FSs were firstly presented by Zadeh (1975). It is an extension of type-1 fuzzy sets (Mendel, 2007; Karnik and Mendel, 2001). In comparison with standard fuzzy sets called type-1 having membership function and crisp, IT2FSs used in uncertainty is a better way and having fuzzy membership functions having crisp. IT2FSs are motivated by the affiliation between linguistic variable facts (Mendel and Wu, 2010; Zadeh, 1975). Standard IT2FSs have not mostly applied in the real world, because it contains complex computing stages (Kahraman et al., 2014; Mendel et al., 2006). Nevertheless, IT2FSs represent a more uncertain approach (Mendel and John, 2002; Mendel et al., 2006). IT2FSs are applied widely on fuzzy decision-making problems in literature (Hu and Wang, 2014; Mendel et al., 2006) because of the ease of applying the calculations (Mendel, 2007). Consequently, IT2FSs are more suitable than standard type-1 fuzzy sets in dealing with decision making problems including judgements having uncertainty and subjectiveness.

In the section, we describe IT2FSs briefly. A IT2FSs $\overset{\approx}{A}$ in the universe of discourse X can be presented by a type-2 membership function $\mu_{\overset{\approx}{A}}$, viewed as shown in Eq. (1) (Mendel et al., 2006; Zadeh, 1975; Zeng et al., 2007):

$$\overset{\approx}{A} = \left\{ \left((x,\ u),\ \mu_{\overset{\approx}{A}}(x,\ u) \right) \middle| \forall x \in X,\ \forall u \in J_x \subseteq [0,1],\ 0 \le \mu_{\overset{\approx}{A}}(x,\ \mu) \le 1 \right\} \tag{1}$$

where $J_x$states an interval [0,1]. IT2FSs $\overset{\approx}{A}$ also can be represented as shown in Eq. (2) (Kahraman et al., 2014; Mendel et al., 2006):

$$\overset{\approx}{A} = \int_{x \in X} \int_{u \in J_X} \mu_{\overset{\approx}{A}}(x,\ u) / (x,\ u) \tag{2}$$

where $J_x \subseteq [0,1]$and $\int$state union over all acceptable x and u. Let $\overset{\approx}{A}$ be IT2FSs in the universe of discourse X presented by type-2 membership function $\mu_{\tilde{\tilde{A}}}$ If all,$\mu_{\tilde{\tilde{A}}}(x,u) = 1$ after $\tilde{\tilde{A}}$ is called an IT2FSs (Buckley, 1985; Kahraman et al., 2014; Zadeh, 1975). An IT2FSs $\tilde{\tilde{A}}$ can pass for particular situation of a type-2 fuzzy set, presented as shown *Eq. (3)* and in Fig. 1 (Kahraman et al., 2014; Mendel et al., 2006).

$$\tilde{\tilde{A}} = \int\limits_{x\in X}\int\limits_{u\in J_X} 1/(x,\ u) \tag{3}$$

The upper and lower membership functions of an IT2FSs is based on type-1 membership functions. A trapezoidal IT2FSs is shown as

$$\begin{aligned}\tilde{\tilde{A}} = \left(\widetilde{A_i^U},\widetilde{A_i^L}\right) = \Big(&\left(a_{i1}^U,\ a_{i2}^U,\ a_{i3}^U,\ a_{i4}^U;\ H_1\left(\widetilde{A_i^U}\right),\ H_2\left(\widetilde{A_i^U}\right)\right),\\ &\left(a_{i1}^L,\ a_{i2}^L,\ a_{i3}^L,\ a_{i4}^L;\ H_1\left(\widetilde{A_i^L}\right),\ H_2\left(\widetilde{A_i^L}\right)\right)\Big)\end{aligned}$$

where $\widetilde{A_i^U}$ and $\widetilde{A_i^L}$are type-1 fuzzy sets, $a_{i1}^U,\ a_{i2}^U,\ a_{i3}^U,a_{i4}^U,\ a_{i1}^L,\ a_{i2}^L,\ a_{i3}^L,\ a_{i4}^L$ are the references points of the IT2FSs $\widetilde{A}_i$, $H_j(\widetilde{A_i^U})$; states the membership estimation of the factor $a_{j(j+1)}^U$ in the upper trapezoidal membership function $(\widetilde{A_i^U})$,$1 \le j \le 2$,$H_j(\widetilde{A_i^L})$; also it states the membership estimation of the factor $a_{j(j+1)}^L$ in the lower trapezoidal membership function $(\widetilde{A_i^L})$,$1 \le j \le 2$, $H_1(\widetilde{A_i^U}) \in [0,1]$, $H_2(\widetilde{A_i^U}) \in [0,1]$,$H_1(\widetilde{A_i^L}) \in [0,1]$,$H_2(\widetilde{A_i^L}) \in [0,1]$and $1 \le j \le n$ (S. M. Chen and Lee, 2010; Kahraman et al., 2014).

Definition 1. The upper and lower membership functions of an IT2FSs are type-1 membership functions. A trapezoidal IT2FS is illustrated a

$$\begin{aligned}\tilde{\tilde{A}} = \left(\widetilde{A_i^U},\widetilde{A_i^L}\right) = \Big(\Big(&\left(a_{i1}^U,\ a_{i2}^U,\ a_{i3}^U,\ a_{i4}^U;\ H_1\left(\widetilde{A_i^U}\right),\ H_2\left(\widetilde{A_i^U}\right)\right),\\ &\left(a_{i1}^L,\ a_{i2}^L,\ a_{i3}^L,\ a_{i4}^L;\ H_1\left(\widetilde{A_i^L}\right),\ H_2\left(\widetilde{A_i^L}\right)\right)\Big)\Big).\end{aligned}$$

where $\widetilde{A_i^U}$ and $\widetilde{A_i^L}$are type-1 fuzzy sets, $a_{i1}^U,\ a_{i2}^U,\ a_{i3}^U,a_{i4}^U,\ a_{i1}^L,\ a_{i2}^L,\ a_{i3}^L,\ a_{i4}^L$are the references points of the IT2FSs $\widetilde{A}_i$,$H_j(\widetilde{A_i^U})$ denotes the membership value of the element $a_{j(j+1)}^U$ in the upper trapezoidal membership function $(\widetilde{A_i^U})$,$1 \le j \le 2$,$H_j(\widetilde{A_i^L})$denotes the membership value of the element $a_{j(j+1)}^L$ in the lower trapezoidal membership function $(\widetilde{A_i^L})$, $1 \le j \le 2$, $H_1(\widetilde{A_i^U}) \in [0,1]$, $H_2(\widetilde{A_i^U}) \in [0,1]$, $H_1(\widetilde{A_i^L}) \in [0,1]$, $H_2(\widetilde{A_i^L}) \in [0,1]$and $1 \le j \le n$.

Definition 2. The addition operation between the two trapezoidal IT2FSs $\tilde{\tilde{A}}_1$ and $\tilde{\tilde{A}}_2$ is defined in Eq. (4) as follows.

$$\begin{aligned}\tilde{\tilde{A}}_1 \oplus \tilde{\tilde{A}}_2 &= \left(\widetilde{A_1^U},\widetilde{A_1^L}\right) \oplus \left(\widetilde{A_2^U},\widetilde{A_2^L}\right)\\ &= \Big(\Big(\big(a_{11}^U + a_{21}^U,\ a_{12}^U + a_{22}^U,\ a_{13}^U + a_{23}^U,\ a_{14}^U + a_{24}^U;\\ &\min\left(H_1\left(\widetilde{A_1^U}\right);\ H_1\left(\widetilde{A_2^U}\right)\right),\ \min\left(H_2\left(\widetilde{A_1^U}\right);\ H_2\left(\widetilde{A_2^U}\right)\right)\big),\\ &\big(a_{11}^L + a_{21}^L,\ a_{12}^L + a_{22}^L,\ a_{13}^L + a_{23}^L,\ a_{14}^L + a_{24}^L;\\ &\min\left(H_1\left(\widetilde{A_1^L}\right);\ H_1\left(\widetilde{A_2^L}\right)\right),\ \min\left(H_2\left(\widetilde{A_1^L}\right);\ H_2\left(\widetilde{A_2^L}\right)\right)\big)\Big)\Big).\end{aligned} \tag{4}$$

Definition 3. The subtraction operation between two the trapezoidal IT2FSs $\tilde{\tilde{A}}_1$ and $\tilde{\tilde{A}}_2$ is defined in Eq. (5)as follows.

$$\begin{aligned}\tilde{\tilde{A}}_1 \ominus \tilde{\tilde{A}}_2 &= \left(\widetilde{A_1^U},\widetilde{A_1^L}\right) \ominus \left(\widetilde{A_2^U},\widetilde{A_2^L}\right)\\ &= \Big(\Big(\big(a_{11}^U - a_{24}^U,\ a_{12}^U - a_{23}^U,\ a_{13}^U - a_{22}^U,\ a_{14}^U - a_{21}^U;\\ &\min\left(H_1\left(\widetilde{A_1^U}\right);\ H_1\left(\widetilde{A_2^U}\right)\right),\ \min\left(H_2\left(\widetilde{A_1^U}\right);\ H_2\left(\widetilde{A_2^U}\right)\right)\big),\\ &\big(a_{11}^L - a_{24}^L,\ a_{12}^L - a_{23}^L,\ a_{13}^L - a_{22}^L,\ a_{14}^L - a_{21}^L;\\ &\min\left(H_1\left(\widetilde{A_1^L}\right);\ H_1\left(\widetilde{A_2^L}\right)\right),\ \min\left(H_2\left(\widetilde{A_1^L}\right);\ H_2\left(\widetilde{A_2^L}\right)\right)\big)\Big)\Big).\end{aligned} \tag{5}$$

Definition 4. The multiplication operation between two the trapezoidal IT2FSs $\tilde{\tilde{A}}_1$ and $\tilde{\tilde{A}}_2$ is defined in Eq. (6) as follows.

$$\begin{aligned}\tilde{\tilde{A}}_1 \otimes \tilde{\tilde{A}}_2 &= \left(\widetilde{A_1^U},\widetilde{A_1^L}\right) \otimes \left(\widetilde{A_2^U},\widetilde{A_2^L}\right)\\ &= \Big(\Big(\big(a_{11}^U x a_{21}^U,\ a_{12}^U x a_{22}^U,\ a_{13}^U x a_{23}^U,\ a_{14}^U x a_{24}^U;\\ &\min\left(H_1\left(\widetilde{A_1^U}\right);\ H_1\left(\widetilde{A_2^U}\right)\right),\ \min\left(H_2\left(\widetilde{A_1^U}\right);\ H_2\left(\widetilde{A_2^U}\right)\right)\big),\\ &\big(a_{11}^L x a_{21}^L,\ a_{12}^L x a_{22}^L,\ a_{13}^L x a_{23}^L,\ a_{14}^L x a_{24}^L;\\ &\min\left(H_1\left(\widetilde{A_1^L}\right);\ H_1\left(\widetilde{A_2^L}\right)\right),\ \min\left(H_2\left(\widetilde{A_1^L}\right);\ H_2\left(\widetilde{A_2^L}\right)\right)\big)\Big)\Big).\end{aligned} \tag{6}$$

Definition 5. The arithmetic operation between the trapezoidal IT2FSs $\tilde{\tilde{A}}_1$ and a crisp value $k > 0$ is defined in Eq. (7) and Eq. (8) as follows.

$$\begin{aligned}k\tilde{\tilde{A}}_1 = \Big(\Big(&\big(k \times a_{11}^U,\ k \times a_{12}^U,\ k \times a_{13}^U,\ k \times a_{14}^U;\ \left(H_1\left(\widetilde{A_1^U}\right),\ H_2\left(\widetilde{A_1^U}\right)\right),\\ &\big(k \times a_{11}^L,\ k \times a_{12}^L,\ k \times a_{13}^L,\ k \times a_{14}^L;\ \left(H_1\left(\widetilde{A_1^L}\right),\ H_2\left(\widetilde{A_1^L}\right)\right)\Big)\Big).\end{aligned} \tag{7}$$

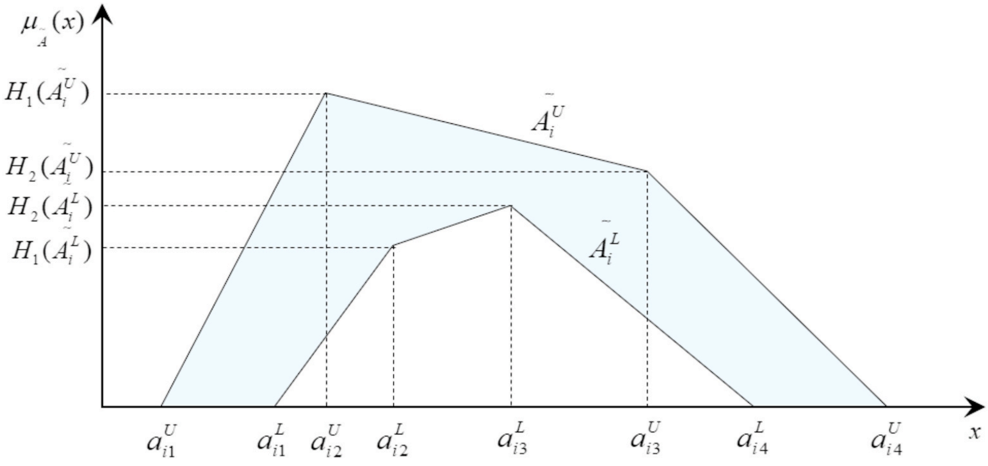

Fig. 1. Interval type 2 fuzzy numbers.

$$\frac{\overset{\simeq}{A}_1}{k} = \left(\left(\left(\left(\frac{1}{k} \times a_{11}^U,\ \frac{1}{k} \times a_{12}^U,\ \frac{1}{k} \times a_{13}^U,\ \frac{1}{k} \times a_{14}^U;\ \left(H_1\left(\widetilde{A_1^U}\right),\ H_2\left(\widetilde{A_1^U}\right)\right)\right),\right.\right.\right. \tag{8}$$

$$\left.\left(\frac{1}{k} \times a_{11}^L,\ \frac{1}{k} \times a_{12}^L,\ \frac{1}{k} \times a_{13}^L,\ \frac{1}{k} \times a_{14}^L;\ \left(H_1\left(\widetilde{A_1^L}\right),\ H_2\left(\widetilde{A_1^L}\right)\right)\right)\right).$$

3.2. *Interval Type-2 Fuzzy Analytic Hierarchy Process*

The AHP was developed by Saaty (1980). It contains a goal, alternatives having criteria by linking to other alternatives, a hierarchy structure of decision-making problem in brief. It is a weighted based-scale method and can identify and involve mismatches in the process of decision-making (Zadeh, 1965). In an ordinary AHP method, specialists have to assign a significant score between 1 and 9 scale to the pairwise comparison so that the priority vector can be defined. In addition, element comparison contains frequently some amount of vagueness and subjectiveness. At times, specialists cannot compare two factors because of deficient knowledge (Büyüközkan et al., 2004). At this stage, IT2FSs that ensure a mathematical strength to secure the vagueness conjunction can be utilized. The linguistic variables and their type-2 fuzzy scales which are utilized in AHP are defined and shown in Table 1.where;

$$1/\overset{\approx}{a} = \left(\left(\frac{1}{a_{14}^U}, \frac{1}{a_{13}^U}, \frac{1}{a_{12}^U}, \frac{1}{a_{11}^U}, H_1\left(a_{12}^U\right), H_2\left(a_{13}^U\right)\right),\right.$$

$$\left.\left(\frac{1}{a_{24}^L}, \frac{1}{a_{23}^L}, \frac{1}{a_{22}^L}, \frac{1}{a_{21}^L}, H_1\left(a_{22}^L\right), H_2\left(a_{23}^L\right)\right)\right).$$

The geometric mean of k type-2 fuzzy sets are calculated as follows for kth decision makers. The factors of the pairwise comparison matrices are measured by utilizing the method of geometric mean as shown in *Eq. (11)* for IT2FSs.

