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Analyzing the impact of COVID-19 vaccination requirements on travelers' selection of hotels using a fuzzy multi-criteria decision-making approach

Yu-Cheng Wang^{a,*}, Tin-Chih Toly Chen^b

^a Department of Aeronautical Engineering, Chaoyang University of Technology, Taichung City, Taiwan

^b Department of Industrial Engineering and Management, National Yang Ming Chiao Tung University, 1001, University Road, Hsinchu, Taiwan

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ABSTRACT

In the later stages of the COVID-19 pandemic, hotels are taking various measures to balance pandemic prevention and business operations. Some hotels require travelers to be fully vaccinated prior to check-in, while others do not. In the latter type of hotels, fully vaccinated travelers may encounter others who are not vaccinated. All of these have created constraints for travelers to choose suitable hotel accommodation during this time. To address this issue, a fuzzy multi-criteria decision-making approach is proposed in this study to help traveler choose suitable hotel accommodation. In the proposed methodology, firstly, hotels are divided into two types considering their requirements for COVID-19 vaccination. Travelers are then asked to list the key factors to consider when choosing between these two types of hotels. To derive the priorities of these key factors, the proportionally calibrated fuzzy geometric mean (pcFGM) method is proposed. Subsequently, the fuzzy VišekriterijumskoKOMPromisnoRangiranje (fuzzy VIKOR) method is applied to evaluate and compare the overall performances of different types of hotels for recommendations to travelers. The applicability of the proposed methodology is illustrated by a real case study. According to the experimental results, most hotels did not request travelers to be full vaccinated. Nevertheless, the hotels recommended to travelers covered both hotel types.

1. Introduction

Travel of all kinds that was disrupted during the COVID-19 pandemic has gradually resumed as countries around the world gradually unblocked in the later stages of the pandemic. For cross-border travel, some countries (including the US, Canada, UK, France, Germany, South Korea, Singapore, etc.) have agreed that travelers who have received two full doses of the COVID-19 vaccine prior to arriving in the destination country may not need to quarantine [1]. Domestic tourism opened even earlier [2].

More and more tourists are gradually bringing hotels back to life [3]. However, how to recommend suitable hotels to travelers in the late stages of the COVID-19 pandemic has become a challenging task for the following reasons:

- Some hotels only accept fully vaccinated travelers [4], some do not. This became a restriction for unvaccinated customers.
- Travelers who have been fully vaccinated can choose between two types of hotels. He/she may have different considerations when choosing different types of hotels [5]. For example, if everyone in a hotel is fully vaccinated, travelers can enjoy the leisure facilities of the hotel in comfort. In this case, the number of leisure facilities

will be considered when choosing a suitable hotel [6]. Conversely, if some people in the hotel are not fully vaccinated, travelers may choose to go out and not use the leisure facilities. In this case, other factors, such as hotel convenience or room rate, are more concerned [7].

Existing hotel recommendation methods have not dealt with similar problems [8–11]. Therefore, the motivation of this study is to fill this gap.

A proportionally calibrated fuzzy geometric mean (pcFGM)-fuzzy VišekriterijumskoKOMPromisnoRangiranje (fuzzy VIKOR) approach is proposed in this study for hotel recommendation in the late stage of the COVID-19 pandemic. Compared with existing hotel recommendation methods, the proposed pcFGM-fuzzy VIKOR approach has the following novelties:

- (1) Depending on a traveler's vaccination status, his/her choice of hotels varies. Therefore, the pcFGM-fuzzy VIKOR method divides the hotels considered by travelers into two types.
- (2) Travelers may have different considerations when choosing different types of hotels [12,13]. Therefore, the pcFGM-fuzzy VIKOR method asks a traveler to list his/her key factors in choosing

* Corresponding author.

E-mail addresses: tony.cobra@msa.hinet.net (Y.-C. Wang), tolychen@ms37.hinet.net (T.-C.T. Chen).

these two types of hotels in order to recommend both types of hotels.

The rest of this paper is organized as follows. Section 2 is dedicated to literature reviews. Section 3 presents the pcFGM-fuzzy VIKOR method proposed in this study. Section 4 details the application of the pcFGM-fuzzy VIKOR method to a real-world case in the COVID-19 pandemic. Section 5 provides the conclusions of this study and some possible themes for future research.

2. Literature review

Many studies have highlighted the pressure on hotel staff during the COVID-19 pandemic. For example, hotel housekeepers have to deal with travelers and face higher health risks than other employees. This situation can be worse when hotels are used as isolated spaces [14]. According to the survey results of Wong et al. [15], during the COVID-19 pandemic, the pressure on hotel employees comes from three sources: traditional hotel-work stress, unstable and more demanding hotel-work-environment stress, and unethical hotel-labor-practices-borne stress.

According to Filimonau et al. [16], the COVID-19 pandemic impacted the normal business operations of hotels, which also affected the job security of senior managers of these hotels and influenced their commitments. A similar phenomenon was also observed by Sierra Marín et al. [17]. After the successful experiences of applying sanitization and greeting robots in hotels during the COVID-19 pandemic, some hospital staff were afraid of being replaced by such robots.

