



Multi-criteria decision making based on intuitionistic cubic fuzzy numbers

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Abstract

This paper develops fuzzy multi-criteria decision making (MCDM) approach to evaluate performance of airports according to the passengers' perspective. Assessments for qualitative measures and quantitative measures are represented by intuitionistic cubic fuzzy numbers (ICFNs), and crisp numbers represents criteria weights, which are obtained via surveys. To construct a strategy for solving MCDM problems, we have developed extended forms of VIKOR method and TOPSIS method for ICFNs and constructed ICF-VIKOR and ICF-TOPSIS algorithm under ICF information in group decision environment. We have applied these methods for an experimental analysis of 7 significant international airports in the Asia-Pacific region to evaluate their performance with conflicting criteria under ICF environment. To show the supremacy of the proposed techniques, we have presented comparative analysis with the existing techniques.

Keywords Airports · Multicriteria decision making · ICF-TOPSIS method · ICF-VIKOR method · Intuitionistic cubic fuzzy set

1 Introduction

Nowadays, service quality and operation effectiveness of international airports are critical, where people are more versatile and organizations are worldwide. To empower an airport to perceive helpful zones for development, it is required to evaluate its exhibition comparative with other practically indistinguishable airports concerning different reasonable assessment criteria. As the assessment depends on the relative procedure, the assessment result can be utilized as management tool and an assistance benchmarking for airports. Numerous assessments on the evaluation of airport performance have been done in the

literature with focus on specific functional areas of airport activities, such as productivity (Guzha et al. 2020; Wan et al. 2013), airline services (Pandey 2016; Shojaei et al. 2018), service quality (Skorupski and Uchroński 2018), efficiency (Olfat et al. 2016), capacity and delays (Pishdar et al. 2019; Yu et al. 2019), competitiveness (Chen et al. 2018) and financial performance (Mahtani and Garg 2018).

Despite the fact that there is no exact and universal definition for airport execution, the overall performance can be estimated from the perspectives of travelers, aircraft, and a decision maker/instructors of the airport (Kumar et al. 2020). The most generally utilized airport performance assessment strategies are the total factor productivity and the data envelopment analysis (DEA) (Loh et al. 2020; Paraschi et al. 2020). Although these techniques are appropriate for estimating the proficiency of airport operations dependent on performance output measures and resource input measures, they don't intend to address the practicality issue concerning the general execution of airports from the viewpoints of the travelers, carriers and airport a decision maker/instructor overall. The assessment of the general execution of airports is a complex decision-making process, which contains qualitative and quantitative components that may struggle with dubious and

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inadequate information. MCGDM has proven to be an effective approach for ranking a finite number of alternatives characterized by multiple conflicting criteria (Garg and Rani 2019; Zhang et al. 2018). It is required to construct a MCGDM effective airport performance evaluation model to resolve this problem.

In many hesitant situations and decision making problems, the experts or decision makers' opinions are not expressed by crisp values, and it is difficult for them to determine exact values for the potential alternatives among the conflicted criteria. Zadeh (1965) introduced the concept of the fuzzy set (FS) for solving problems under such uncertain conditions. After then in this theory, Atanassov found some flaws and established the idea of Atanassov's IF set (AIFS) (Atanassov 1986). AIFS is the generalization of Zadeh fuzzy sets (Chen and Huang 2003; Chen 2017; Chen and Jong 1997; Manoj et al. 1998). Several researchers have contributed in the AIFS approach to different fields, which results the great progress of AIFSs in technical and theoretical aspects (Grag and Kumar 2020; Zhao et al. 2010). Under a complex environment in the decision making process intuitionistic fuzzy numbers (IFNs) can properly express the information of a decision maker about objects (Chen 2013, Chen and Chang (2016), Chen et al. (2016); Zou et al. 2020). However, AIFS is not capable to explain some uncertain problems. To solve such issues Jun et al. (2011) established the idea of cubic fuzzy set (CFS). The solutions of uncertainty problems were made possible by this theory. Cubic set theory also explains the unpredictable, unsatisfied and satisfied information, which were not possible to explain by FS and AIFS theory (Ashraf et al. 2019a, b, 2020; Riaz and Tehrim 2019). Cubic set is having more desirable information than AIFS and FS (Ashraf et al. 2019a, b; Jana et al. 2019; Fahmi et al. 2019). The researchers have been giving more attention to these theories over the last decades and have applied them effectively to the different situations in the decision-making process (Fahmi et al. 2018).

Although these theories have been beneficially applied in MCGDM, but there are still some limitations. To overcome such limitations, recently Muneeza et al. (2020) introduced intuitionistic cubic fuzzy set (ICFS) theory. The ICFS theory could be successfully applied to deal with imprecise or hesitant situations. ICFS is a new approach to intuitionistic fuzzy set through application of cubic set theory. ICFS is the hybrid set which can contain much more information to express a cubic fuzzy set and an intuitionistic fuzzy set simultaneously for handling the uncertainties in the data Muhammad Qiyas et al. (2020a, b). ICFS is suitable tool by considering some membership degrees for airport alternatives versus the criteria under a set. Muneeza and Abdullah (2020) applied intuitionistic cubic fuzzy aggregation information to

multicriteria group decision support systems for small hydropower plant locations selection. Several classical MCGDM strategies have been proposed by researchers in literature, such as the PROMETHEE (Preference Ranking Organization method for Enrichment Evaluations) method by Mareschal et al. (1984), the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method by Hwang et al. (2012) and the VIKOR (VIseKriterijumska Optimizacija I Kompromisno Resenje in Serbian, meaning multiattribute optimization and compromise solution) method by Hashemi et al. (2018).

The idea of TOPSIS method was established, by Hwang and Yoon (1981). Many authors developed this method later. The high flexibility of the TOPSIS method allows us to add additional extensions in order to make the best choices in different situations. Practically, to solve many theoretical and real-world problems TOPSIS and its modifications are used (Kumar 2020; Rouyendegh et al. 2020). The results can be easily evaluated by using TOPSIS method in complex decision making, which contains a lot of qualitative information. For ranking and selection of alternatives, the TOPSIS method is a useful and practical technique. Jahanshahloo et al. (2006) extended TOPSIS method on the basis of interval data to solve MCGDM problems. By Opricovic et al. (2004) according to relative examination of VIKOR method and TOPSIS method, both the methods use different normalization methods and different aggregation functions. TOPSIS method is dependent on the operation that the optimal point should have the shortest distance from the positive ideal solution (PIS) and the farthest from the negative ideal solution (NIS). The decision makers might like to have a decision which is not only low risky but highly beneficial as could be expected. Therefore risk avoider decision makers prefer this strategy. Besides, computing the optimal point in the VIKOR is based on the particular measure of "closeness" to the PIS. It is suitable for those conditions in which the decision maker wants extreme low risk and higher benefit.