Table 1
IT2FSs scales of the linguistic variables (Kahraman et al., 2014). The steps of IT2FAHP method are as follows (Kahraman et al., 2014).

Step 1: Built the matrix type-2 fuzzy pairwise comparison $\overset{\approx}{A}$ and built the average matrix of decision. Each factor of the pairwise comparison matrix is comprised of an IT2FSs. The pairwise comparison matrix is shown in Eq. (9):

$$A_k{}^{\approx} = \left(a_{ij}^k \approx\right)_{nxn} = \begin{bmatrix} 1 & \overset{\approx}{a}_{12}^k & \cdots & \overset{\approx}{a}_{1n}^k \\ \overset{\approx}{a}_{21}^k & 1 & \cdots & \overset{\approx}{a}_{2n}^k \\ \vdots & \vdots & \ddots & \vdots \\ \overset{\approx}{a}_{n1}^k & \overset{\approx}{a}_{n2}^k & \cdots & 1 \end{bmatrix} = \begin{bmatrix} 1 & \overset{\approx}{a}_{12}^k & \cdots & \overset{\approx}{a}_{1n}^k \\ 1\Big/\overset{\approx}{a}_{12}^k & 1 & \cdots & \overset{\approx}{a}_{2n}^k \\ \vdots & \vdots & \ddots & \vdots \\ 1\Big/\overset{\approx}{a}_{1n}^k & 1\Big/\overset{\approx}{a}_{1n}^k & \cdots & 1 \end{bmatrix} \tag{9}$$

$$\overset{\approx}{A} = \left(\overset{\approx}{a}_{ij}\right)_{nxn} \tag{10}$$

Linguistic variables		Interval type-2 fuzzy sets
AS	Absolutely Strong	((7, 8, 9, 9; 1, 1), (7.2, 8.2, 8.8, 9.0; 0.8, 0.8))
VS	Very Strong	((5, 6, 8, 9; 1, 1), (5.2, 6.2, 7.8, 8.8; 0.8, 0.8))
FS	Fairly Strong	((3, 4, 6, 7; 1, 1), (3.2, 4.2, 5.8, 6.8; 0.8, 0.8))
SS	Slightly Strong	((1, 2, 4, 5; 1, 1), (1.2, 2.2, 3.8, 4.8; 0.8, 0.8))
E	Exactly Strong	((1, 1, 1, 1; 1, 1), (1, 1, 1, 1; 1, 1))
If parameter *i* has one of the linguistic variables appointed to it when match with parameter *j*, then *j* has the mutual value when match with *I*		Reciprocals of the above

$$\overset{\approx}{a}_{ij} = \left[\overset{\approx}{a}_{ij}^1 \otimes \overset{\approx}{a}_{ij}^2 \otimes \cdots \otimes \overset{\approx}{a}_{ij}^k\right]^{1/\mathrm{k}} = \sqrt[k]{\overset{\approx}{a}_{ij}^1 \otimes \overset{\approx}{a}_{ij}^2 \otimes \cdots \otimes \overset{\approx}{a}_{ij}^k} \tag{11}$$

where;

$$\sqrt[n]{\overset{\approx}{a}_{ij}} = \left(\left(\sqrt[n]{a_{ij1}^U}, \sqrt[n]{a_{ij2}^U}, \sqrt[n]{a_{ij3}^U}, \sqrt[n]{a_{ij4}^U}; H_1^U\left(\widetilde{a_{ij}}\right), H_2^U\left(\widetilde{a_{ij}}\right),\right),\right.$$

$$\left.\left(\sqrt[n]{a_{ij1}^L}, \sqrt[n]{a_{ij2}^L}, \sqrt[n]{a_{ij3}^L}, \sqrt[n]{a_{ij4}^L}; H_1^L\left(\widetilde{a_{ij}}\right), H_2^L\left(\widetilde{a_{ij}}\right),\right)\right).$$

For the evaluation method, the linguistic variables are given in Table 1. The geometric mean is used to aggregate decision makers.

Step 2: Analyse the consistent of the fuzzy pairwise comparison matrices. Suppose $A = [a_{ij}]$is a positive reciprocal matrix. $\overset{\approx}{A} = [\overset{\approx}{a}_{ij}]$ is a positive reciprocal matrix. If the result of the comparisons of $A = [a_{ij}]$ is consistent, it can refer to the conclusion of the comparisons of $\overset{\approx}{A} = [\overset{\approx}{a}_{ij}]$ is consistent (Buckley, 1985).

Step 3: Calculate the fuzzy geometric mean for each criterion. $\overset{\approx}{r}_i$ refers to the geometric mean of each row of $\overset{\approx}{A} = [\overset{\approx}{a}_{ij}]$is computed in Eq. (12).

$$\overset{\approx}{r}_i = \left[\overset{\approx}{a}_{i1} \otimes \overset{\approx}{a}_{i2} \otimes \cdots \otimes \overset{\approx}{a}_{in}\right]^{1/n} \tag{12}$$

where;

$$\sqrt[n]{\overset{\approx}{a}_{ij}} = \left(\left(\sqrt[n]{a_{ij1}^U}, \sqrt[n]{a_{ij2}^U}, \sqrt[n]{a_{ij3}^U}, \sqrt[n]{a_{ij4}^U}; H_1^U\left(\widetilde{a_{ij}}\right), H_2^U\left(\widetilde{a_{ij}}\right),\right),\right.$$

$$\left.\left(\sqrt[n]{a_{ij1}^L}, \sqrt[n]{a_{ij2}^L}, \sqrt[n]{a_{ij3}^L}, \sqrt[n]{a_{ij4}^L}; H_1^L\left(\widetilde{a_{ij}}\right), H_2^L\left(\widetilde{a_{ij}}\right),\right)\right).$$

Step 4: Calculate the weights of criteria by normalization. The type-2 fuzzy weight of the i^{th} criterion is computed in Eq. (13).

$$\overset{\approx}{w}_i = \overset{\approx}{r}_i \otimes \left[\overset{\approx}{r}_1 \oplus \cdots \oplus \overset{\approx}{r}_i \oplus \cdots \oplus \overset{\approx}{r}_n\right]^{-1} \tag{13}$$

where;

$$\frac{\overset{\approx}{a}}{\overset{\approx}{b}} = \left(\left(\frac{a_1^U}{b_4^U}, \frac{a_2^U}{b_3^U}, \frac{a_3^U}{b_2^U}, \frac{a_4^U}{b_1^U}, min\left(H_1^U\left(\tilde{a}\right), H_1^U\left(\tilde{b}\right), min\left(H_2^U\left(\tilde{a}\right), H_2^U\left(\tilde{b}\right)\right)\right)\right),\right.$$

$$\left.\left(\frac{a_1^L}{b_4^L}, \frac{a_2^L}{b_3^L}, \frac{a_3^L}{b_2^L}, \frac{a_4^L}{b_1^L}, min\left(H_1^L\left(\tilde{a}\right), H_1^L\left(\tilde{b}\right), min\left(H_2^L\left(\tilde{a}\right), H_2^L\left(\tilde{b}\right)\right)\right)\right)\right).$$

Step 5: Although there are several methods of defuzzification of the type-2 fuzzy weights method in existing literature; the method of criteria Center of Area (COA) is preferred to defuzzify the lower and upper membership values of IT2FSs into Best Nonfuzzy Performance (BNP) value in the paper. The BNP value is worked out in Eq. (14) as below (Bellman and Zadeh, 1970; Kılıç and Kaya, 2015). Then eventually it is finalized by applying basic arithmetic mean for each defuzzification value of $\widetilde{A_i^U}$ and $\widetilde{A_i^L}$.

$$\widetilde{w_j} = \frac{\int x\mu(x)dx}{\int \mu(x)dx}$$

$$= \left(w_{j3}w_{j4} - w_{j1}w_{j2} + \frac{\left(w_{j4} - w_{j3}\right)^2 - \left(w_{j2} - w_{j1}\right)^2}{3}\right)\Big/\left(w_{j3} + w_{j4} - w_{j1} - w_{j2}\right) \tag{14}$$

3.3. *Interval Type-2 Fuzzy TOPSIS*

The TOPSIS method first was proposed by Hwang and Yoon (1981). In this study IT2FTOPSIS is taken into consideration and handled based on fuzzy multiple attributes group decision-making problems (Chen and

Table 2
Linguistic terms and its corresponding IT2FSs (Chen and Lee, 2010).

Linguistic terms		Interval type-2 fuzzy sets
VL	Very Low	((0, 0, 0, 0.1; 1, 1), (0, 0, 0, 0.05; 0.9, 0.9))
L	Low	((0, 0.1, 0.1, 0.3; 1, 1), (0.05, 0.1, 0.1, 0.2; 0.9, 0.9))
ML	Medium Low	((0.1, 0.3, 0.3, 0.5; 1, 1), (0.2, 0.3, 0.3, 0.4; 0.9, 0.9))
M	Medium	((0.3, 0.5, 0.5, 0.7; 1, 1), (0.4, 0.5, 0.5, 0.6; 0.9, 0.9))
MH	Medium High	((0.5, 0.7, 0.7, 0.9; 1, 1), (0.6, 0.7, 0.7, 0.8; 0.9, 0.9))
H	High	((0.7, 0.9, 0.9, 1; 1, 1), (0.8, 0.9, 0.9, 0.95; 0.9, 0.9))
VH	Very High	((0.9, 1, 1, 1; 1, 1), (0.95, 1, 1, 1; 0.9, 0.9))

Lee, 2010; Lee and Chen, 2008). Assume that there is a set X of alternatives, where $X = \{x_1, x_2, .., x_n\}$and assume that there is a set F of attributes, where $F = \{f_1, f_2, .., f_m\}$. Assume that there are k decision-makers $D_1, D_2, ..., and\, D_k$ The set F of attributes can be divided into two sets F_1 and F_2, where F_1 denotes the set of benefit attributes, F_2 denotes the set of cost attributes $F_1 \cap F_2 = \phi$ and $F_1 \cup F_2 = F$. In Table 2, Linguistic terms and its corresponding IT2FSs has been used for TOPSIS (Chen and Lee, 2010). The proposed method is now presented as follows:

Step 1: Construct the decision matrix Y_p of the p^{th} decision maker and construct the average decision matrix Y, respectively in Eq. (15), shown as follows;

$$Y_p = \left(\overset{\approx}{f}{}_{ij}^{p}\right)_{mxn} = \begin{array}{c|cccc|} & x_1 & x_2 & \cdots & x_n \\ f_1 & \overset{\approx}{f}{}_{11}^{p} & \overset{\approx}{f}{}_{12}^{p} & \cdots & \overset{\approx}{f}{}_{1n}^{p} \\ f_2 & \overset{\approx}{f}{}_{21}^{p} & \overset{\approx}{f}{}_{22}^{p} & \cdots & \overset{\approx}{f}{}_{2n}^{p} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ f_m & \overset{\approx}{f}{}_{m1}^{p} & \overset{\approx}{f}{}_{m2}^{p} & \cdots & \overset{\approx}{f}{}_{mn}^{p} \end{array} \tag{15}$$

$$Y = \left(\overset{\approx}{f}_{ij}\right)_{mxn}, \tag{16}$$

Where $\overset{\approx}{f}_{ij} = \overset{\approx}{f}{}_{ij}^{1} \oplus \frac{\overset{\approx}{f}{}_{ij}^{2} \oplus \cdots \oplus \overset{\approx}{f}{}_{ij}^{k}}{k}$, $\overset{\approx}{f}_{ij}$ is an IT2FSs, $1 \le i \le m$, $1 \le j \le n$, $1 \le p \le k$, and k denotes the number of decision makers in Eq. (16).

Step 2: Construct the weighting matrix W_p of the attributes of the p^{th} decision makers and construct the average weighting matrix W, respectively in Eq. (17), shown as follows:

$$W_p = \left(\overset{\approx}{w}{}_i^p\right)_{1xm} = \begin{array}{c} \begin{matrix} f_1 & f_2 & \cdots & f_m \end{matrix} \\ \left[\overset{\approx}{w}{}_1^p \overset{\approx}{w}{}_2^p \cdots \overset{\approx}{w}{}_m^p\right] \end{array} \tag{17}$$

$$W = \left(\overset{\approx}{w}_i\right)_{1xm}, \tag{18}$$

Where $\overset{\approx}{w}_i = \overset{\approx}{w}{}_i^1 \oplus \frac{\overset{\approx}{w}{}_i^2 \oplus \cdots \oplus \overset{\approx}{w}{}_i^k}{k}$, $\overset{\approx}{w}_i$ is an IT2FSs, $1 \le i \le m$. and $1 \le p \le k$, and k denotes the number of decision makers in Eq. (18).

Step 3: Construct the weighted decision matrix Y_w in Eq. (19).

$$Y_w = \left(\overset{\approx}{v}_{ij}\right)_{mxn} = \begin{array}{c|cccc|} & x_1 & x_2 & \cdots & x_n \\ f_1 & \overset{\approx}{v}_{11} & \overset{\approx}{v}_{12} & \cdots & \overset{\approx}{v}_{1n} \\ f_2 & \overset{\approx}{v}_{21} & \overset{\approx}{v}_{22} & \cdots & \overset{\approx}{v}_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ f_m & \overset{\approx}{v}_{m1} & \overset{\approx}{v}_{m2} & \cdots & \overset{\approx}{v}_{mn} \end{array} \tag{19}$$

Where $\overset{\approx}{v}_{ij} = \overset{\approx}{w}_{ij} \otimes \overset{\approx}{f}_{ij}$,$1 \le i \le m$. and $1 \le j \le n$.

Step 4: Based on Eq. (9) calculate the ranking value $Rank(\overset{\approx}{v}_{ij})$ of the IT2FSs $\overset{\approx}{v}_{ij}$, where $1 \le j \le n$. Construct the ranking weighted decision matrix Y_w^* in Eq. (20) and Eq. (21).

$$Y_w^* = \left(Rank\left(\overset{\approx}{v}_{ij}\right)\right)_{mxn}, \tag{20}$$

Where $1 \le i \le m$. and $1 \le j \le n$.

Lee and Chen (2008) presented the concept of ranking values of trapezoidal IT2FSs. Let $\overset{\approx}{A}_i$be an IT2FSs. The ranking value $Rank(\overset{\approx}{A}_i)$ of the trapezoidal IT2FSs $\overset{\approx}{A}_i$ is defined as follows;

$$\begin{aligned} Rank\left(\overset{\approx}{A}_i\right) = {} & M_1\left(\tilde{A}_i^U\right) + M_1\left(\tilde{A}_i^L\right) + M_2\left(\tilde{A}_i^U\right) + M_2\left(\tilde{A}_i^L\right) + M_3\left(\tilde{A}_i^U\right) + M_3\left(\tilde{A}_i^L\right) \\ & - \frac{1}{4}\left(S_1\left(\tilde{A}_i^U\right) + S_1\left(\tilde{A}_i^L\right) + S_2\left(\tilde{A}_i^U\right) + S_2\left(\tilde{A}_i^L\right) + S_3\left(\tilde{A}_i^U\right) + S_3\left(\tilde{A}_i^L\right)\right. \\ & \left. + S_4\left(\tilde{A}_i^U\right) + S_4\left(\tilde{A}_i^L\right)\right) + H_1\left(\tilde{A}_i^U\right) + H_1\left(\tilde{A}_i^L\right) + H_2\left(\tilde{A}_i^U\right) + H_2\left(\tilde{A}_i^L\right) \end{aligned} \tag{21}$$

Where $M_p(\tilde{A}_i^j)$ denotes the average of the elements a_{ip}^j and $a_{i(p+1)}^j$, $M_p\left(\tilde{A}_i^j\right) = \frac{1}{2}(a_{ip}^j + a_{i(p+1)}^j)$, $1 \le p \le 3$, $S_q(\tilde{A}_i^j)$ denotes the standard deviation of the elements a_{iq}^j and $a_{i(q+1)}^j$, $S_q(\tilde{A}_i^j) = \sqrt{\frac{1}{2}\sum_{k=q}^{q+1}\left(a_{ik}^j - \frac{1}{2}\sum_{k=q}^{q+1} a_{ik}^j\right)^2}$, $1 \le p \le 3$, $S_4(\tilde{A}_i^j)$ denotes the standard deviation of the elements a_{i1}^j, a_{i2}^j, a_{i3}^j, a_{i4}^j, $S_4(\tilde{A}_i^j) = \sqrt{\frac{1}{4}\sum_{k=1}^{4}\left(a_{ik}^j - \frac{1}{4}\sum_{k=1}^{4} a_{ik}^j\right)^2}$, $H_P(\tilde{A}_i^j)$denotes the membership value of the element $a_{i(q+1)}^j$in the trapezoidal membership function $\tilde{A}_i^j$, $1 \le p \le 2, j \in \{U, L\}$ and $1 \le i \le n$. In Eq. (21), the summation of $M_1(\tilde{A}_i^U)$, $M_1(\tilde{A}_i^L)$, $M_2(\tilde{A}_i^U)$, $M_2(\tilde{A}_i^L)$, $M_3(\tilde{A}_i^U)$, $M_3(\tilde{A}_i^L)$, $H_1(\tilde{A}_i^U)$, $H_1(\tilde{A}_i^L)$, $H_2(\tilde{A}_i^U)$ and $H_2(\tilde{A}_i^L)$ are called the basic ranking score, where we deduct the average of $S_1(\tilde{A}_i^U)$, $S_1(\tilde{A}_i^L)$, $S_2(\tilde{A}_i^U)$, $S_2(\tilde{A}_i^L)$, $S_3(\tilde{A}_i^U)$, $S_3(\tilde{A}_i^L)$, $S_4(\tilde{A}_i^U)$ and $S_4(\tilde{A}_i^L)$from the basic ranking score to give the dispersive IT2FSs a penalty, where $1 \le i \le n$.

Step 5: Determine the positive ideal solution $x^+ = (v_1^+, v_2^+, ..., v_m^+)$ and the negative ideal solution $x^- = (v_1^-, v_2^-, ..., v_m^-)$ in Eq. (22) and Eq. (23), where;

$$v_i^+ = \begin{cases} \max\limits_{1 \le j \le n}\left\{Rank\left(\overset{\approx}{v}_{ij}\right)\right\}, & if\ f_i \in F_1 \\ \min\limits_{1 \le j \le n}\left\{Rank\left(\overset{\approx}{v}_{ij}\right)\right\}, & if\ f_i \in F_2 \end{cases} \tag{22}$$

and

$$v_i^- = \begin{cases} \min\limits_{1 \le j \le n}\left\{Rank\left(\overset{\approx}{v}_{ij}\right)\right\}, & if\ f_i \in F_1 \\ \max\limits_{1 \le j \le n}\left\{Rank\left(\overset{\approx}{v}_{ij}\right)\right\}, & if\ f_i \in F_2 \end{cases} \tag{23}$$

Where F_1 denotes the set benefit attributes, F_2denotes the set of cost attributes, and $1 \le i \le m$.

Step 6: Calculate the distance $d^+(x_j)$ between each alternative x_j and the positive ideal solution x^+ in Eq. (24) and Eq. (25), shown as follows:

$$d^{+}\left(x_j\right)=\sqrt{\sum_{i=1}^{m}\left(Rank\left(\overset{\approx}{v}_{ij}\right)-v_i^{+}\right)^2}, \tag{24}$$

Where $1 \leq j \leq n$. calculate the distance $d^{-}(x_j)$ between each alternative $x_j$and the negative ideal solution x^{-}, shown as follows:

$$d^{-}\left(x_j\right)=\sqrt{\sum_{i=1}^{m}\left(Rank\left(\overset{\approx}{v}_{ij}\right)-v_i^{-}\right)^2}, \tag{25}$$

Where $1 \leq j \leq n$.

Step 7: Calculate the relative degree of closeness $C(x_j)$ of $x_j$with respect to the positive ideal solution, Eq. (26), shown follows

$$C(x_j)=\frac{d^{-}(x_j)}{d^{+}(x_j)+d^{-}(x_j)}, \tag{26}$$

Where $1 \leq j \leq n$.

Step 8: Sort of the values of $C(x_j)$ in a descending sequences, where $1 \leq j \leq n$.The larger the value of $C(x_j)$, the higher the preference of the alternative x_j, where $1 \leq j \leq n$.

4. Application

We have proposed a model for aircraft selection. The model based on IT2FAHP and IT2FTOPSIS methods. In Table 3, specification of the aircraft to be selected are given. A flowchart of the proposed model is shown in Fig. 2.

Similar criteria used in the literature regarding aircraft selection were classified and they were categorized into 3 different groups in terms of Technical, Economic and Environmental. 4 criteria among 7 Technical criteria and 2 criteria among 4 Economic criteria have been computed by means of IT2FAHP as a first phase. These criteria along with 2 criteria related to Environmental have been computed by IT2FAHP as a second phase in order to calculate weight or criteria for IT2FTOPSIS method.

4.1. *First phase determining the criteria by IT2FAHP*

In this section, first phase of IT2FAHP is used for criteria in order to determine criteria to be used for second phase of IT2FAHP and selection of aircraft by means of IT2FTOPSIS.

Step 1: The criteria used in literature are summarized and classified in Table 4.

Table 3
Aircrafts specification.

	Airbus A320neo	Airbus A321neo	Boeing 737 MAX 8	Boeing 737 MAX 9
Seat Capacity	150–180	170–210	162–178	178–193
Fuel Consumption	2.79 kg/km	3.30 kg/km	3.04 L/100 km	3.30 L/100 km
Maximum Take-Off Weight	79.00 tonnes	93.50 tonnes	82.00 tonnes	88.00 tonnes
Price of Aircraft	110,6	129,5	121,6	128,9
Fuel Per Seat	2.25 L/100 km	2.19 L/100 km	2.28 L/100 km	2.28 L/100 km

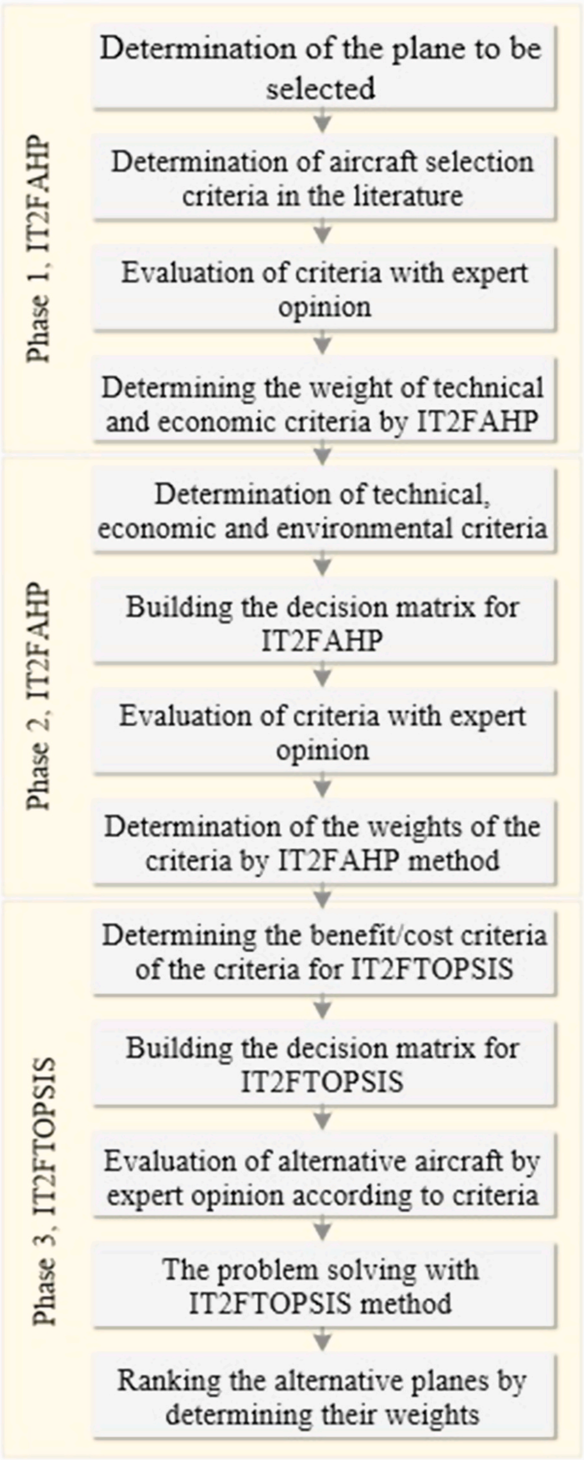

Fig. 2. Proposed methodology.

Table 4
Summarized classification of criteria in literature.

C_1 Technical Aspects	C_2 Economic Aspects	C_3 Environmental Aspects
C_{12} Range	C_{21} Maintenance Cost	C_{31} Pollution
C_{12} Fuel Consumption Per Seat Mile	C_{22} Salvage Cost	C_{32} Noise
C_{13} Speed	C_{23} Operating Cost	
C_{14} Useful Life of the Aircraft	C_{24} Price of Aircraft	
C_{15} Landing and Take-Off Distance		
C_{16} Maximum Take-Off Weight		
C_{17} Aircraft Seat Capacity		

Step 2: Five decision makers have evaluated criteria of Technical and Economic in order to compute by IT2FAHP. The criteria of *Technical Aspects* and *Economic Aspects* are presented in Table 5 and Table 8.

Step 3: The elements of the pairwise comparison matrices are calculated by using the geometric mean method. They are calculated through Eq. (11) as follows for $\overset{\approx}{a}_{12}$ which is belonging to the criteria of *Technical Aspects* in Table 5:

$\overset{\approx}{a}_{12} = [\overset{\approx}{a}{}^{1}_{12} \otimes \overset{\approx}{a}{}^{2}_{12} \otimes \overset{\approx}{a}{}^{2}_{12} \otimes \overset{\approx}{a}{}^{2}_{12} \otimes \overset{\approx}{a}{}^{5}_{12}]^{1/5}$ according to *Eq. (11)* and five decision-makers.

$$\begin{aligned}\overset{\approx}{a}_{12} &= [(1,\ 1,\ 1,\ 1;\ 1,\ 1)(1,\ 1,\ 1,\ 1;\ 1,\ 1)\otimes(1,\ 2,\ 4,\ 5;\ 1,\ 1)(1.2,\ 2.2,\ 3.8,\ 4.8;\ 0.8,\ 0.8)\otimes\\ &(5,\ 6,\ 8,\ 9;\ 1,\ 1)(5.2,\ 6.2,\ 7.8,\ 7.8;\ 0.8,\ 0.8)\otimes(5,\ 6,\ 8,\ 9;\ 1,\ 1)(5.2,\ 6.2,\ 7.8,\ 7.8;\ 0.8,\ 0.8)\otimes\\ &(5,\ 6,\ 8,\ 9;\ 1,\ 1)(5.2,\ 6.2,\ 7.8,\ 7.8;\ 0.8,\ 0.8)]^{5}\\ &= (1.38,\ 3.78,\ 4.82,\ 5.24;\ 1,\ 1)(3.29,\ 3.90,\ 4.71,\ 5.16;\ 0.8,\ 0.8)\end{aligned}$$

The remaining pairwise comparison matrices are calculated the same way as comparison matrix presented in Table 6.