Opricovic and Tzeng (2003) presented VIKOR method with incomplete information with conflicting and non-commensurable criteria to assess the land use secretaries. To solve decision problem, Opricovic (1998) presented the VIKOR technique as a MCGDM method. For solving the MCGDM problems with triangular IF information, Wan et al. (2013) presented the VIKOR method. Huchang et al. (2013) extended the classical VIKOR technique to hesitant fuzzy environment. For solving MCGDM problems, Vahdani Hadipour (2010) presented an interval-valued fuzzy (IVF) VIKOR method. Park Cho and Young (2011) presented the VIKOR technique in interval-valued IF information for decision making. The VIKOR method has a lot of applications in numerous fields, such as engineering, logistics and supply chain management, design, medical

diagnosis, construction, and transportation (Ighravwe and Oke 2020; Li et al. 2020; Nazam et al. 2020; Sun et al. 2020; Yildirim and Mercangoz 2020). Since intuitionistic fuzzy VIKOR (IFVIKOR) is an important research topic and to solve MCGDM problems a lot of researchers focus on the IFVIKOR method (Luo et al. 2017; Zeng et al. 2019). The main purpose of this article is to demonstrate the TOPSIS method and VIKOR method under ICF information for evaluating the different priorities of the choices amid the multicriteria decision making (MCGDM) process. In addition to the significant advanced approaches originated before in this field, to represent our proposed techniques we seriously have left no stone unturned, so that it can overcome all other past troubles to resolve the real world problems concern. Based on intuitionistic cubic fuzzy information make some formulations to MCGDM and briefly describe the decision making process based on TOPSIS and VIKOR method. We did an experimental analysis of 7 significant international airports in the Asia-Pacific region to demonstrate feasibility and practicality of the mentioned new techniques.

Our proposed method is different from all the previous techniques for decision making due to the fact that the proposed method use intuitionistic cubic fuzzy information, which will not cause any loss of information in the process. So it's efficient and feasible for real-world decision making applications. To show the supremacy of the proposed technique we give the comparison section which showed that our proposed structure is more effective and generalized as compared to existing structures of fuzzy sets. In this paper we developed ICF-VIKOR method and developed intuitionistic cubic fuzzy VIKOR (ICF-VIKOR) algorithm in MCGDM environment. Based on the developed models an interpretative case under ICF information has discussed to solve Asia-Pacific airports performance assessment with different criteria. Which are progressively adaptable and practical for airports performance evaluation.

To complete the mentioned task, the remaining paper is arranged as follows. In the next section, firstly review some fundamental concepts of IFS, IVFS, CFS and ICFS. In Sect. 3, ICF-TOPSIS algorithm for MCGDM is presented. In Sect. 4, ICF-VIKOR algorithm with ICF information is developed. In Sect. 5, based on the proposed models the performance evaluation of significant international airports in the Asia-Pacific region has presented. In Sect. 6, we justified our advance approach with the pre-existing approaches for effectiveness and feasibility. Finally in the last section, the conclusions and future work are presented.

2 Preliminaries

Some basic definitions and their fundamental characteristics are reviewed in this section.

Definition 2.1 Zadeh (1965) Let \tilde{T} be a non-empty set. A fuzzy set I of \tilde{T} is defined by;

$$I = \{(\hat{j}, \bar{o}_I(\hat{j})) | \hat{j} \in \tilde{T}\}, \tag{1}$$

where $\bar{o}_I(\hat{j}) : \tilde{T} \rightarrow [0, 1]$ is the function of membership of a FS I .

Definition 2.2 Atanassov (1999) Let \tilde{T} be a non-empty set. An intuitionistic fuzzy set I of \hat{j} is given by:

$$I = \{(\hat{j}, \bar{o}_I(\hat{j}), \ddot{u}_I(\hat{j})) | \hat{j} \in \tilde{T}\}, \tag{2}$$

where for each element $\hat{j} \in \tilde{T}$ to the set \tilde{T} , the functions $\bar{o}_I(\hat{j}) : \tilde{T} \rightarrow [0, 1]$ denotes the membership grade and the non-membership grade is denoted by $\ddot{u}_I(\hat{j}) : \tilde{T} \rightarrow [0, 1]$, with $0 \leq \ddot{u}_I(\hat{j}) + \bar{o}_I(\hat{j}) \leq 1$ for every $\hat{j} \in \tilde{T}$. The pair $(\bar{o}_I(\hat{j}), \ddot{u}_I(\hat{j}))$ is called IFN or IF value (IFV).

Definition 2.3 Atanassov (1999) Let $I_2 = (\bar{o}_{I_2}(\hat{j}), \ddot{u}_{I_2}(\hat{j}))$ and $I_1 = (\bar{o}_{I_1}(\hat{j}), \ddot{u}_{I_1}(\hat{j}))$ be any two IFNs. Then, the IF distance of I_2 and I_1 is given as,

$$\partial(I_2, I_1) = |I_2 - I_1| = \frac{1}{2} (|\bar{o}_{I_2}(\hat{j}) - \bar{o}_{I_1}(\hat{j})| + |\ddot{u}_{I_2}(\hat{j}) - \ddot{u}_{I_1}(\hat{j})|). \tag{3}$$

Definition 2.4 Jun et al. (2011) Let \tilde{T} be a non-empty set. A cubic fuzzy set I in \tilde{T} is given as following,

$$I = \{(\hat{j}, [\bar{o}_I^-(\hat{j}), \bar{o}_I^+(\hat{j})], \ddot{u}_I(\hat{j})) | \hat{j} \in \tilde{T}\}, \tag{4}$$

where $[\bar{o}_I^-(\hat{j}), \bar{o}_I^+(\hat{j})]$ represents the degree of membership and $\ddot{u}_I(\hat{j})$ denotes the degree of non-membership.