$\overset{\approx}{r}_i = [\overset{\approx}{a}_{i1} \otimes \overset{\approx}{a}_{i2} \otimes \overset{\approx}{a}_{i3} \otimes \overset{\approx}{a}_{i4} \otimes \overset{\approx}{a}_{i5} \otimes \overset{\approx}{a}_{i6} \otimes \overset{\approx}{a}_{i7}]^{1/7}$according to *Eq. (12)*

$$\begin{aligned}\overset{\approx}{r}_1 &= [(1,\ 1,\ 1,\ 1;\ 1,\ 1)(1,\ 1,\ 1,\ 1;\ 1,\ 1)\otimes\\ &(0.19,\ 0,22,\ 0.30,\ 0.38;\ 1,\ 1)(0.20,\ 0.22,\ 0.29,\ 0.36;\ 0.8,\ 0.8)\otimes\\ &(1.38,\ 3.78,\ 4.82,\ 5.24;\ 1,\ 1)(3.29,\ 3.90,\ 4.74,\ 5.16;\ 0.8,\ 0.8)\\ &\otimes\ (0.38,\ 0.20,\ 0.33,\ 0.54;\ 1,\ 1)(0.17,\ 0.20,\ 0.31,\ 0.48;\ 0.8,\ 0.8)\\ &\otimes\ (1.55,\ 1.74,\ 2.05,\ 2.18;\ 1,\ 1)(1.59,\ 1.78,\ 2.02,\ 2.15;\ 0.8,\ 0.8)\\ &\otimes\ (0.37,\ 0.43,\ 0.57,\ 0.69;\ 1,\ 1)(0.38,\ 0.44,\ 0.56,\ 0.66;\ 0.8,\ 0.8)\\ &\otimes\ (0.15,\ 0.17,\ 0.28,\ 0.42;\ 1,\ 1)(0.15,\ 0.18,\ 0.26,\ 0.38;\ 0.8,\ 0.8)]^{1/7}\\ &= (0.51,\ 0.58,\ 0.77,\ 0.95;\ 1,\ 1)(0.52,\ 0.50,\ 0.74,\ 0.90;\ 0.8,\ 0.8)\end{aligned}$$

The remain $\overset{\approx}{r}_i$ are computed in the same way as below;

$$\overset{\approx}{r}_2 = (1.38,\ 2.61,\ 3.68,\ 4.19;\ 1,\ 1)(2.11,\ 2.73,\ 3.57,\ 4.09;\ 0.8,\ 0.8)$$

$$\overset{\approx}{r}_3 = (0.30,\ 0.34,\ 0.45,\ 0.79;\ 1,\ 1)(0.31,\ 0.35,\ 0.44,\ 0.53;\ 0.8,\ 0.8)$$

$$\overset{\approx}{r}_4 = (0.81,\ 1.29,\ 2.07,\ 2.35;\ 1,\ 1)(1.00,\ 1.37,\ 1.98,\ 2.50;\ 0.8,\ 0.8)$$

$$\overset{\approx}{r}_5 = (0.34,\ 0.37,\ 0.50,\ 0.79;\ 1,\ 1)(0.34,\ 0.38,\ 0.48,\ 0.59;\ 0.8,\ 0.8)$$

$$\overset{\approx}{r}_6 = (0.69,\ 0.82,\ 1.17,\ 1.51;\ 1,\ 1)(0.72,\ 0.85,\ 1.13,\ 1.42;\ 0.8,\ 0.8)$$

$$\overset{\approx}{r}_7 = (1.06,\ 1.44,\ 2.19,\ 2.67;\ 1,\ 1)(1.14,\ 1.52,\ 2.11,\ 2.56;\ 0.8,\ 0.8)$$

Step 5: The type-2 fuzzy weights are computed by normalization as below:

$\overset{\approx}{w}_i = \overset{\approx}{r}_i \otimes [\overset{\approx}{r}_1 \oplus \overset{\approx}{r}_2 \oplus \overset{\approx}{r}_3 \oplus \overset{\approx}{r}_4 \oplus \overset{\approx}{r}_5 \oplus \overset{\approx}{r}_6 \oplus \overset{\approx}{r}_7]^{-1}$according to *Eq. (13)*

Table 5
Linguistic variables of the pairwise comparison matrix for C1 Technical Aspects.

	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}
C_{11}	E,E,E,E,E	E,SS,VS,VS,VS	E,1/AS,1/VS,1/FS,1/FS	SS,SS,SS,FS,AS	E,E,E,1/FS,1/FS	1/FS,E,FS,FS,VS	SS,SS,FS,VS,VS
C_{12}	E,1/SS,1/VS,1/VS,1/VS	E,E,E,E,E	1/AS,1/AS,1/FS,1/FS,E	1/VS,1/SS,1/SS,1/SS,SS	1/AS,1/VS,1/FS,1/FS,1/SS	1/VS,1/FS,1/FS,1/SS,1/SS	1/FS,1/FS,1/FS,1/SS,E
C_{13}	E,AS,VS,FS,FS	AS,AS,FS,FS,E	E,E,E,E,E	SS,SS,FS,FS,VS	1/VS,1/SS,E,E,FS	1/SS,E,FS,FS,VS	SS,FS,FS,VS,VS
C_{14}	1/SS,1/SS,1/SS,1/FS,1/AS	VS,SS,SS,SS,1/SS	1/SS,1/SS,1/FS,1/FS,1/VS	E,E,E,E,E	1/AS,1/VS,1/SS,1/SS,FS	1/FS,1/SS,1/SS,1/SS,FS	1/FS,1/SS,SS,SS,SS
C_{15}	1/SS,1/SS,1/SS,1/FS,1/AS	AS,VS,FS,FS,SS	VS,SS,E,E,1/FS	AS,VS,SS,SS,1/FS	E,E,E,E,E	E,E,FS,FS,FS	SS,SS,FS,FS,VS
C_{16}	FS,E,1/FS,1/FS,1/VS	VS,FS,FS,SS,SS	SS,E,1/FS,1/FS,1/VS	FS,SS,SS,SS,1/FS	E,E,1/FS,1/FS,1/FS	E,E,E,E,E	1/SS,E,SS,SS,FS
C_{17}	1/SS,1/SS,1/FS,1/VS,1/VS	FS,FS,FS,SS,E	1/SS,1/FS,1/FS,1/VS,1/VS	FS,SS,1/SS,1/SS,1/SS	1/SS,1/SS,1/FS,1/FS,1/VS	SS,E,1/SS,1/SS,1/FS	E,E,E,E,E

Table 6
Type-2 fuzzy pairwise comparison matrix for C1 Technical Aspects.

Step 4: According to the type-2 fuzzy pairwise comparison matrix in IT2FAHP, the type-2 fuzzy weights of criteria are obtained by the following computational procedures:

	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}
C_{11}	(1, 1, 1, 1; 1, 1) (1, 1, 1, 1; 1, 1)	(0.19, 0,22, 0.30, 0.38; 1, 1) (0.20, 0.22, 0.29, 0.36; 0.8, 0.8)	(1.38, 3.78, 4.82, 5.24; 1, 1) (3.29, 3.90, 4.74, 5.16; 0.8, 0.8)	(0.38, 0.20, 0.33, 0.54; 1, 1) (0.17, 0.20, 0.31, 0.48; 0.8, 0.8)	(1.55, 1.74, 2.05, 2.18; 1, 1) (1.59, 1.78, 2.02, 2.15; 0.8, 0.8)	(0.37, 0.43, 0.57, 0.69; 1, 1) (0.38, 0.44, 0.56, 0.66; 0.8, 0.8)	(0.15, 0.17, 0.28, 0.42; 1, 1) (0.15, 0.18, 0.26, 0.38; 0.8, 0.8)
C_{12}	(2.63, 3.37, 4.59, 5.16; 1, 1) (2.79, 3.50, 4.48, 5.05; 0.8, 0.8)	(1, 1, 1, 1; 1, 1) (1, 1, 1, 1; 1, 1)	(0.64, 4.00, 4.93, 5.24; 1, 1) (3.51, 4.12, 4.82, 5.18; 0.8, 0.8)	(1.00, 1.64, 3.03, 4.08; 1, 1) (1.13, 1.77, 2.87, 3.82; 0.8, 0.8)	(1.38, 4.34, 6.36, 7.24; 1, 1) (3.41, 4,56, 6.15, 7.06; 0.8, 0.8)	(2.14, 3.29, 5.40, 6.43; 1, 1) (2.38, 3.51, 5.20, 6.23; 0.8, 0.8)	(1.93, 2.64, 3.87, 4.43; 1, 1) (2.08, 2.77, 3.75, 4.32; 0.8, 0.8)
C_{13}	(0.19, 0.21, 0.26, 0.72; 1, 1) (0.19, 0.21, 0.26, 0.30; 0.8, 0.8)	(0.19, 0.20, 0.25, 1.55; 1, 1) (0.19, 0.21, 0.24, 0.29; 0.8, 0.8)	(1, 1, 1, 1; 1, 1) (1, 1, 1, 1; 1, 1)	(0.16, 0.19, 0.30, 0.47; 1, 1) (0.16, 0.19, 0.29, 0.42; 0.8, 0.8)	(0.93, 1.15, 1.52, 1.72; 1, 1) (0.98, 1.19, 1.48, 1.68; 0.8, 0.8)	(0.30, 0.37, 0.53, 0.64; 1, 1) (0.31, 0.38, 0.51, 0.62; 0.8, 0.8)	(0.14, 0.16, 0.24, 0.34; 1, 1) (0.14, 0.17, 0.23, 0.31; 0.8, 0.8)
C_{14}	(1.84, 3.03, 5.10, 2.63; 1, 1) (2.09, 3.26, 4.89, 5.84; 0.8, 0.8)	(0.25, 0.33, 0.61, 1.00; 1, 1) (0.26, 0.35, 0.56, 0.88; 0.8, 0.8)	(2.14, 3.29, 5.40, 6.43; 1, 1) (2.38, 3.51, 5.20, 6.23; 0.8, 0.8)	(1, 1, 1, 1; 1, 1) (1, 1, 1, 1; 1, 1)	(0.60, 2.00, 3.10, 3.68; 1, 1) (1.51, 2.12, 2.98, 3.56; 0.8, 0.8)	(0.84, 1.40, 2.49, 3.11; 1, 1) (0.96, 1.50, 2.38, 2.98; 0.8, 0.8)	(0.47, 0.66, 1.25, 2.04; 1, 1) (0.51, 0.70, 1.16, 1.80; 0.8, 0.8)
C_{15}	(0.46, 0.49, 0.57, 0.64; 1, 1) (0.46, 0.50, 0.56, 0.63; 0.8, 0.8)	(0.14, 0.16, 0.23, 0.72; 1, 1) (0.14, 0.16, 0.22, 0.29; 0.8, 0.8)	(0.58, 0.66, 0.87, 1.07; 1, 1) (0.60, 0.68, 0.84, 1.02; 0.8, 0.8)	(0.27, 0.32, 0.50, 1.66; 1, 1) (0.28, 0.34, 0.47, 0.66; 0.8, 0.8)	(1, 1, 1, 1; 1, 1) (1, 1, 1, 1; 1, 1)	(0.31, 0.34, 0.44, 0.52; 1, 1) (0.32, 0.35, 0.42, 0.50; 0.8, 0.8)	(0.16, 0.19, 0.30, 0.47; 1, 1) (0.16, 0.19, 0.29, 0.42; 0.8, 0.8)
C_{16}	(1.45, 1.74, 2.35, 2.71; 1, 1) (1.51, 1.80, 2.29, 2.64; 0.8, 0.8)	(0.16, 0.19, 0.30, 0.47; 1, 1) (0.16, 0.19, 0.29, 0.42; 0.8, 0.8)	(1.55, 1.89, 2.70, 3.38; 1, 1) (1.62, 1.96, 2.60, 3.21; 0.8, 0.8)	(0.32, 0.40, 0.72, 1.18; 1, 1) (0.34, 0.42, 0.66, 1.04; 0.8, 0.8)	(1.93, 2.30, 2.93, 3.21; 1, 1) (2.01, 2.37, 2.87, 3.16; 0.8, 0.8)	(1, 1, 1, 1; 1, 1) (1, 1, 1, 1; 1, 1)	(0.36, 0.46, 0.76, 1.11; 1, 1) (0.38, 0.48, 0.72, 1.01; 0.8, 0.8)
C_{17}	(2.37, 3.57, 5.72, 6.77; 1, 1) (2.62, 3.79, 5.51, 6.56; 0.8, 0.8)	(0.19, 0.21, 0.26, 0.72; 1, 1) (0.19, 0.21, 0.26, 0.30; 0.8, 0.8)	(2.95, 4.10, 6.21, 7.24; 1, 1) (3.19, 4.31, 6.00, 7.03; 0.8, 0.8)	(0.49, 0.80, 1.52, 2.11; 1, 1) (0.56, 0.86, 1.43, 1.96; 0.8, 0.8)	(2.14, 3.29, 5.40, 6.43; 1, 1) (2.38, 3.51, 5.20, 6.23; 0.8, 0.8)	(0.90, 1.32, 2.17, 2.81; 1, 1) (0.99, 1.40, 2.07, 2.65; 0.8, 0.8)	(1, 1, 1, 1; 1, 1) (1, 1, 1, 1; 1, 1)

$$\begin{aligned}\tilde{\tilde{w}}_1 = {} & (0.51,\ 0.58,\ 0.77,\ 0.95;\ 1,\ 1)(0.52,\ 0.59,\ 0.74,\ 0.90;\ 0.8,\ 0.8)\otimes \\ & [(0.51,\ 0.58,\ 0.77,\ 0.95;\ 1,\ 1)(0.52,\ 0.59,\ 0.74,\ 0.90;\ 0.8,\ 0.8)\oplus \\ & (1.38,\ 2.61,\ 3.68,\ 4.19;\ 1,\ 1)(2.11,\ 2.73,\ 3.57,\ 4.09;\ 0.8,\ 0.8)\oplus \\ & (0.30,\ 0.34,\ 0.45,\ 0.79;\ 1,\ 1)(0.31,\ 0.35,\ 0.44,\ 0.53;\ 0.8,\ 0.8)\oplus \\ & (0.81,\ 1.29,\ 2.07,\ 2.35;\ 1,\ 1)(1.00,\ 1.37,\ 1.98,\ 2.50;\ 0.8,\ 0.8)\oplus \\ & (0.34,\ 0.37,\ 0.50,\ 0.79;\ 1,\ 1)(0.34,\ 0.38,\ 0.48,\ 0.59;\ 0.8,\ 0.8)\oplus \\ & (0.69,\ 0.82,\ 1.17,\ 1.51;\ 1,\ 1)(0.72,\ 0.85,\ 1.13,\ 1.42;\ 0.8,\ 0.8)\oplus \\ & (1.06,\ 1.44,\ 2.19,\ 2.67;\ 1,\ 1)(1.14,\ 1.52,\ 2.11,\ 2.56;\ 0.8,\ 0.8)]^{-1} \\ = {} & (0.04,\ 0.05,\ 0.10,\ 0.19;\ 1,\ 1)(0.04,\ 0.06,\ 0.10,\ 0.15;\ 0.8,\ 0.8)\end{aligned}$$

The remaining $\tilde{\tilde{w}}_1$ are obtained as follows:

$$\tilde{\tilde{w}}_2 = (0.10,\ 0.24,\ 0.50,\ 0.82,\ 1,\ 1)(0.17,\ 0.26,\ 0.46,\ 0.67,\ 0.8,\ 0.8)$$

$$\tilde{\tilde{w}}_3 = (0.02,\ 0.03,\ 0.06,\ 0.16,\ 1,\ 1)(0.02,\ 0.03,\ 0.06,\ 0.09,\ 0.8,\ 0.8)$$

$$\tilde{\tilde{w}}_4 = (0.06,\ 0.12,\ 0.28,\ 0.46,\ 1,\ 1)(0.08,\ 0.13,\ 0.25,\ 0.41,\ 0.8,\ 0.8)$$

$$\tilde{\tilde{w}}_5 = (0.03,\ 0.04,\ 0.07,\ 0.16,\ 1,\ 1)(0.03,\ 0.04,\ 0.06,\ 0.10,\ 0.8,\ 0.8)$$

$$\tilde{\tilde{w}}_6 = (0.05,\ 0.08,\ 0.16,\ 0.30,\ 1,\ 1)(0.06,\ 0.08,\ 0.15,\ 0.23,\ 0.8,\ 0.8)$$

$$\tilde{\tilde{w}}_7 = (0.08,\ 0.13,\ 0.29,\ 0.52,\ 1,\ 1)(0.09,\ 0.15,\ 0.27,\ 0.42,\ 0.8,\ 0.8)$$

Step 6: The weights are obtained by using IT2FAHP method *Eq. (14)*. Type-2 fuzzy weights have been defuzzied via the method of BNP. It is calculated for C_{11} of criteria as below

$$C^U_{11} = \left(0.10x0.19 - 0.04x0.05 + \frac{(0.19-0.10)^2 - (0.05-0.04)^2}{3}\right) \Big/ (0.10 + 0.19 - 0.04 - 0.05) = 0.261$$

$$C^L_{11} = \left(0.10x0.15 - 0.04x0.06 + \frac{(0.15-0.10)^2 - (0.06-0.04)^2}{3}\right) \Big/ (0.10 + 0.15 - 0.04 - 0.06) = 0.251$$

Value of C^U_{11} and value of C^L_{11} are computed by arithmetic mean and crisp value of weight of C_{11} is computed at the end.

$$C_{11} = \left(\frac{C^U_{11} + C^L_{11}}{2}\right) = \left(\frac{0.261 + 0.251}{2}\right) = 0,256$$

As a result of the remaining crisp value of, it is applied to the criteria

Table 7
Fuzzy and normalized weights of technical criteria.