Definition 2.5 Zhou et al. (2014) Let \tilde{T} be a fixed set. An interval valued fuzzy set I in \tilde{T} is given as following:

$$I = \{(\hat{j}, [\bar{o}_I^-(\hat{j}), \bar{o}_I^+(\hat{j})], [\ddot{u}_I^-(\hat{j}), \ddot{u}_I^+(\hat{j})]) | \hat{j} \in \tilde{T}\}, \tag{5}$$

where $[\bar{o}_I^-(\hat{j}), \bar{o}_I^+(\hat{j})]$ represents non-membership and membership function is represented by $[\ddot{u}_I^-(\hat{j}), \ddot{u}_I^+(\hat{j})]$.

Definition 2.6 Muneeza et al. (2020) Let $\tilde{T} \neq \phi$, then ICF set I in \tilde{T} , is defined as following:

$$I = \{\hat{j}, \langle c_I, c'_I \rangle | \hat{j} \in \tilde{T}\}, \tag{6}$$

or

$$I = \{(\hat{j}, \langle [z^-, z^+], \vartheta \rangle, \langle [s^-, s^+], \delta \rangle) | \hat{j} \in \check{T}\}, \tag{7}$$

where $\langle [z^-, z^+], \vartheta \rangle$ denotes the membership grade and $\langle [s^-, s^+], \delta \rangle$ denotes the non-membership grade of I . Where $[z^-, z^+] \subset [0, 1], \vartheta : \check{T} \rightarrow [0, 1], \delta : \check{T} \rightarrow [0, 1]$ and $[s^-, s^+] \subset [0, 1]$, such that $\vartheta + \delta \leq 1$ and $\sup[z^-, z^+] + \sup[s^-, s^+] \leq 1$. Furthermore we have,

$$\begin{aligned} \pi(I) &= \{ \langle [1, 1] - [(z^-, z^+) + (s^-, s^+)], \langle 1 - (\vartheta + \delta) \rangle \rangle \}, \\ \pi(I) &= \{ [1 - (z^- + s^-), 1 - (z^+ + s^+)], 1 - (\vartheta + \delta) \}, \end{aligned} \tag{8}$$

called ICFS hesitation margin of $\hat{j} \in \check{T}$ for ICFS. The pair $([z^-, z^+], \vartheta, [s^-, s^+], \delta)$ is called the ICF number (ICFN) or ICF value (ICFV) and is denoted by $I, i.z., I = ([z^-, z^+], \vartheta, [s^-, s^+], \delta)$.

Definition 2.7 Muneeza et al. (2020) Let $I = (\langle [z^-, z^+], \vartheta \rangle, \langle [s^-, s^+], \delta \rangle)$ be an ICFN. Then, score function of $I, S(I)$ is defined as following

$$S(I) = [(z^- + z^+ + \vartheta - s^- + s^+ - \delta)/3], \tag{9}$$

such that $S(I) \in [-1, 1]$.

Definition 2.8 Muneeza et al. (2020) For ICFN I , an accuracy function $H(I)$ is given as,

$$H(I) = [(z^- + z^+ + \vartheta + s^- + s^+ + \delta)/3], \tag{10}$$

where $H(I) \in [0, 1]$.

Definition 2.9 Muneeza et al. (2020) Let

$$I_1 = (\langle [z_1^-, z_1^+], \vartheta_1 \rangle, \langle [s_1^-, s_1^+], \delta_1 \rangle),$$

and

$$I_2 = (\langle [z_2^-, z_2^+], \vartheta_2 \rangle, \langle [s_2^-, s_2^+], \delta_2 \rangle),$$

be two ICFNs their scores are given as $S(I_1)$ and $S(I_2)$ respectively. Then,

$$S(I_1) < S(I_2) \implies I_1 < I_2.$$

3 Intuitionistic cubic fuzzy MCGDM problem

Suppose there are \bar{n} alternatives $\mathbb{W} = \{\mathbb{W}_1, \mathbb{W}_2, \dots, \mathbb{W}_{\bar{n}}\}$ and \hat{e} criteria $\mathbb{C} = \{\mathbb{C}_1, \mathbb{C}_2, \dots, \mathbb{C}_{\hat{e}}\}$ to be evaluated with weight vector $\check{u} = (\check{u}_1, \check{u}_2, \dots, \check{u}_{\bar{n}})^T$ such that $\sum_{i=1}^{\bar{n}} \check{u}_i = 1$ and $\check{u}_i \in [0, 1]$. To assess the accomplishment based on criteria \mathbb{C}_i of the alternative \mathbb{W}_i , the decision makers give the statistics about the alternative \mathbb{W}_i , not satisfying the criteria and also about the alternative \mathbb{W}_i , satisfying the criteria \mathbb{C}_i . Let the rating of alternatives \mathbb{W}_i on criteria \mathbb{C}_i , given by decision makers be ICFNs in $\check{T} : I_{i\check{i}} = \langle \mathbb{C}_{i\check{i}}, \mathbb{C}'_{i\check{i}} \rangle$

$(i = 1, 2, \dots, \bar{n})(\check{i} = 1, 2, \dots, \hat{e})$. Let $\mathbb{C}'_{i\check{i}}$ denotes the degree of alternative \mathbb{W}_i not satisfying the criteria \mathbb{C}_i and $\mathbb{C}_{i\check{i}}$ shows the degree of alternative \mathbb{W}_i satisfying the criteria \mathbb{C}_i , such that $\mathbb{C}_{i\check{i}} = \langle [e_{i\check{i}}^-, e_{i\check{i}}^+], \lambda_{i\check{i}} \rangle$, and $\mathbb{C}'_{i\check{i}} = \langle [r_{i\check{i}}^-, r_{i\check{i}}^+], \delta_{i\check{i}} \rangle$. Thus a multi criteria decision making problem can be briefly represented by ICF decision matrix. Which is defined below

$$\hat{\partial} = (I_{i\check{i}})_{\bar{n} \times \hat{e}} = (\langle c_{i\check{i}}, c'_{i\check{i}} \rangle)_{\bar{n} \times \hat{e}}, (i = 1, 2, \dots, \bar{n}; \check{i} = 1, 2, \dots, \hat{e}). \tag{11}$$

3.1 ICF-TOPSIS method

Hwang and Yoon (2011) produced the concept of TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method. It is one of very applicable MCGDM methods. This strategy is dependent on the concept of the degree of optimality established in an alternative where various criteria represent the notion of the best alternative Jahanshahloo et al. (2006). In practice, the TOPSIS technique is based on the idea that the best alternative will be at the shortest distance from the PIS and at largest distance from the NIS. Under different decision contexts TOPSIS method has been applied Li et al. (2010). This is because of (a) its computational viability, (b) its significance in tackling different viable decision problems and simplicity, and (c) its understandability. On the basis of idea stated above, the NIS R^- and the PIS R^+ can be evaluated by across all alternatives with respect to each service attribute selecting the minimum value and the maximum value respectively. The computation steps of TOPSIS are stated below.

Step 1 Normalize $\hat{\partial} = (I_{i\check{i}})_{\bar{n} \times \hat{e}} = (\langle c_{i\check{i}}, c'_{i\check{i}} \rangle)_{\bar{n} \times \hat{e}}, (\check{i} = 1, 2, \dots, \hat{e}; i = 1, 2, \dots, \bar{n})$. Generally the criteria can be classified into two groups, benefit criteria and cost criteria. Will not do process of normalization, If all the criteria are of similar type. But if $\hat{\partial}$ contains both cost criteria and benefit criteria, then the rating values of the cost criteria can be changed into the benefit criteria by the following normalization method,

$$\check{L}_{i\check{i}} = \langle v_{i\check{i}}, t_{i\check{i}} \rangle = \begin{cases} \hat{\partial}_{i\check{i}}^c, & \text{if the criteria is of cost type} \\ \hat{\partial}_{i\check{i}}, & \text{if the criteria is of benefit type} \end{cases} \tag{12}$$

$\hat{\partial}_{i\check{i}}^c$ is the complement of $\hat{\partial}_{i\check{i}}$. Thus we have the normalized ICF decision matrix. The normalized form of $\hat{\partial}$, denoted by $\hat{\partial}^{\bar{n}}$ and is given by $\hat{\partial}^{\bar{n}} = (\check{L}_{i\check{i}})_{\bar{n} \times \hat{e}} = (\langle v_{i\check{i}}, t_{i\check{i}} \rangle)_{\bar{n} \times \hat{e}}, (\check{i} = 1, 2, \dots, \hat{e}; i = 1, 2, \dots, \bar{n})$.

Step 2 Calculating the NIS R^- and PIS R^+ , which are given as,

$$\begin{aligned} R^- &= (\wp_1^-, \wp_2^-, \dots, \wp_{\tilde{n}}^-), \\ R^+ &= (\wp_1^+, \wp_2^+, \dots, \wp_{\tilde{n}}^+), \end{aligned} \tag{13}$$

where if the criteria are of minimizing type, then

$$\begin{aligned} \wp_j^+ &= \min\{\wp_{ij}/1 \leq i \leq \tilde{n}\} \text{ and} \\ \wp_j^- &= \max\{\wp_{ij}/1 \leq i \leq \tilde{n}\}, \end{aligned} \tag{14}$$

if the criteria are of maximizing type, then

$$\begin{aligned} \wp_j^+ &= \max\{\wp_{ij}/1 \leq i \leq \tilde{n}\} \text{ and} \\ \wp_j^- &= \min\{\wp_{ij}/1 \leq i \leq \tilde{n}\}, \end{aligned} \tag{15}$$

and which are evaluated by the Sco function

$$S(I) = [(\tilde{z}^- + \tilde{z}^+ + \vartheta - \tilde{s}^- + \tilde{s}^+ - \delta)/3]. \tag{16}$$

Step 3 Calculate the distance for each alternative to R^+ and R^- with criteria weight vector $\ddot{u} = (\ddot{u}_1, \ddot{u}_2, \dots, \ddot{u}_{\tilde{e}})$.

$$\begin{aligned} \partial_i^- &= \sqrt{\sum_{j=1}^{\tilde{e}} \ddot{u}_j (\wp_j^- - \wp_{ij}^-)^2} \\ \text{and } \partial_i^+ &= \sqrt{\sum_{j=1}^{\tilde{e}} \ddot{u}_j (\wp_j^+ - \wp_{ij}^+)^2}. \end{aligned} \tag{17}$$

Step 4 To the ideal solution, evaluate the closeness coefficients by each alternative by utilizing the below structure,

$$cc_i = \partial_i^- / (\partial_i^- + \partial_i^+) (i = 1, 2, 3, \dots, \tilde{n}), \tag{18}$$

get the overall closeness coefficients.

Step 5 By utilizing the Sco of ICFNs, rank the alternatives and choose the best one.

3.2 ICF-VIKOR Method

Opricovic and Tzeng (2002) introduced the idea of VIKOR technique. Making the decision result more appropriate, VIKOR procedure can minimize the individual regret and maximize the group utility simultaneously. Since ICFS is a suitable tool to portray nonspecificity and fuzziness in assessment information and to arrive a suitable solution the VIKOR technique is an effective MCGDM technique, based on ICF information we have extended the VIKOR strategy and develop ICF-VIKOR method. The proposed strategy relies upon the decision principle of the classical VIKOR technique. This technique gives the maximum group utility of the majority and the minimum with regard to the opponent’s individual regret. Additionally, the coefficient of decision mechanism can be changed

according to actual requirements to adjust group utility and individual regret, which can increase the decision-making adaptability.

The following steps are included in ICF-VIKOR method.

Step 1 Normalization is not required if all the criteria are of same type otherwise normalize the decision matrix.

Step 2 Find the NIS R^- and PIS R^+ , by utilizing the below structure.

$$\begin{aligned} R^+ &= (\wp_1^+, \wp_2^+, \wp_3^+, \dots, \wp_{\tilde{e}}^+), R^- \\ &= (\wp_1^-, \wp_2^-, \wp_3^-, \dots, \wp_{\tilde{e}}^-), \end{aligned} \tag{19}$$

if the criteria are of minimizing type, then

$$\begin{aligned} \wp_j^+ &= \min\{\wp_{ij}/1 \leq i \leq \tilde{n}\} \text{ and } \wp_j^- \\ &= \max\{\wp_{ij}/1 \leq i \leq \tilde{n}\}, \end{aligned} \tag{20}$$

if the criteria are of maximizing type, then

$$\begin{aligned} \wp_j^+ &= \max\{\wp_{ij}/1 \leq i \leq \tilde{n}\} \text{ and } \wp_j^- \\ &= \min\{\wp_{ij}/1 \leq i \leq \tilde{n}\}, \end{aligned} \tag{21}$$

which we get by using $S(I) = [(\tilde{z}^- + \lambda + \tilde{z}^+ - \tilde{s}^- - \tilde{s}^+ - i)/3]$.