Criteria	Fuzzy Weight	Weight	Normalized	Rank
C_{11}	(0.04, 0.05, 0.10, 0.19; 1, 1)(0.04, 0.06, 0.10, 0.15; 0.8, 0.8)	0.092	0.074	5
C_{12}	(0.10, 0.24, 0.49, 0.82; 1, 1)(0.17, 0.26, 0.46, 0.67; 0.8, 0.8)	0.408	0.327	1
C_{13}	(0.02, 0.03, 0.06, 0.16; 1, 1)(0.02, 0.03, 0.06, 0.09; 0.8, 0.8)	0.062	0.049	7
C_{14}	(0.06, 0.12, 0.28, 0.46; 1, 1)(0.08, 0.13, 0.25, 0.41; 0.8, 0.8)	0.228	0.183	3
C_{15}	(0.03, 0.03, 0.07, 0.16; 1, 1)(0.03, 0.04, 0.06, 0.10; 0.8, 0.8)	0.066	0.053	6
C_{16}	(0.05, 0.08, 0.16, 0.30; 1, 1)(0.06, 0.08, 0.14, 0.23; 0.8, 0.8)	0.141	0.113	4
C_{17}	(0.08, 0.13, 0.29, 0.52; 1, 1)(0.09, 0.15, 0.27, 0.42; 0.8, 0.8)	0.249	0.200	2

Table 8
Linguistic variables of the pairwise comparison matrix for C_2 Economic Aspects.

	C_{21}	C_{22}	C_{23}	C_{24}
C_{21}	E,E,E,E, E,E	1/VS,1/FS, 1/FS, 1/FS,1/SS	1/SS,E,SS, SS,VS	1/FS,E,SS, VS,VS
C_{22}	VS,FS, FS, FS,SS	E,E,E,E, E,E	SS,FS,FS, VS,AS	SS,SS,VS, AS,AS
C_{23}	SS,E,1/SS, 1/SS,1/VS	1/SS,1/FS,1/FS, 1/VS,1/AS	E,E,E,E, E,E	1/SS,1/SS,1/SS, SS,FS
C_{24}	FS,E,1/SS, 1/VS,1/VS	1/SS,1/SS,1/VS, 1/AS,1/AS	SS,SS,SS, 1/SS,1/FS	E,E,E,E, E,E

the same way in Table 7 for C_{11}. Nevertheless, the same methods are applied to calculate the weights of each level criteria.

Selected criteria are C_{12}, C_{17}, C_{14} and C_{16} in order of top four criteria.

Step 7: The weights of Economic Aspects have been calculated in the same steps. In Table 8, five decision makers have evaluated criteria of Economic in order to compute by IT2FAHP.

Step 8: The comparison matrix of Economic Aspects has been calculated by IT2FAHP method as shown in Table 9.

Step 9: The weights of Economic Aspects has been calculated by IT2FAHP as shown in Table 10.

- C_{12}, C_{17}, C_{14} and C_{16} of criteria of *Economic Aspects* are related to *Technical Aspects*
- C_{23} and C_{24} of criteria are related to *Economics Aspects*
- C_{31} and C_{32} of criteria are related to *Environmental Aspects*

4.2. Second phase determining weight of the criteria by IT2FAHP

In the section, the weights of criteria which were provided IT2FAHP in previously section have been calculated for IT2FTOPSIS. The same process of IT2FAHP is applied for calculation of criteria. As below follows.

Step 10: The weights of the criteria have been calculated in the same steps. In Table 11, five decision makers have evaluated the criteria in order to compute by IT2FAHP.

Step 11: The comparison matrix of the criteria has been calculated by IT2FAHP method as shown in Table 12.

Table 9
Type-2 fuzzy pairwise comparison matrix for C2 Economic Aspects.

	C_{21}	C_{22}	C_{23}	C_{24}
C_{21}	(1, 1, 1, 1; 1, 1) (1, 1, 1, 1; 1, 1)	(2.67, 3.78, 5.86, 6.88; 1, 1) (2.90, 3.99, 5.65, 6.68; 0.8, 0.8)	(0.34, 0.44, 0.70, 1.00; 1, 1) (0.36, 0.46, 0.66, 0.91; 0.8, 0.8)	(0.37, 0.44, 0.61, 0.78; 1, 1) (0.39, 0.45, 0.59, 0.73; 0.8, 0.8)
C_{22}	(0.15, 0.17, 0.26, 0.37; 1, 1) (0.15, 0.18, 0.25, 0.35; 0.8, 0.8)	(1, 1, 1, 1; 1, 1) (1, 1, 1, 1; 1, 1)	(0.41, 0.51, 0.72, 0.89; 1, 1) (0.43, 0.53, 0.70, 0.85; 0.8, 0.8)	(0.74, 0.87, 1.15, 1.35; 1, 1) (0.77, 0.90, 1.12, 1.30; 0.8, 0.8)
C_{23}	(1.00, 1.43, 2.30, 2.95; 1, 1) (1.09, 1.51, 2.20, 2.79; 0.8, 0.8)	(3.16, 4.34, 6.36, 3.16; 1, 1) (3.41, 4.56, 6.15, 7.06; 0.8, 0.8)	(1, 1, 1, 1; 1, 1) (1, 1, 1, 1; 1, 1)	(0.71, 0.84, 1.12, 1.33; 1, 1) (0.74, 0.87, 1.09, 1.28; 0.8, 0.8)
C_{24}	(1.29, 1.64, 2.30, 2.67; 1, 1) (1.37, 1.71, 2.23, 2.59; 0.8, 0.8)	(3.00, 4.34, 6.36, 1.36; 1, 1) (3.29, 4.58, 6.14, 6.97; 0.8, 0.8)	(0.47, 0.66, 1.25, 2.04; 1, 1) (0.51, 0.70, 1.16, 1.80; 0.8, 0.8)	(1, 1, 1, 1; 1, 1) (1, 1, 1, 1; 1, 1)

Step 12: The weights of the criteria have been calculated by IT2FAHP as shown in Table 13. The fuzzy weight of criteria has been calculated by ITF2AHP and it is ready for using IT2FTOPSIS.

4.3. Third phase selection of aircraft by IT2FTOPSIS

In this section, aircraft has been selected by IT2FTOPSIS method. In previously section, weight of criteria has been computed by means of IT2FAHP.

Step 13: In Fig. 3, The hierarchical structure of selection model is shown. Furthermore, alternatives of aircraft for selection by IT2F-TOPSIS are described as follows: *X_1: Airbus A320neo, X_2: Airbus A321neo, X_3: Boeing 737 MAX 8* and *X_4: Boeing 737 MAX 9*.

Step 14: In Table 2, linguistic terms and its corresponding IT2FSs has been used for TOPSIS (Chen and Lee, 2010).

Step 15: In Table 14, decision matrix and its linguistic terms evaluated by five decision makers are shown.

Table 10
Fuzzy and normalized weights of economic criteria. Selected criteria are C23 and C24 in order of top two criteria. Summarized the criteria to be used for second phase of IT2FAHP as well as IT2FTOPSIS computing in order to rank the alternatives are as below described.

Criteria	Fuzzy Weight	Weight	Normalized	Rank
C_{21}	(0.13, 0.16, 0.30, 0.44; 1, 1)(0.12, 0.17, 0.28, 0.42; 0.8, 0.8)	0.256	0.228	3
C_{22}	(0.08, 0.04, 0.08, 0.13; 1, 1)(0.03, 0.05, 0.08, 0.12; 0.8, 0.8)	0.077	0.069	4
C_{23}	(0.20, 0.26, 0.52, 0.61; 1, 1)(0.18, 0.28, 0.49, 0.72; 0.8, 0.8)	0.408	0.363	1
C_{24}	(0.20, 0.25, 0.50, 0.47; 1, 1)(0.18, 0.27, 0.46, 0.69; 0.8, 0.8)	0.382	0.340	2

Step 16: According to Eq. (18), $\tilde{\tilde{f}}_{ij} = \frac{\tilde{\tilde{f}}^1_{ij} \oplus \tilde{\tilde{f}}^2_{ij} \oplus \cdots \oplus \tilde{\tilde{f}}^k_{ij}}{k}$, $\tilde{\tilde{f}}_{ij}$ is an IT2FSs, $1 \le i \le m$, $1 \le j \le n$, $1 \le p \le k$, and k denotes the number of decision makers. Where;

$$\begin{aligned}\tilde{\tilde{f}}_{11} &= [(0.3,\ 0.5,\ 0.5,\ 0.7;\ 1,\ 1)(0.4,\ 0.5,\ 0.5,\ 0.6;\ 0.9,\ 0.9)\oplus\\ &(0.7,\ 0.9,\ 0.9,\ 1;\ 1,\ 1)(0.8,\ 0.9,\ 0.9,\ 0.95;\ 0.9,\ 0.9)\oplus\\ &(0.7,\ 0.9,\ 0.9,\ 1;\ 1,\ 1)(0.8,\ 0.9,\ 0.9,\ 0.95;\ 0.9,\ 0.9)\oplus\\ &(0.9,\ 1,\ 1,\ 1;\ 1,\ 1)(0.95,\ 1,\ 1,\ 1;\ 0.9,\ 0.9)\oplus\\ &(0.7,\ 0.9,\ 0.9,\ 1;\ 1,\ 1)(0.8,\ 0.9,\ 0.9,\ 0.95;\ 0.9,\ 0.9)]/5\\ &= (0.66,\ 0.84,\ 0.84,\ 0.94;\ 1,\ 1)(0.75,\ 0.84,\ 0.84,\ 0.89;\ 0.9,\ 0.9)\end{aligned}$$

The remain $\tilde{\tilde{f}}_{ij}$ are computed in the same way as shown in Table 15;

Step 17: Weights of criteria as $W$are given in Table 13.

Step 18: With these weights of criteria, the weighted decision matrix $Y_w$is constructed. According to Eq. (19), $\tilde{\tilde{v}}_{ij} = \tilde{\tilde{w}}_{ij} \otimes \tilde{\tilde{f}}_{ij}$, $1 \le i \le m$.and $1 \le j \le n$.where;

$$\begin{aligned}\tilde{\tilde{v}}_{11} &= (0.04,\ 0.08,\ 0.21,\ 0.41;\ 1,\ 1)(0.05,\ 0.09,\ 0.19,\ 0.33;\ 0.8,\ 0.8)\otimes\\ &(0.66,\ 0.84,\ 0.84,\ 0.94;\ 1,\ 1)(0.75,\ 0.84,\ 0.84,\ 0.89;\ 0.9,\ 0.9)\\ &= (0.03,\ 0.07,\ 0.18,\ 0.39;\ 1,\ 1)(0.04,\ 0.08,\ 0.16,\ 0.29;\ 0.9,\ 0.9)\end{aligned}$$

The remain $\tilde{\tilde{v}}_{ij}$ are computed by the same way in Table 16.

Step 19: According to Eq. (21), the ranking values $Rank(\tilde{\tilde{v}}_{ij})$of the IT2FSs $\tilde{\tilde{v}}_{ij}$, where $1 \le j \le n$. are presented as below follows;

$$\begin{aligned}Rank(\tilde{\tilde{v}}_{11}) = {}& M_1\left(\widetilde{v^U_{11}}\right) + M_1\left(\widetilde{v^L_{11}}\right) + M_2\left(\widetilde{v^U_{11}}\right) + M_2\left(\widetilde{v^L_{11}}\right) + M_3\left(\widetilde{v^U_{11}}\right) + M_3\left(\widetilde{v^L_{11}}\right)\\ & -\frac{1}{4}\left(S_1\left(\widetilde{v^U_{i1}}\right) + S_1\left(\widetilde{v^L_{11}}\right) + S_2\left(\widetilde{v^U_{1i}}\right) + S_2\left(\widetilde{v^L_{11}}\right) + S_3\left(\widetilde{v^U_{11}}\right) + S_3\left(\widetilde{v^L_{11}}\right)\right.\\ & \left. + S_4\left(\widetilde{v^U_{11}}\right) + S_4\left(\widetilde{v^L_{11}}\right)\right) \quad + H_1\left(\widetilde{v^U_{11}}\right) + H_1\left(\widetilde{v^L_{11}}\right) + H_2\left(\widetilde{v^U_{11}}\right) + H_2\left(\widetilde{v^L_{11}}\right)\end{aligned}$$

$$\begin{aligned}Rank(\tilde{\tilde{v}}_{11}) &= (0.05 + 0.06 + 0.12 + 0.12 + 0.28 + 0.23)\\ &-\frac{1}{4}(0.02 + 0.02 + 0.05 + 0.04 + 0.10 + 0.07 + 0.14 + 0.10)\\ &+ (1 + 0.9 + 1 + 0.9)\\ &= 4.52\end{aligned}$$

The remain $Rank(\tilde{\tilde{v}}_{ij})$ are computed in the same way as below follows;

$Rank(\tilde{\tilde{v}}_{12}) = 4.57$, $Rank(\tilde{\tilde{v}}_{13}) = 4.50$, $Rank(\tilde{\tilde{v}}_{14}) = 4.47$, $Rank(\tilde{\tilde{v}}_{21}) = 4.18$, $Rank(\tilde{\tilde{v}}_{22}) = 4.35$, $Rank(\tilde{\tilde{v}}_{23}) = 4.23$, $Rank(\tilde{\tilde{v}}_{22}) = 4.30$, $Rank(\tilde{\tilde{v}}_{31}) = 4.81$, $Rank(\tilde{\tilde{v}}_{32}) = 4.86$, $Rank(\tilde{\tilde{v}}_{33}) = 4.52$, $Rank(\tilde{\tilde{v}}_{34}) = 4.52$, $Rank(\tilde{\tilde{v}}_{41}) = 4.00$, $Rank(\tilde{\tilde{v}}_{42}) = 4.17$, $Rank(\tilde{\tilde{v}}_{43}) = 4.08$, $Rank(\tilde{\tilde{v}}_{44}) = 4.18$, $Rank(\tilde{\tilde{v}}_{51}) = 4.85$, $Rank(\tilde{\tilde{v}}_{52}) = 4.83$, $Rank(\tilde{\tilde{v}}_{53}) = 4.73$, $Rank(\tilde{\tilde{v}}_{54}) = 4.73$, $Rank(\tilde{\tilde{v}}_{61}) = 5.05$, $Rank(\tilde{\tilde{v}}_{62}) = 5.13$, $Rank(\tilde{\tilde{v}}_{63}) = 4.77$, $Rank(\tilde{\tilde{v}}_{64}) = 5.10$, $Rank(\tilde{\tilde{v}}_{71}) = 3.95$, $Rank(\tilde{\tilde{v}}_{72}) = 3.98$, $Rank(\tilde{\tilde{v}}_{73}) = 3.95$, $Rank(\tilde{\tilde{v}}_{74}) = 3.97$, $Rank(\tilde{\tilde{v}}_{81}) = 3.90$, $Rank(\tilde{\tilde{v}}_{82}) = 3.90$, $Rank(\tilde{\tilde{v}}_{83}) = 3.89$, $Rank(\tilde{\tilde{v}}_{84}) = 4.89$.