Step 3 Calculate the values \check{L}_i, \check{O}_i and R_i can be obtained by using the below equations,

$$\check{L}_i = \sum_{j=1}^{\tilde{e}} \frac{\ddot{u}_j \partial(\wp_{ij}, \wp_j^+)}{\partial(\wp_j^+, \wp_j^-)}, \tag{22}$$

$$R_i = \max_{i \leq j \leq \tilde{e}} \frac{\ddot{u}_j \partial(\wp_{ij}, \wp_j^+)}{\partial(\wp_j^+, \wp_j^-)}, \tag{23}$$

and

$$\check{O}_i = \frac{\nu(\check{L}_i - \check{L}^*)}{(\check{L}_i^- - \check{L}^*)} + \frac{(1 - \nu)(R_i - R^*)}{(R^- - R^*)}. \tag{24}$$

Here $R^- = \max R_i, R^* = \min R_i, \check{L}_i^- = \max \check{L}_i,$ and $\check{L}^* = \min \check{L}_i.$

Step 4 Rank the alternatives by calculating each $\check{L}_i, R_i,$ and \check{O}_i values in a decreasing order.

Step 5 Calculate a solution.

4 Numerical application of the proposed methods

Nowadays, the operation proficiency and service quality of world wide airports are basic, people are more versatile and organizations are global. To empower an airport to perceive valuable zones for advancement, it is reasonable to

survey its exhibition in comparison with other basically indistinguishable airports concerning different sensible assessment criteria. We did an experimental analysis of 7 significant international airports in the Asia-Pacific region to show how the fuzzy multicriteria decision maker approach works. During the last centuries, air travel requests in the Asia-Pacific territory an ordinary annual development rate of 11%, the most elevated in the world. Because of the high monetary development rate in Asia the business ventures serving the Asia-Pacific region are extended. Asia's major airports are starting at now near cutoff with 16 of the world's 25 busiest air routes. Local flight industry is one of the reasons of Asia's rapid economic development. Air transportation is relied upon to accept a greater part in this area more than anyplace else on the planet. In numerous Asian countries the high populace and pay development rates are needed to convey an astounding increment increase all around transportation services demand. The area starting at now speaks to more than 50% of the all out people. Due to AP's particular financial attributes the use of execution measures (criteria) in airport assessment issue is direly critical. Optimal performance can be likened with gainfulness in the business serious climate.

However, the circumstances under which airports work are along way from competition. Geographical, economic, political, adecision makerministrative and social conditions all hinder direct competition among airports Doga et al. (2020). To evaluate the airport execution from the perspectives of different partners in the operations of airport, contingent upon the targets of the assessment issue various execution criteria can be used. The airport operator would focus more on measures worried about the operational productivity of the airport on account of airport performance evaluation. The more enthusiasm of travelers is in criteria related to quality and safety of service. Hence, to reflect the operational properties of global airports, the criteria for the assessment of execution ought to be produced using the quality degree of the services given by the airport and as seen by the travelers. The examination the exhibition assessment of Asia-Pacific's 7 huge worldwide airports on measures airport offices, traveler adecision makerinistration quality, and operational adecision makerinistration. Half of the worldwide traffic of the district is handled by the 7 significant airports chose. The motivation behind this performance assessment of Asia-Pacific's 7 significant international airports on measures recognizing airport facilities, operational management and passenger service condition. The 7 chosen major airports process half of the of the region's air traffic.

These airports are (\mathcal{U}_1) – Chek Lap Kok International AP– Hong Kong (HKG), (\mathcal{U}_2) – Capital International airport - Beijing (PEK), (\mathcal{U}_3) – Taoyuan International

airport - Taiwan (TPE), (\mathcal{U}_4) – Suvarnabhumi International airport - Bangkok (BKK), (\mathcal{U}_5) – Kansai International airport - Osaka (KIX), (\mathcal{U}_6) – Changi International airport - Singapore (SIN), (\mathcal{U}_7) – Narita International airport - Tokyo (NRT).

The performance of these 7 airports to be surveyed dependent on the 5 quality level/ performance measures by the passengers. These service criteria are (\mathcal{C}_1) – comfort (clog level and neatness in the terminal structure) (\mathcal{C}_2) – security (prosperity measures and security facilities), (\mathcal{C}_3) – processing time (total time needed during enrollment, development assessment and customs) (\mathcal{C}_4) – courtesy of staff (support and invitingness of airport staff), and (\mathcal{C}_5) – information visibility (data show for flights, airport facilities, and signposting).

These service criteria are to be estimated based on passengers' recognition, which are to be assessed under ICFNs. In this investigation, airport specialists utilize the assessment measurements (criteria) weight vector $(0.3, 0.25, 0.2, 0.15, 0.1)^T$. specialists introduced the assessment network appeared in Table 1. In the accompanying, for execution assessment of airports, we utilize the proposed techniques, i.e., VIKOR strategy and TOPSIS strategy.

4.1 By ICF-TOPSIS method

- Step 1** In Table 1 all the criteria are of same type, i.e., benefit type. Will not normalize the data.
- Step 2** Evaluate the PIS R^+ and NIS R^- , by the use of below formulae,

$$\begin{aligned} R^- &= (\varphi_1^-, \varphi_2^-, \dots, \varphi_e^-), \\ R^+ &= (\varphi_1^+, \varphi_2^+, \dots, \varphi_e^+), \end{aligned} \quad (25)$$

where

$$\begin{aligned} \varphi_j^- &= \min\{\varphi_{ij}/1 \leq i \leq 7\}, \\ \varphi_j^+ &= \max\{\varphi_{ij}/1 \leq i \leq 7\}, \end{aligned} \quad (26)$$

which are evaluated by utilizing $S(I)$,

- Step 3** For each alternative, evaluate the distance to R^- and R^+ using the proposed distance measures with criteria weight vector $\ddot{u} = (\ddot{u}_1, \ddot{u}_2, \dots, \ddot{u}_e)$
 $= (0.3, 0.25, 0.2, 0.15, 0.1)$.i.e.,

$$\begin{aligned} \partial_i^- &= \sqrt{\sum_{j=1}^e \ddot{u}_j (\varphi_j^- - \varphi_{ij})^2} \text{ and } \partial_i^+ \\ &= \sqrt{\sum_{j=1}^e \ddot{u}_j (\varphi_j^+ - \varphi_{ij})^2}. \end{aligned} \quad (27)$$

Table 1 The data given by decision maker

	C_1	C_2	C_3	C_4	C_5
Ψ_1	$\begin{pmatrix} ([0.17, 0.40], \\ 0.56), \\ ([0.15, 0.53], \\ 0.34) \end{pmatrix}$	$\begin{pmatrix} ([0.15, 0.40], \\ 0.63), \\ ([0.2, 0.57], \\ 0.36) \end{pmatrix}$	$\begin{pmatrix} ([0.11, 0.33], \\ 0.38), \\ ([0.22, 0.58], \\ 0.48) \end{pmatrix}$	$\begin{pmatrix} ([0.30, 0.57], \\ 0.36), \\ ([0.15, 0.43], \\ 0.43) \end{pmatrix}$	$\begin{pmatrix} ([0.12, 0.44], \\ 0.39), \\ ([0.23, 0.50], \\ 0.43) \end{pmatrix}$
Ψ_2	$\begin{pmatrix} ([0.11, 0.43], \\ 0.38), \\ ([0.35, 0.57], \\ 0.37) \end{pmatrix}$	$\begin{pmatrix} ([0.29, 0.63], \\ 0.39), \\ ([0.12, 0.38], \\ 0.48) \end{pmatrix}$	$\begin{pmatrix} ([0.15, 0.40], \\ 0.24), \\ ([0.30, 0.50], \\ 0.47) \end{pmatrix}$	$\begin{pmatrix} ([0.12, 0.46], \\ 0.4), \\ ([0.20, 0.45], \\ 0.51) \end{pmatrix}$	$\begin{pmatrix} ([0.13, 0.51], \\ 0.47), \\ ([0.15, 0.45], \\ 0.38) \end{pmatrix}$
Ψ_3	$\begin{pmatrix} ([0.23, 0.61], \\ 0.36), \\ ([0.12, 0.35], \\ 0.34) \end{pmatrix}$	$\begin{pmatrix} ([0.15, 0.44], \\ 0.48), \\ ([0.15, 0.45], \\ 0.27) \end{pmatrix}$	$\begin{pmatrix} ([0.16, 0.57], \\ 0.43), \\ ([0.15, 0.43], \\ 0.47) \end{pmatrix}$	$\begin{pmatrix} ([0.12, 0.38], \\ 0.53), \\ ([0.20, 0.45], \\ 0.45) \end{pmatrix}$	$\begin{pmatrix} ([0.10, 0.42], \\ 0.43), \\ ([0.17, 0.50], \\ 0.28) \end{pmatrix}$
Ψ_4	$\begin{pmatrix} ([0.10, 0.40], \\ 0.47), \\ ([0.20, 0.53], \\ 0.25) \end{pmatrix}$	$\begin{pmatrix} ([0.22, 0.52], \\ 0.50), \\ ([0.27, 0.48], \\ 0.30) \end{pmatrix}$	$\begin{pmatrix} ([0.12, 0.43], \\ 0.48), \\ ([0.20, 0.54], \\ 0.39) \end{pmatrix}$	$\begin{pmatrix} ([0.20, 0.52], \\ 0.32), \\ ([0.22, 0.48], \\ 0.53) \end{pmatrix}$	$\begin{pmatrix} ([0.32, 0.62], \\ 0.40), \\ ([0.10, 0.33], \\ 0.50) \end{pmatrix}$
Ψ_5	$\begin{pmatrix} ([0.12, 0.40], \\ 0.62), \\ ([0.31, 0.56], \\ 0.23) \end{pmatrix}$	$\begin{pmatrix} ([0.25, 0.61], \\ 0.52), \\ ([0.12, 0.39], \\ 0.28) \end{pmatrix}$	$\begin{pmatrix} ([0.11, 0.39], \\ 0.29), \\ ([0.18, 0.51], \\ 0.53) \end{pmatrix}$	$\begin{pmatrix} ([0.13, 0.43], \\ 0.43), \\ ([0.15, 0.42], \\ 0.38) \end{pmatrix}$	$\begin{pmatrix} ([0.20, 0.50], \\ 0.40), \\ ([0.10, 0.40], \\ 0.23) \end{pmatrix}$
Ψ_6	$\begin{pmatrix} ([0.1, 0.38], \\ 0.38), \\ ([0.25, 0.60], \\ 0.25) \end{pmatrix}$	$\begin{pmatrix} ([0.15, 0.42], \\ 0.44), \\ ([0.15, 0.50], \\ 0.20) \end{pmatrix}$	$\begin{pmatrix} ([0.11, 0.44], \\ 0.49), \\ ([0.18, 0.56], \\ 0.23) \end{pmatrix}$	$\begin{pmatrix} ([0.13, 0.52], \\ 0.31), \\ ([0.15, 0.45], \\ 0.56) \end{pmatrix}$	$\begin{pmatrix} ([0.15, 0.45], \\ 0.41), \\ ([0.15, 0.46], \\ 0.48) \end{pmatrix}$
Ψ_7	$\begin{pmatrix} ([0.15, 0.42], \\ 0.44), \\ ([0.15, 0.50], \\ 0.20) \end{pmatrix}$	$\begin{pmatrix} ([0.11, 0.39], \\ 0.29), \\ ([0.18, 0.51], \\ 0.53) \end{pmatrix}$	$\begin{pmatrix} ([0.20, 0.52], \\ 0.32), \\ ([0.22, 0.48], \\ 0.53) \end{pmatrix}$	$\begin{pmatrix} ([0.10, 0.42], \\ 0.43), \\ ([0.17, 0.50], \\ 0.28) \end{pmatrix}$	$\begin{pmatrix} ([0.15, 0.45], \\ 0.41), \\ ([0.15, 0.46], \\ 0.48) \end{pmatrix}$