Step 20: According to Eq. (22) and Eq. (23), positive ideal solution $x^+ = (v_1^+, v_2^+, \ldots, v_m^+)$and the negative ideal solution $x^- = (v_1^-, v_2^-, \ldots, v_m^-)$have been computed respectively as below follows;

$$\begin{aligned}x^+ &= \left(v_1^+, v_2^+, \ldots, v_m^+\right)\\ &= (\min(Rank(\tilde{\tilde{v}}_{11}),\ Rank(\tilde{\tilde{v}}_{12}),\ Rank(\tilde{\tilde{v}}_{13}),\ Rank(\tilde{\tilde{v}}_{14})),\\ &\max(Rank(\tilde{\tilde{v}}_{21}),\ Rank(\tilde{\tilde{v}}_{22}),\ Rank(\tilde{\tilde{v}}_{23}),\ Rank(\tilde{\tilde{v}}_{24})),\\ &\max(Rank(\tilde{\tilde{v}}_{31}),\ Rank(\tilde{\tilde{v}}_{32}),\ Rank(\tilde{\tilde{v}}_{33}),\ Rank(\tilde{\tilde{v}}_{34})),\\ &\max(Rank(\tilde{\tilde{v}}_{41}),\ Rank(\tilde{\tilde{v}}_{42}),\ Rank(\tilde{\tilde{v}}_{43}),\ Rank(\tilde{\tilde{v}}_{44})),\\ &\min(Rank(\tilde{\tilde{v}}_{51}),\ Rank(\tilde{\tilde{v}}_{52}),\ Rank(\tilde{\tilde{v}}_{53}),\ Rank(\tilde{\tilde{v}}_{54})),\\ &\min(Rank(\tilde{\tilde{v}}_{61}),\ Rank(\tilde{\tilde{v}}_{62}),\ Rank(\tilde{\tilde{v}}_{63}),\ Rank(\tilde{\tilde{v}}_{64})),\\ &\min(Rank(\tilde{\tilde{v}}_{71}),\ Rank(\tilde{\tilde{v}}_{72}),\ Rank(\tilde{\tilde{v}}_{73}),\ Rank(\tilde{\tilde{v}}_{74})),\\ &\min(Rank(\tilde{\tilde{v}}_{81}),\ Rank(\tilde{\tilde{v}}_{82}),\ Rank(\tilde{\tilde{v}}_{83}),\ Rank(\tilde{\tilde{v}}_{84}))),\\ &= (Rank(\tilde{\tilde{v}}_{14}),\ Rank(\tilde{\tilde{v}}_{22}),\ Rank(\tilde{\tilde{v}}_{32}),\ Rank(\tilde{\tilde{v}}_{44}),\\ &Rank(\tilde{\tilde{v}}_{53}),\ Rank(\tilde{\tilde{v}}_{63}),\ Rank(\tilde{\tilde{v}}_{73}),\ Rank(\tilde{\tilde{v}}_{83}))\\ &= (4.47,\ 4.35,\ 4.86,\ 4.18,\ 4.73,\ 4.77,\ 3.95,\ 3.89)\end{aligned}$$

$$\begin{aligned}x^- &= \left(v_1^-, v_2^-, \ldots, v_m^-\right)\\ &= (\max(Rank(\tilde{\tilde{v}}_{11}),\ Rank(\tilde{\tilde{v}}_{12}),\ Rank(\tilde{\tilde{v}}_{13}),\ Rank(\tilde{\tilde{v}}_{14})),\\ &\min(Rank(\tilde{\tilde{v}}_{21}),\ Rank(\tilde{\tilde{v}}_{22}),\ Rank(\tilde{\tilde{v}}_{23}),\ Rank(\tilde{\tilde{v}}_{24})),\\ &\min(Rank(\tilde{\tilde{v}}_{31}),\ Rank(\tilde{\tilde{v}}_{32}),\ Rank(\tilde{\tilde{v}}_{33}),\ Rank(\tilde{\tilde{v}}_{34})),\\ &\min(Rank(\tilde{\tilde{v}}_{41}),\ Rank(\tilde{\tilde{v}}_{42}),\ Rank(\tilde{\tilde{v}}_{43}),\ Rank(\tilde{\tilde{v}}_{44})),\\ &\max(Rank(\tilde{\tilde{v}}_{51}),\ Rank(\tilde{\tilde{v}}_{52}),\ Rank(\tilde{\tilde{v}}_{53}),\ Rank(\tilde{\tilde{v}}_{54})),\\ &\max(Rank(\tilde{\tilde{v}}_{61}),\ Rank(\tilde{\tilde{v}}_{62}),\ Rank(\tilde{\tilde{v}}_{63}),\ Rank(\tilde{\tilde{v}}_{64})),\\ &\max(Rank(\tilde{\tilde{v}}_{71}),\ Rank(\tilde{\tilde{v}}_{72}),\ Rank(\tilde{\tilde{v}}_{73}),\ Rank(\tilde{\tilde{v}}_{74})),\\ &\max(Rank(\tilde{\tilde{v}}_{81}),\ Rank(\tilde{\tilde{v}}_{82}),\ Rank(\tilde{\tilde{v}}_{83}),\ Rank(\tilde{\tilde{v}}_{84}))),\\ &= (Rank(\tilde{\tilde{v}}_{12}),\ Rank(\tilde{\tilde{v}}_{21}),\ Rank(\tilde{\tilde{v}}_{33}),\ Rank(\tilde{\tilde{v}}_{41}),\\ &Rank(\tilde{\tilde{v}}_{51}),\ Rank(\tilde{\tilde{v}}_{62}),\ Rank(\tilde{\tilde{v}}_{72}),\ Rank(\tilde{\tilde{v}}_{84}))\end{aligned}$$

Table 11
Linguistic variables of the pairwise comparison matrix for the criteria.

	C_{12}	C_{17}	C_{14}	C_{16}	C_{23}	C_{24}	C_{31}	C_{32}
C_{12}	E,E,E, E,E	1/VS,1/FS,1/SS, 1/SS,FS	1/SS,1/SS,FS, FS,VS	1/VS,1/FS,1/FS SS,VS	1/FS,E,SS, FS,FS	1/SS,SS,SS, FS,VS	1/VS,1/FS,1/FS, 1/FS,1/SS	1/AS,1/VS,1/VS, 1/FS,1/SS
C_{17}	VS,FS,SS, SS,1/FS	E,E,E, E,E	1/SS,SS,FS, VS,VS	1/VS,1/FS,1/SS, 1/SS,E	1/SS,SS,SS, SS,FS	SS,SS,SS, FS,VS	1/FS,1/FS,1/FS, 1/SS,1/SS	1/VS,1/VS,1/FS, 1/FS,1/SS
C_{14}	SS,SS,1/FS, 1/FS,1/VS	SS,1/SS,1/FS, 1/VS,1/VS	E,E,E, E,E	1/VS,1/FS,1/SS, 1/SS,1/SS	1/FS,1/FS,SS, SS,SS	E,SS,SS, FS,FS	1/VS,1/VS,1/FS, 1/SS,1/SS	1/AS,1/FS,1/FS, 1/FS,1/FS
C_{16}	VS,FS,FS 1/SS,1/VS	VS,FS,SS, SS,E	VS,FS,SS, SS,SS	E,E,E, E,E	1/FS,SS,SS, FS,FS	1/FS,SS,SS, FS,FS	1/FS,1/FS,1/SS, 1/SS,E	1/VS,1/FS,1/FS, 1/SS,E
C_{23}	FS,E,1/SS, 1/FS,1/FS	VS,FS,SS, SS,E	FS,FS,1/SS, 1/SS,1/SS	FS,1/SS,1/SS, 1/FS,1/FS	E,E,E, E,E	1/FS,1/SS,SS, SS,SS	1/VS,1/VS,1/FS, 1/SS,1/SS	1/VS,1/VS,1/FS, 1/FS,1/FS
C_{24}	SS,1/SS,1/SS, 1/FS,1/VS	1/SS,1/SS,1/SS, 1/FS,1/VS	E,1/SS,1/SS, 1/FS,1/FS	FS,1/SS,1/SS, 1/FS,1/FS	FS,SS,1/SS, 1/SS,1/SS	E,E,E, E,E	1/AS,1/VS,1/VS, 1/SS,1/SS	1/AS,1/VS,1/FS, 1/FS,1/SS
C_{31}	VS,FS,FS, FS,SS	FS,FS,FS, SS,SS	VS,VS,FS, SS,SS	FS,FS,SS, SS,E	VS,VS,FS, SS,SS	AS,VS,VS, SS,SS	E,E,E, E,E	1/SS,1/SS,1/SS, 1/SS,FS
C_{32}	AS,VS,VS, FS,SS	VS,VS,FS, FS,SS	AS,FS,FS, FS,FS	VS,FS,FS, SS,E	VS,VS,FS, FS,FS	AS,VS,FS, FS,SS	SS,SS,SS, SS,1/FS	E,E,E, E,E

Table 12
Type-2 fuzzy pairwise comparison matrix for the criteria.