Table 2 Ranking of the alternatives

Alternatives	Sistance for alternative to ∂_i^+	Distance for alternative to ∂_i^-	To the ideal solution the closeness coefficients of alternatives (cc_i)	Ranking
Ψ_1	0.11	0.084	0.433	5
Ψ_2	0.099	0.18	0.645	2
Ψ_3	0.062	0.107	0.650	1
Ψ_4	0.093	0.095	0.505	3
Ψ_5	0.11	0.105	0.488	4
Ψ_6	0.111	0.08	0.420	6
Ψ_7	0.113	0.071	0.386	7

Step 4 Evaluate the closeness coefficients to the ideal solution by each alternative by utilizing the below proposed structure,

$$cc_i = \partial_i^- / (\partial_i^- + \partial_i^+) (i = 1, 2, 3, \dots, 7), \quad (28)$$

the get overall closeness coefficients.

Step 5 Select the best one by ranking the alternatives by using the Sco of ICFNs. Which is given as,

$$\Psi_3 > \Psi_2 > \Psi_4 > \Psi_5 > \Psi_1 > \Psi_6 > \Psi_7. \quad (29)$$

In Table 2, all the alternatives ranking is given. With largest closeness coefficient Ψ_3 is the best one.

4.2 By ICF-VIKOR method

Here By VIKOR method we solve the numerical problem. Using $\ddot{u} = (.3, .25, .2, .15, .1)^T$ as the criteria weight vector the VIKOR method has the below steps,

Step 1 In Table 1, as all the criteria are of benefit type, i.e., same type. So will not normalize the data.

Table 3 Ranking of the alternatives

Alternatives	\check{L}_i	R_i	\check{O}_i	Rank
Ψ_1	0.88	0.28	0.88	6
Ψ_2	0.781	0.30	0.848	5
Ψ_3	0.33	0.12	0.00	1
Ψ_4	0.748	0.29	0.794	4
Ψ_5	0.66	0.184	0.45	2
Ψ_6	0.91	0.316	1.0	7
Ψ_7	0.78	0.25	0.72	3

Step 2 Evaluate the R^- and R^+ by below given formulae,

$$R^- = (\wp_1^-, \wp_2^-, \wp_3^-, \dots, \wp_7^-), R^+ = (\wp_1^+, \wp_2^+, \wp_3^+, \dots, \wp_7^+), \quad (30)$$

where

$$\wp_j^- = \min\{\wp_{ij} / 1 \leq i \leq 7\} \text{ and } \wp_j^+ = \max\{\wp_{ij} / 1 \leq i \leq 7\}, \quad (31)$$

which are evaluated by $S(I)$.

Step 3 Evaluate the values \check{O}_i , R_i and \check{L}_i by using below formulae,

$$\check{L}_i = \sum_{j=1}^e \frac{\ddot{u}_j \partial(\wp_{ij}, \wp_j^+)}{\partial(\wp_j^+, \wp_j^-)}, \quad (32)$$

$$R_i = \max_{i \leq j \leq e} \frac{\ddot{u}_j \partial(\wp_{ij}, \wp_j^+)}{\partial(\wp_j^+, \wp_j^-)}, \quad (33)$$

and

$$\check{O}_i = \frac{v(\check{L}_i - \check{L}^*)}{(\check{L}^- - \check{L}^*)} + \frac{(1 - v)(R_i - R^*)}{(R^- - R^*)}. \quad (34)$$

Assume $v = .5$, then Table 3 presents the results. Also

$$\check{L}^* = .33, \check{L}^- = .91, R^* = .12, R^- = .316.$$

Step 4 Rank the alternatives by sorting each \check{L}_i , R_i , and \check{O}_i values in an decreasing order. The values of \check{O}_i are ranked as

$$\check{O}_6 > \check{O}_1 > \check{O}_2 > \check{O}_4 > \check{O}_7 > \check{O}_5 > \check{O}_3. \quad (35)$$

Step 5 From the ranking results it can be seen that Ψ_3 , which is ranked the best by measure \check{O}_3 (minimum), is the compromise solution.

Table 4 Sensitivity analysis

ν	\check{O}_1	\check{O}_2	\check{O}_3	\check{O}_4	\check{O}_5	\check{O}_6	\check{O}_7	Ranking
0.1	0.829	0.90	0	0.85	0.35	1	0.67	$\mathbb{U}_3 > \mathbb{U}_5 > \mathbb{U}_7 > \mathbb{U}_4 > \mathbb{U}_1 > \mathbb{U}_2 > \mathbb{U}_6$
0.2	0.842	0.890	0	0.838	0.375	1	0.685	$\mathbb{U}_3 > \mathbb{U}_5 > \mathbb{U}_7 > \mathbb{U}_4 > \mathbb{U}_1 > \mathbb{U}_2 > \mathbb{U}_6$
0.3	0.855	0.876	0	0.823	0.399	1	0.697	$\mathbb{U}_3 > \mathbb{U}_5 > \mathbb{U}_7 > \mathbb{U}_4 > \mathbb{U}_1 > \mathbb{U}_2 > \mathbb{U}_6$
0.4	0.869	0.862	0	0.808	0.423	1	0.708	$\mathbb{U}_3 > \mathbb{U}_5 > \mathbb{U}_7 > \mathbb{U}_4 > \mathbb{U}_2 > \mathbb{U}_1 > \mathbb{U}_6$
0.5	0.882	0.848	0	0.794	0.45	1	0.72	$\mathbb{U}_3 > \mathbb{U}_5 > \mathbb{U}_7 > \mathbb{U}_4 > \mathbb{U}_2 > \mathbb{U}_1 > \mathbb{U}_6$
0.6	0.889	0.833	0	0.779	0.471	1	0.73	$\mathbb{U}_3 > \mathbb{U}_5 > \mathbb{U}_7 > \mathbb{U}_4 > \mathbb{U}_2 > \mathbb{U}_1 > \mathbb{U}_6$
0.7	0.908	0.819	0	0.764	0.496	1	0.742	$\mathbb{U}_3 > \mathbb{U}_5 > \mathbb{U}_4 > \mathbb{U}_7 > \mathbb{U}_2 > \mathbb{U}_1 > \mathbb{U}_6$
0.8	0.921	0.805	0	0.75	0.52	1	0.753	$\mathbb{U}_3 > \mathbb{U}_5 > \mathbb{U}_4 > \mathbb{U}_7 > \mathbb{U}_2 > \mathbb{U}_1 > \mathbb{U}_6$
0.9	0.935	0.79	0	0.735	0.544	1	0.764	$\mathbb{U}_3 > \mathbb{U}_5 > \mathbb{U}_4 > \mathbb{U}_7 > \mathbb{U}_2 > \mathbb{U}_1 > \mathbb{U}_6$
1	0.948	0.777	0	0.72	0.568	1	0.775	$\mathbb{U}_3 > \mathbb{U}_5 > \mathbb{U}_4 > \mathbb{U}_7 > \mathbb{U}_2 > \mathbb{U}_1 > \mathbb{U}_6$

5 Sensitivity analysis

In ICF-VIKOR strategy, ν , the coefficient of decision making is basic to the ranking results. Hence, to assess the stability of our proposed method in these MCGDM algorithms a sensitivity analysis is conducted. For every ν from 0 to 1 at 0.1 intervals, to assess the impact of various ν on the ranking result we figure the comparing compromise solution. Table 4 shows the sensitivity analysis of airport performance evaluation. Three different ranking results are created for all the tested values of ν , which are given as

$$\mathbb{U}_3 > \mathbb{U}_5 > \mathbb{U}_4 > \mathbb{U}_7 > \mathbb{U}_2 > \mathbb{U}_1 > \mathbb{U}_6,$$

$$\mathbb{U}_3 > \mathbb{U}_5 > \mathbb{U}_7 > \mathbb{U}_4 > \mathbb{U}_2 > \mathbb{U}_1 > \mathbb{U}_6,$$

and

$$\mathbb{U}_3 > \mathbb{U}_5 > \mathbb{U}_7 > \mathbb{U}_4 > \mathbb{U}_1 > \mathbb{U}_2 > \mathbb{U}_6.$$

it is clear that ν effects the ranking results, \mathbb{U}_3 is the optimal solution. The sensitivity analysis for airport performance evaluation is shown in Table 4.

Thus, for Air port performance evaluation both the methods (TOPSIS, VIKOR) have been successfully applied.

Table 5 Comparison (Ranking of the alternatives by Muneeza et al. (2020) approach)

Approaches	Ranking
ICFWA	$\mathbb{U}_3 > \mathbb{U}_5 > \mathbb{U}_7 > \mathbb{U}_4 > \mathbb{U}_1 > \mathbb{U}_2 > \mathbb{U}_6$
ICFOWA	$\mathbb{U}_3 > \mathbb{U}_5 > \mathbb{U}_7 > \mathbb{U}_4 > \mathbb{U}_1 > \mathbb{U}_2 > \mathbb{U}_6$
ICFHA	$\mathbb{U}_3 > \mathbb{U}_5 > \mathbb{U}_7 > \mathbb{U}_4 > \mathbb{U}_1 > \mathbb{U}_2 > \mathbb{U}_6$
ICFWG	$\mathbb{U}_3 > \mathbb{U}_5 > \mathbb{U}_7 > \mathbb{U}_4 > \mathbb{U}_1 > \mathbb{U}_2 > \mathbb{U}_6$
ICFOWG	$\mathbb{U}_3 > \mathbb{U}_5 > \mathbb{U}_7 > \mathbb{U}_4 > \mathbb{U}_2 > \mathbb{U}_1 > \mathbb{U}_6$
ICFHG	$\mathbb{U}_3 > \mathbb{U}_5 > \mathbb{U}_7 > \mathbb{U}_4 > \mathbb{U}_2 > \mathbb{U}_1 > \mathbb{U}_6$

6 Comparative analysis

In this section we compare our proposed approach with existing aggregation information. Muneeza developed the notion of ICFS Muneeza et al. (2020). Using the concept of Muneeza et al. (2020) we solved our developed problem. We apply all the steps of Muneeza et al. (2020) approach, and using the criteria weight vector $\check{u} = (\check{u}_1, \check{u}_2, \dots, \check{u}_e)^T = (.3, .25, .2, .15, .1)^T$, We obtain the following ranking.

To demonstrate the effectiveness of the created algorithm using TOPSIS and VIKOR methodologies, we have given a numerical example and assess the selection of the best alternative using the proposed technique, based on ICF information. By using the developed methods we have presented the ranking of the alternatives in Table 3 and Table 4. From these tables, it is clear that using the proposed methods, the ranking orders of the alternatives are similar to the results obtained from the Muneeza et al. (2020) method which are shown in Table 5. All have the same best alternative, i.e., \mathbb{U}_3 (see Tables 2, 3, 4).

Accordingly, the proposed method is truly prominent, because it can neglect any loss of data which earlier occur during the information aggregation processing., which makes the developed strategies more realistic, flexible and prominent.

7 Conclusion

The airport performance evaluation incorporates both qualitative and quantitative assessment data. We have air terminal as a fuzzy MCGDM problem that requires ranking of all airports. Our developed MCGDM approach can successfully deal with both qualitative and quantitative execution measures for the exhibition assessment of airports.

Motivated by IFNs, in this paper we have presented extended form of VIKOR strategy and TOPSIS strategy under ICF information. We have also presented the decision making technique based on proposed methods by making some formulations to MCGDM. We have indicated the observational examination of 7 Asia-Pacific global airports to show the applicability of the proposed strategy. The evaluation results would outfit an air terminal with definite information about its relative characteristics and weaknesses to the extent execution estimates related with the aircraft, the traveler and air terminal adecision maker. With its ease in calculation and idea, the technique has common application dealing with multi criteria evaluation problems including both new examinations of quantitative attributes and fuzzy assessment of subjective properties. Airport performance assessment requires considering various assessment criteria. The assessment regularly incorporates both subjective and quantitative assessment data. We have characterized airport performance evaluation as a fuzzy MCGDM problem that needs ranking of all airports. Our developed multi criteria decision making approach can successfully deal both subjective and quantitative execution measures for the performance evaluation of airports.

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Declarations

Conflict of Interest The authors declared that they have no conflict of interest

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