	C_{12}	C_{17}	C_{14}	C_{16}	C_{23}	C_{24}	C_{31}	C_{32}
C₁₂	(1, 1, 1, 1; 1, 1) (1, 1, 1, 1; 1, 1)	(1.16, 1.74, 2.86, 3.50; 1, 1) (1.29, 1.85, 2.74, 3.36; 0.8, 0.8)	(0.30, 0.43, 0.70, 0.89; 1, 1) (0.32, 0.45, 0.67, 0.85; 0.8, 0.8)	(1.00, 1.25, 1.89, 2.45; 1, 1) (1.05, 1.30, 1.81, 2.31; 0.8, 0.8)	(0.41, 0.49, 0.72, 0.95; 1, 1) (0.43, 0.51, 0.68, 0.89; 0.8, 0.8)	(0.23, 0.30, 0.53, 0.80; 1, 1) (0.24, 0.32, 0.50, 0.73; 0.8, 0.8)	(2.67, 3.78, 5.86, 6.88; 1, 1) (2.90, 3.99, 5.65, 6.68; 0.8, 0.8)	(1.53, 4.70, 6.73, 7.61; 1, 1) (3.76, 4.93, 6.52, 7.44; 0.8, 0.8)
C₁₇	(0.29, 0.35, 0.57, 0.86; 1, 1) (0.30, 0.36, 0.54, 078; 0.8, 0.8)	(1, 1, 1, 1; 1, 1) (1, 1, 1, 1; 1, 1)	(0.20, 0.26, 0.43, 0.58; 1, 1) (0.22, 0.28, 0.40, 0.54; 0.8, 0.8)	(1.72, 2.49, 3.78, 4.36; 1, 1) (1.89, 2.63, 3.66, 4.25; 0.8, 0.8)	(0.26, 0.35, 0.66, 1.11; 1, 1) (0.28, 0.37, 0.61, 0.97; 0.8, 0.8)	(0.17, 0.20, 0.35, 0.58; 1, 1) (0.17, 0.21, 0.32, 0.51; 0.8, 0.8)	(1.93, 3.03, 5.10, 6.12; 1, 1) (2.16, 3.24, 4.90, 5.92; 0.8, 0.8)	(2.95, 4.10, 6.21, 7.24; 1, 1) (3.19, 4.31, 6.00, 7.03; 0.8, 0.8)
C₁₄	(1.12, 1.43, 2.35, 3.38; 1, 1) (1.18, 1.50, 2.22, 3.09; 0.8, 0.8)	(1.72, 2.35, 3.78, 4.90; 1, 1) (1.85, 2.48, 3.61, 4.62; 0.8, 0.8)	(1, 1, 1, 1; 1, 1) (1, 1, 1, 1; 1, 1)	(1.72, 2.86, 4.98, 6.02; 1, 1) (1.96, 3.08, 4.78, 5.81; 0.8, 0.8)	(0.59, 0.76, 1.35, 2.18; 1, 1) (0.62, 0.80, 1.26, 1.93; 0.8, 0.8)	(0.24, 0.28, 0.44, 0.64; 1, 1) (0.25, 0.29, 0.41, 0.58; 0.8, 0.8)	(2.37, 3.57, 5.72, 6.77; 1, 1) (2.62, 3.79, 5.51, 6.56; 0.8, 0.8)	(1.55, 4.59, 6.51, 7.36; 1, 1) (3.76, 4.80, 6.30, 7.19; 0.8, 0.8)
C₁₆	(0.41, 053, 0.80, 1.00; 1, 1) (0.43, 0.55, 0.77, 0.95; 0.8, 0.8)	(0.23, 0.26, 0.40, 0.58; 1, 1) (0.24, 0.27, 0.38, 0.53; 0.8, 0.8)	(0.17, 0.20, 0.35, 0.58; 1, 1) (0.17, 0.21, 0.32, 0.51; 0.8, 0.8)	(1, 1, 1, 1; 1, 1) (1, 1, 1, 1; 1, 1)	(0.30, 0.37, 0.62, 0.95; 1, 1) (0.31, 0.39, 0.58, 0.86; 0.8, 0.8)	(0.30, 0.37, 0.62, 0.95; 1, 1) (0.31, 0.39, 0.58, 0.86; 0.8, 0.8)	(1.55, 2.30, 3.57, 4.15; 1, 1) (1.71, 2.43, 3.45, 4.03; 0.8, 0.8)	(2.14, 2.86, 4.10, 4.66; 1, 1) (2.30, 2.99, 3.98, 4.55; 0.8, 0.8)
C₂₃	(1.05, 1.40, 2.05, 2.41; 1, 1) (1.13, 1.46, 1.98, 2.33; 0.8, 0.8)	(0.90, 1.52, 2.86, 3.88; 1, 1) (1.03, 1.64, 2.70, 3.63; 0.8, 0.8)	(0.46, 0.74, 1.32, 1.69; 1, 1) (0.52, 0.79, 1.25, 1.61; 0.8, 0.8)	(1.05, 1.61, 2.70, 3.33; 1, 1) (1.17, 1.71, 2.59, 3.19; 0.8, 0.8)	(1, 1, 1, 1; 1, 1) (1, 1, 1, 1; 1, 1)	(0.47, 0.66, 1.25, 2.04; 1, 1) (0.51, 0.70, 1.16, 1.80; 0.8, 0.8)	(2.37, 3.57, 5.72, 6.77; 1, 1) (2.62, 3.79, 5.51, 6.56; 0.8, 0.8)	(3.68, 4.70, 6.73, 7.74; 1, 1) (3.89, 4.91, 6.53, 7.54; 0.8, 0.8)
C₂₄	(1.25, 1.89, 3.29, 4.36; 1, 1) (1.38, 2.01, 3.12, 4.09; 0.8, 0.8)	(1.72, 2.86, 4.98, 6.02; 1, 1) (1.96, 3.08, 4.78, 5.81; 0.8, 0.8)	(1.55, 2.30, 3.57, 4.15; 1, 1) (1.71, 2.43, 3.45, 4.03; 0.8, 0.8)	(1.05, 1.61, 2.70, 3.33; 1, 1) (1.17, 1.71, 2.59, 3.19; 0.8, 0.8)	(0.49, 0.80, 1.52, 2.11; 1, 1) (0.56, 0.86, 1.43, 1.96; 0.8, 0.8)	(1, 1, 1, 1; 1, 1) (1, 1, 1, 1; 1, 1)	(1.23, 4.10, 6.21, 7.11; 1, 1) (3.09, 4.33, 5.99, 6.94; 0.8, 0.8)	(1.38, 4.34, 6.36, 7.24; 1, 1) (3.41, 4.56, 6.15, 7.06; 0.8, 0.8)
C₃₁	(0.15, 0.17, 0.26, 0.37; 1, 1) (0.15, 0.18, 0.25, 0.35; 0.8, 0.8)	(0.16, 0.20, 0.33, 0.52; 1, 1) (0.17, 0.20, 0.31, 0.46; 0.8, 0.8)	(0.15, 0.17, 0.28, 0.42; 1, 1) (0.15, 0.18, 0.26, 0.38; 0.8, 0.8)	(0.24, 0.28, 0.44, 0.64; 1, 1) (0.25, 0.29, 0.41, 0.58; 0.8, 0.8)	(0.15, 0.17, 0.28, 0.42; 1, 1) (0.15, 0.18, 0.26, 0.38; 0.8, 0.8)	(0.14, 0.16, 0.24, 0.82; 1, 1) (0.14, 0.17, 0.23, 0.32; 0.8, 0.8)	(1, 1, 1, 1; 1, 1) (1, 1, 1, 1; 1, 1)	(1.00, 2.00, 4.00, 5.00; 1, 1) (1.20, 2.20, 3.80, 4.80; 0.8, 0.8)
C₃₂	(0.13, 0.15, 0.21, 0.65; 1, 1) (0.13, 0.15, 0.25, 0.27; 0.8, 0.8)	(0.14, 0.16, 0.24, 0.34; 1, 1) (0.14, 0.17, 0.23, 0.31; 0.8, 0.8)	(0.14, 0.15, 0.22, 0.64; 1, 1) (0.14, 0.16, 0.21, 0.27; 0.8, 0.8)	(0.21, 0.24, 0.35, 0.47; 1, 1) (0.22, 0.25, 0.33, 0.44; 0.8, 0.8)	(0.13, 0.15, 0.21, 0.27; 1, 1) (0.13, 0.15, 0.20, 0.26; 0.8, 0.8)	(0.14, 0.16, 0.23, 0.72; 1, 1) (0.14, 0.16, 0.22, 0.29; 0.8, 0.8)	(0.20, 0.25, 0.50, 1.00; 1, 1) (0.21, 0.26, 0.45, 0.83; 0.8, 0.8)	(1, 1, 1, 1; 1, 1) (1, 1, 1, 1; 1, 1)

Table 13
Fuzzy and normalized weights of the criteria.

Criteria	Fuzzy Weights	Weight	Normalized	Rank
C₁₂	(0.04, 0.08, 0.21, 0.41; 1, 1)(0.05, 0.09, 0.19, 0.33; 0.8, 0.8)	0.181	0.128	4
C₁₇	(0.03, 0.06, 0.16, 0.33; 1, 1)(0.04, 0.06, 0.14, 0.26; 0.8, 0.8)	0.139	0.098	5
C₁₄	(0.06, 0.12, 0.32, 0.64; 1, 1)(0.08, 0.13, 0.28, 0.16; 0.8, 0.8)	0.139	0.196	2
C₁₆	(0.03, 0.04, 0.11, 0.23; 1, 1)(0.03, 0.05, 0.10, 0.18; 0.8, 0.8)	0.100	0.071	6
C₂₃	(0.06, 0.12, 0.32, 0.62; 1, 1)(0.07, 0.13, 0.29, 0.50; 0.8, 0.8)	0.271	0.192	3
C₂₄	(0.06, 0.16, 0.44, 0.82, 1, 1)(0.10, 0.18, 0.40, 0.66; 0.8, 0.8)	0.362	0.256	1
C₃₁	(0.01, 0.02, 0.05, 0.13; 1, 1)(0.01, 0.02, 0.05, 0.10; 0.8, 0.8)	0.050	0.035	7
C₃₂	(0.01, 0.01, 0.03, 0.10; 1, 1)(0.01, 0.01, 0.03, 0.05; 0.8, 0.8)	0.034	0.024	8

$$= (4.57,\ 4.18,\ 4.52,\ 4.00,\ 4.85,\ 5.13,\ 3.98,\ 3.90)$$

Step 21: According to Eq. (24) and Eq. (25), the distance $\mathrm{d}^{+}(x_j)$ between each alternative x_j and the positive ideal solution x^{+} and the distance $\mathrm{d}^{-}(x_j)$ between each alternative $x_j$and the negative ideal solution x^{-} have been computed respectively, where $1 \le j \le 4$ as below follows;

$$\mathrm{d}^{+}(x_1) = \sqrt{\sum_{i=1}^{m}\left(Rank(\tilde{\tilde{v}}_{i1}) - v_i^{+}\right)^2} = 0.40\text{and}\quad \mathrm{d}^{-}(x_1) = \sqrt{\sum_{i=1}^{m}\left(Rank(\tilde{\tilde{v}}_{i1}) - v_i^{-}\right)^2} = 0.31\mathrm{d}^{+}(x_2) = \sqrt{\sum_{i=1}^{m}\left(Rank(\tilde{\tilde{v}}_{i2}) - v_i^{+}\right)^2} = 0.39\text{and}\quad \mathrm{d}^{-}(x_2) = \sqrt{\sum_{i=1}^{m}\left(Rank(\tilde{\tilde{v}}_{i2}) - v_i^{-}\right)^2} = 0.47\mathrm{d}^{+}(x_3) = \sqrt{\sum_{i=1}^{m}\left(Rank(\tilde{\tilde{v}}_{i3}) - v_i^{+}\right)^2} = 0.38\text{and } \mathrm{d}^{-}(x_3) = \sqrt{\sum_{i=1}^{m}\left(Rank(\tilde{\tilde{v}}_{i3}) - v_i^{-}\right)^2} = 0.40\mathrm{d}^{+}(x_4) = \sqrt{\sum_{i=1}^{m}\left(Rank(\tilde{\tilde{v}}_{i4}) - v_i^{+}\right)^2} = 0.73\text{and}\quad \mathrm{d}^{-}(x_4) = \sqrt{\sum_{i=1}^{m}\left(Rank(\tilde{\tilde{v}}_{i4}) - v_i^{-}\right)^2} = 0.27$$

Step 22: According to Eq. (26), the relative degree of closeness $C(x_j)$ of $x_j$with respect to the positive ideal solution have been computed respectively, where $1 \le j \le 4$ as below follows;

$$C(x_1) = \frac{\mathrm{d}^{-}(x_1)}{\mathrm{d}^{+}(x_1) + \mathrm{d}^{-}(x_1)} = \frac{0.31}{0.40 + 0.31} = 0.44.$$

The remain $C(x_j)$ are computed by the same way as; $C(x_2) = 0.55$, $C(x_3) = 0.51$and $C(x_4) = 0.27$.

Step 23: Eventually, best alternatives are $C(x_2) > C(x_3) > C(x_1) > C(x_4)$.in order among $C(x_1)$, $C(x_2)$, $C(x_3)$and $C(x_4)$so, best aircraft ranking presented as $X_2 > X_3 > X_1 > X_4$ in Table 17.

In Table 17, the aircraft performance ranking is given as a result of the application of the IT2FAHP and IT2FTOPSIS methods. In the study, four aircraft types with short and medium ranges were evaluated, these also represent the four most purchased aircraft by airlines in the last years. Within the scope of the study, the aircraft were evaluated in terms of technical aspects, economic aspects and environmental aspects. The findings of the analysis show that the *Airbus A321neo* is the most suitable aircraft alternative for airline companies. The second most suitable alternative is the *Boeing 737 MAX 8*. However, the *Boeing 737 MAX 8* type planes have been grounded worldwide since March 2019. Therefore, it is important for airlines to consider the performance-safety

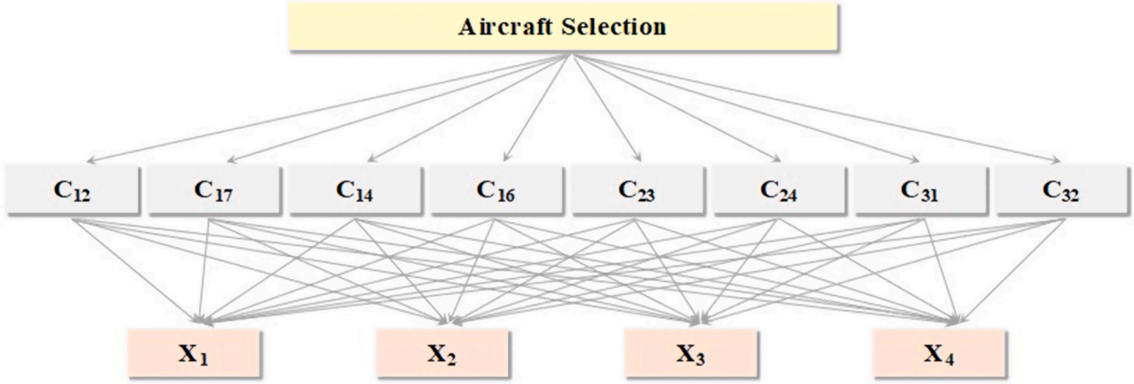

Fig. 3. The hierarchical structure of selection model.

balance when choosing between aircraft alternatives.

5. Conclusion

MCDM methods enable airlines to use the resources of the sector effectively. In addition, considering environmental and economic factors, these resources can be used more effectively and efficiently. Therefore, the selection of aircraft using new MCDM methods provides an advantage to the stakeholders of the sector and airlines.

Fleet planning and the selection of appropriate aircraft are critical for airlines. Airlines can increase their profits and reduce their costs thanks to the selection of suitable aircraft. Many methods are used for this which is of strategic importance for airline companies and the selection of aircraft using new MCDM methods offers airlines a satisfactory solution to this problem. Therefore, in order to gain competitive advantage in the market and increase long-term gains, airline companies should consider the results obtained by combining scientific methods for appropriate aircraft selection.

Using this model, airlines can choose aircraft that are appropriate for their fleet and operations, taking into account the economic performance, technical performance, and environmental impact. In addition, by changing the criteria and sub-criteria in the model, aircraft with different types and sizes can be selected. This model can be used not only for the selection of wide and narrow body commercial aircraft, but also for the selection of training aircraft, cargo aircraft and military training aircraft. Therefore, by using this model, fleet planners can add different criteria and evaluate the aircraft according to their interests. In addition, it is important for decision makers to make the right decisions in the aviation industry, which is a global business and highly uncertain. In addition to the use of this method for aircraft selection, the model presented here can be used for route selection, network design, assessment of airline service quality, risk analysis, and project planning.

In this paper we have proposed a model for aircraft evaluation. The model includes tree criteria (economic performance, technical performance, and environmental impact) and eight sub-criteria (fuel consumption per seat mile, expected service life of the aircraft, maximum take-off weight, aircraft seat capacity, operating cost, price of aircraft, pollution and noise). The model framework is based on a hybrid approach that uses both the AHP and the Fuzzy Set Theory.

One of advantages of the IT2FAHP and IT2FTOPSIS hybrid method over classic MCDM methods is to give a more specific solution from a cluster in an uncertain environment, as such it helps decision makers make more accurate decisions for aircraft selection in an increasingly uncertain environment.

In this study, unlike other studies in the literature, we focused on commercial aircraft selection by combining IT2FAHP and IT2FTOPSIS methods. In the first stage, we determined the criteria and sub-criteria related to aircraft selection by using previous studies in the literature. Therefore, we created three main criteria: technical aspects, economic aspects and environmental aspects, and sub-criteria related to them. In the second stage, we selected the appropriate criteria using the IT2FAHP method and weighted these criteria. In the IT2FAHP process, we used the knowledge of aviation experts. We used the IT2FTOPSIS method to rank alternatives. The contributions of our study can be summarized as follows:

1. IT2FAHP and IT2FTOPSIS methods provide very useful solutions for the selection of the appropriate alternative, weighting the appropriate alternative and the ranking of different alternatives. However, these methods have not been used before on aircraft type selection problem.
2. In the determination of the criteria, we preferred the alternatives used frequently in the literature. With these alternatives, we evaluated the aircraft in terms of technical aspects, economic aspects and environmental aspects. Therefore, we evaluated the alternatives for aircraft selection in multiple dimensions.
3. While determining the set of criteria and sub-criteria, both expert opinion and the IT2FAHP method were used
4. IT2FAHP and IT2FTOPSIS methods are the latest MCDM methods introduced to the literature. When these methods are used for decision making under uncertainty, they give superior results to other methods. Therefore, it can be said that the findings obtained in this study are more robust.
5. Airline companies can use the methods we used for aircraft selection using their own technical staff and experts. Airlines can also automate this process. In this way, airlines can choose the most suitable aircraft for the selection of the appropriate aircraft, without being affected by changing market and competitive conditions.
6. This model can also be used in future aircraft selection studies. Commercial aircraft and military aircraft can be selected by changing the criteria and sub-criteria in the model.

Table 14
Decision matrix.

Criteria																				
Alternatives																				
	X_1					X_2					X_3					X_4				
	DM_1	**DM_2**	**DM_3**	**DM_4**	**DM_5**	**DM_1**	**DM_2**	**DM_3**	**DM_4**	**DM_5**	**DM_1**	**DM_2**	**DM_3**	**DM_4**	**DM_5**	**DM_1**	**DM_2**	**DM_3**	**DM_4**	**DM_5**
C_{12}	M	H	H	VH	H	H	MH	VH	H	VH	MH	VH	M	VH	H	VH	VH	M	H	M
C_{17}	ML	M	H	M	MH	MH	MH	VH	H	VH	M	H	M	MH	MH	H	H	ML	H	H
C_{14}	H	H	H	M	MH	H	H	MH	MH	H	H	M	M	M	ML	H	M	ML	MH	ML
C_{16}	ML	ML	ML	MH	M	MH	M	H	VH	H	M	MH	M	M	MH	H	MH	MH	H	H
C_{23}	H	MH	H	H	MH	VH	MH	MH	H	MH	MH	VH	ML	MH	H	MH	VH	M	MH	MH
C_{24}	ML	H	M	H	VH	MH	H	VH	M	MH	M	M	MH	ML	MH	MH	H	H	M	MH
C_{31}	ML	MH	H	M	VH	MH	MH	MH	VH	VH	M	H	ML	MH	H	MH	VH	M	MH	H
C_{32}	M	M	H	M	ML	ML	M	MH	MH	M	M	MH	ML	ML	M	ML	H	M	M	ML

Table 15
Decision matrix.

	X_1	X_2	X_3	X_4
C_{12}	(0.66, 0.84, 0.84, 0.94; 1, 1) (0.75, 0.84, 0.84, 0.89; 0.9, 0.9)	(0.74, 0.90, 0.90, 0.98; 1, 1) (0.82, 0.90, 0.90, 0.94; 0.9, 0.9)	(0.66, 0.82, 0.82, 0.92; 1, 1) (0.74, 0.82, 0.82, 0.87; 0.9, 0.9)	(0.62, 0.78, 0.78, 0.88; 1, 1) (0.70, 0.78, 0.78, 0.83; 0.9, 0.9)
C_{17}	(0.38, 0.58, 0.58, 0.76; 1, 1) (0.48, 0.58, 0.58, 0.67; 0.9, 0.9)	(0.70, 0.86, 0.86, 0.96; 1, 1) (0.78, 0.86, 0.86, 0.91; 0.9, 0.9)	(0.46, 0.66, 0.66, 0.84; 1, 1) (0.56, 0.66, 0.66, 0.75; 0.9, 0.9)	(0.58, 0.78, 0.78, 0.90; 1, 1) (0.68, 0.78, 0.78, 0.84; 0.9, 0.9)
C_{14}	(0.58, 0.78, 0.78, 0.92; 1, 1) (0.68, 0.78, 0.78, 0.85; 0.9, 0.9	(0.62, 0.82, 0.82, 0.96; 1, 1) (0.72, 0.82, 0.82, 0.89; 0.9, 0.9)	(0.34, 0.54, 0.54, 0.72; 1, 1) (0.44, 0.54, 0.54, 0.63; 0.9, 0.9)	(0.34, 0.54, 0.54, 0.72; 1, 1) (0.44, 0.54, 0.54, 0.63; 0.9, 0.9)
C_{16}	(0.22, 0.42, 0.42, 0.62; 1, 1) (0.32, 0.42, 0.42, 0.52; 0.9, 0.9)	(0.62, 0.80, 0.80, 0.92; 1, 1) (0.71, 0.80, 0.80, 0.86; 0.9, 0.9)	(0.38, 0.58, 0.58, 0.78; 1, 1) (0.48, 0.58, 0.58, 0.68; 0.9, 0.9)	(0.62, 0.82, 0.82, 0.96; 1, 1) (0.72, 0.82, 0.82, 0.89; 0.9, 0.9)
C_{23}	(0.62, 0.82, 0.82, 0.96; 1, 1) (0.72, 0.82, 0.82, 0.89; 0.9, 0.9)	(0.62, 0.80, 0.80, 0.94; 1, 1) (0.71, 0.80, 0.80, 0.87; 0.9, 0.9)	(0.54, 0.72, 0.72, 0.86; 1, 1) (0.63, 0.72, 0.72, 0.79; 0.9, 0.9)	(0.54, 0.72, 0.72, 0.88; 1, 1) (0.63, 0.72, 0.72, 0.80; 0.9, 0.9)
C_{24}	(0.54, 0.72, 0.72, 0.84; 1, 1) (0.63, 0.72, 0.72, 0.78; 0.9, 0.9)	(0.58, 0.76, 0.76, 0.90; 1, 1) (0.67, 0.76, 0.76, 0.83; 0.9, 0.9)	(0.34, 0.54, 0.54, 0.74; 1, 1) (0.44, 0.54, 0.54, 0.64; 0.9, 0.9)	(0.54, 0.74, 0.74, 0.90; 1, 1) (0.64, 0.74, 0.74, 0.82; 0.9, 0.9
C_{31}	(0.50, 0.68, 0.68, 0.82; 1, 1) (0.59, 0.68, 0.68, 0.75; 0.9, 0.9)	(0.66, 0.82, 0.82, 0.94; 1, 1) (0.74, 0.82, 0.82, 0.88; 0.9, 0.9)	(0.46, 0.66, 0.66, 0.82; 1, 1) (0.56, 0.66, 0.66, 0.74; 0.9, 0.9)	(0.58, 0.76, 0.76, 0.90; 1, 1) (0.67, 0.76, 0.76, 0.83; 0.9, 0.9)
C_{32}	(0.43, 0.68, 0.68, 0.90; 1, 1) (0.55, 0.68, 0.68, 0.79; 0.9, 0.9)	(0.43, 0.68, 0.68, 0.93; 1, 1) (0.55, 0.68, 0.68, 0.80; 0.9, 0.9)	(0.33, 0.58, 0.58, 0.83; 1, 1) (0.45, 0.58, 0.58, 0.70; 0.9, 0.9)	(0.38, 0.63, 0.63, 0.85; 1, 1) (0.50, 0.63, 0.63, 0.74; 0.9, 0.9)

For airline companies, it is very important to evaluate and select the most suitable aircraft among alternatives. Appropriate aircraft selection is important for the long-term competitive strategies of the airline companies, and the selection of the appropriate aircraft can provide competitive advantage. Therefore, airline companies should determine a useful and long-term method for aircraft selection. Considering the process followed and the methods used in the structuring of this study, it is expected to provide important contributions to airline companies in the selection of appropriate aircraft. In addition, the process and methods used can be adapted for use in other sectors. It is recommended that the process followed and the methods used in this study are preferred in selection studies carried out from now on.

The study is thought to be related to the COVID-19 pandemic in several respects. First, demand for the airline has decreased significantly due to the COVID-19 pandemic. In the air transport industry, the number of passengers in 2018 is likely to be reached in 2023–2024. Therefore, many airlines will be removed aircraft with high operating and maintenance costs from their fleets. This will also allow decision-makers to consider whether or not the aircraft meets the COVID-19 pandemic requirements when determining the aircraft to leave the fleet. The model used in this article will also guide decision makers in the process of removing aircraft from the fleet. Secondly, many airlines which ceased their flights completely due to the COVID-19 pandemic experienced a risk of financial distress and bankruptcy. In this process, airlines with low fixed costs and operating costs and those with efficient aircraft against capacity reduction may be less affected by the pandemic. In addition, airlines with aircrafts that have been converted to cargo transportation more easily and at lower costs may have taken advantage.

Table 16
Weighted decision matrix.

X_1	X_2	X_3	X_4
$\tilde{\tilde{v}}_{11}$ (0.03, 0.07, 0.18, 0.39; 1, 1) (0.04, 0.08, 0.16, 0.29; 0.9, 0.9)	$\tilde{\tilde{v}}_{12}$(0.03, 0.07, 0.19, 0.40; 1, 1) (0.04, 0.08, 0.17, 0.31; 0.9, 0.9)	$\tilde{\tilde{v}}_{13}$(0.03, 0.07, 0.17, 0.38; 1, 1) (0.04, 0.07, 0.16, 0.29; 0.9, 0.9)	$\tilde{\tilde{v}}_{14}$(0.03, 0.06, 0.16, 0.36; 1, 1) (0.04, 0.07, 0.15, 0.27; 0.9, 0.9)
$\tilde{\tilde{v}}_{21}$ (0.01, 0.03, 0.09, 0.25; 1, 1) (0.02, 0.04, 0.08, 0.17; 0.9, 0.9)	$\tilde{\tilde{v}}_{22}$(0.02, 0.05, 0.13, 0.31; 1, 1) (0.03, 0.05, 0.12, 0.23; 0.9, 0.9)	$\tilde{\tilde{v}}_{23}$(0.01, 0.04, 0.10, 0.28; 1, 1) (0.02, 0.04, 0.09, 0.19; 0.9, 0.9)	$\tilde{\tilde{v}}_{24}$(0.02, 0.04, 0.12, 0.29; 1, 1) (0.03, 0.05, 0.11, 0.21; 0.9, 0.9)
$\tilde{\tilde{v}}_{31}$ (0.03, 0.09, 0.25, 0.59; 1, 1) (0.05, 0.10, 0.22, 0.43; 0.9, 0.9)	$\tilde{\tilde{v}}_{32}$(0.04, 0.10, 0.26, 0.62; 1, 1) (0.06, 0.11, 0.23, 0.45; 0.9, 0.9)	$\tilde{\tilde{v}}_{33}$(0.02, 0.06, 0.17, 0.46; 1, 1) (0.03, 0.07, 0.15, 0.32; 0.9, 0.9)	$\tilde{\tilde{v}}_{34}$(0.02, 0.06, 0.17, 0.46; 1, 1) (0.03, 0.07, 0.15, 0.32; 0.9, 0.9)
$\tilde{\tilde{v}}_{41}$ (0.01, 0.02, 0.05, 0.15; 1, 1) (0.01, 0.02, 0.04, 0.09; 0.9, 0.9)	$\tilde{\tilde{v}}_{42}$(0.02, 0.03, 0.09, 0.22; 1, 1) (0.02, 0.04, 0.08, 0.16; 0.9, 0.9)	$\tilde{\tilde{v}}_{43}$(0.01, 0.02, 0.06, 0.18; 1, 1) (0.01, 0.03, 0.06, 0.12; 0.9, 0.9)	$\tilde{\tilde{v}}_{44}$(0.02, 0.04, 0.09, 0.22; 1, 1) (0.02, 0.04, 0.08, 0.16; 0.9, 0.9)
$\tilde{\tilde{v}}_{51}$(0.04, 0.10, 0.26, 0.60; 1, 1) (0.05, 0.11, 0.23, 0.44; 0.9, 0.9)	$\tilde{\tilde{v}}_{52}$(0.04, 0.09, 0.25, 0.59; 1, 1) (0.05, 0.10, 0.23, 0.43; 0.9, 0.9)	$\tilde{\tilde{v}}_{53}$(0.03, 0.08, 0.23, 0.54; 1, 1) (0.04, 0.09, 0.21, 0.39; 0.9, 0.9)	$\tilde{\tilde{v}}_{54}$(0.03, 0.08, 0.23, 0.55; 1, 1) (0.04, 0.09, 0.21, 0.40; 0.9, 0.9)
$\tilde{\tilde{v}}_{61}$ (0.03, 0.12, 0.31, 0.69; 1, 1) (0.06, 0.13, 0.29, 0.52; 0.9, 0.9)	$\tilde{\tilde{v}}_{62}$(0.04, 0.12, 0.33, 0.74; 1, 1) (0.07, 0.14, 0.30, 0.55; 0.9, 0.9)	$\tilde{\tilde{v}}_{63}$(0.02, 0.09, 0.24, 0.61; 1, 1) (0.04, 0.10, 0.21, 0.42; 0.9, 0.9)	$\tilde{\tilde{v}}_{64}$(0.03, 0.12, 0.32, 0.74; 1, 1) (0.06, 0.13, 0.29, 0.54; 0.9, 0.9)
$\tilde{\tilde{v}}_{71}$ (0.01, 0.01, 0.03, 0.11; 1, 1) (0.01, 0.01, 0.03, 0.07; 0.9, 0.9)	$\tilde{\tilde{v}}_{72}$(0.01, 0.02, 0.04, 0.12; 1, 1) (0.01, 0.02, 0.04, 0.08; 0.9, 0.9)	$\tilde{\tilde{v}}_{73}$(0.01, 0.01, 0.03, 0.11; 1, 1) (0.01, 0.01, 0.03, 0.07; 0.9, 0.9)	$\tilde{\tilde{v}}_{74}$(0.01, 0.01, 0.04, 0.12; 1, 1) (0.01, 0.02, 0.03, 0.07; 0.9, 0.9)
$\tilde{\tilde{v}}_{81}$ (0.00, 0.01, 0.02, 0.09; 1, 1) (0.01, 0.01, 0.02, 0.04; 0.9, 0.9)	$\tilde{\tilde{v}}_{82}$(0.00, 0.01, 0.02, 0.09; 1, 1) (0.01, 0.01, 0.02, 0.04; 0.9, 0.9)	$\tilde{\tilde{v}}_{83}$(0.00, 0.01, 0.02, 0.08; 1, 1) (0.00, 0.01, 0.02, 0.04; 0.9, 0.9)	$\tilde{\tilde{v}}_{84}$(0.00, 0.01, 0.02, 0.08; 1, 1) (0.00, 0.01, 0.02, 0.04; 0.9, 0.9)

Table 17
Ranking of alternatives.

Alternatives	Aircraft	$C_{(Xi)}$	Rank
X_1	Airbus A320neo	0.44	3
X_2	Airbus A321neo	0.55	1
X_3	Boeing 737 MAX 8	0.51	2
X_4	Boeing 737 MAX 9	0.27	4

Therefore, factors such as “being able to be used in pandemic periods” and “being transformed into a cargo aircraft with a short time and low cost” can be taken into consideration in future aircraft selections. Finally, after this process, the effect of the COVID-19 pandemic can be seen in the design of the aircraft. In other words, in the design of new aircrafts, critical factors such as social distance and hand hygiene can be taken into account with the COVID-19 pandemic. Airlines can add the criterion of “suitability for epidemic diseases” in new plane orders. This is one of the important factors that aircraft manufacturers should consider.

CRediT author contribution statement

Kasım Kiracı: Conceptualization, and design of study, Funding acquisition, Formal analysis, Writing - original draft, Approval of the version of the manuscript to be published. **Ercan Akan:** Conceptualization, design of study, Formal analysis, Writing - original draft, Approval of the version of the manuscript to be published.

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