To overcome the above problems, Hao et al. [18] established a management framework for hotels to deal with the challenges posed by the COVID-19 pandemic. In addition, they have also observed the trends of hotel reshaping after the pandemic to multi-business and multi-channel, product redesign and investment reconfiguration, digital and intelligent transformation, and market reshuffle. Lai and Wong [19] compared the important tasks to a hotel in the early and pandemic phases of the COVID-19 pandemic. According to the survey results, in the early stage, pandemic prevention, pricing and maintenance, seeking governmental assistance, and human resource reallocation were more important tasks. In the pandemic phase, pandemic prevention was still critical, while pricing became unimportant. In addition, human resources were also forced to take unpaid vacations. Guillet and Chu [3] conducted a survey and reported the following. To manage the revenues of a hotel during the COVID-19 pandemic, business analysis, pricing, and demand modeling and forecasting are more important than inventory management, price optimization, and booking control. Kim and Han [20] systematically compare COVID-19 control measures adopted by major hotel chains. They also found that preventive measures, brand value and social services were found to be more important factors in choosing the right hotel following the COVID-19 outbreak.

In the view of Jiang and Wen [5], during the COVID-19 pandemic, travelers are more concerned about the cleanliness of certain surfaces in a hotel. In addition, a hotel should strengthen its relationship with the healthcare sector. Atadil and Lu [21] surveyed 500 hotel guests. After processing the survey results using factor analysis and multiple regression analysis, they found that medical preparedness, hygiene control, health communication, and self-service technologies are essential to the image of a safe hotel during the COVID-19 pandemic. Chen et al. [22] compared the factors affecting travelers' selection of suitable hotels before and after the outbreak of the COVID-19 pandemic. Then, they proposed a fuzzy analytic hierarchy process (FAHP)-enhanced fuzzy geometric mean (eFGM)-fuzzy technique for order preference by similarity to ideal solution (FTOPSIS) approach [23] to recommend suitable hotels to travelers amid the COVID-19 pandemic, in which five factors were considered critical to the recommendation process: room rate, room rate discount, the number of epidemic prevention measures, the number of stars, and hotel rating.

In sum, past studies have the following deficiencies:

- (1) Most past studies have shown that hotel managers or employees are facing challenges, but these studies have not explored the difficult choices faced by travelers who plan to stay in hotels.
- (2) Most past studies are based on the statistical analysis of questionnaire surveys. Related results are difficult to support quantitative hotel management applications.

This study aims to make up for these deficiencies.

3. The proposed methodology

The research questions of this study include

- Considering the different vaccination requirements of hotels, what are the criteria for travelers to choose suitable hotels during the COVID-19 pandemic?
- How to recommend suitable hotels to vaccinated or unvaccinated travelers?

To answer the above questions, this study proposes the pcFGM-fuzzy VIKOR approach and conducts a regional experiment. The pcFGM-fuzzy VIKOR approach comprises the following steps:

Step 1. Collect the data of hotels around the traveler's destination.

Step 2. Divide these hotels according to their requirements for traveler vaccination.

Step 3. For either type of hotels, construct a fuzzy judgment matrix (or modify the fuzzy judgment matrix) by performing pairwise comparisons of the relative priorities of factors critical to the selection of a suitable hotel. Travelers who have not been fully vaccinated only need to construct a fuzzy judgment matrix to choose hotels without the restriction.

Step 4. For either category of hotels, evaluate the fuzzy consistency ratio (\widetilde{CR}) of the fuzzy judgment matrix.

Step 5. For either category of hotels, if \widetilde{CR} is small enough, proceed to Step 6; otherwise, return to Step 3.

Step 6. For either category of hotels, derive the fuzzy priorities of critical factors.

Step 7. Evaluate the overall performance of each hotel based on the derived fuzzy priorities using fuzzy VIKOR [24].

Step 8. Rank hotels by their overall performances to choose the top-performing hotel.

A flowchart is presented in Fig. 1 to illustrate the procedure. The steps are described in the following sections.

3.1. Steps 1 and 2

In the proposed methodology, first the data of hotels considered by a traveler are collected. Usually hotels near the destination of the traveler will be taken into account [25].

Subsequently, these hotels are divided into two types: full vaccination required and full vaccination not required. A fully vaccinated traveler can stay in both types of hotels, as illustrated by Fig. 2.

3.2. Step 3

A traveler compares the relative priority of a criterion for evaluating a hotel over that of another using linguistic terms. These linguistic terms are represented by triangular fuzzy numbers (TFNs) [26], as shown in Table 1. Since the relative priority is a subjective concept and therefore uncertain, expressing it in terms of a TFN is reasonable [27]. As a result, a fuzzy judgment matrix $\widetilde{A}(v) = [\widetilde{a}_{ij}(v)]$ is constructed. $\widetilde{a}_{ij}(v)$ is the relative priority of criterion i of category v over criterion j ; $i, j = 1 \sim n$ (the number of criteria). $v = 1$ (vaccination required) or 2 (vaccination not required). A fuzzy judgment matrix is no different from a traditional judgment matrix, except that its elements are TFNs. As a consequence, fuzzy eigen analysis is performed on the fuzzy judgment matrix instead of traditional eigen analysis.

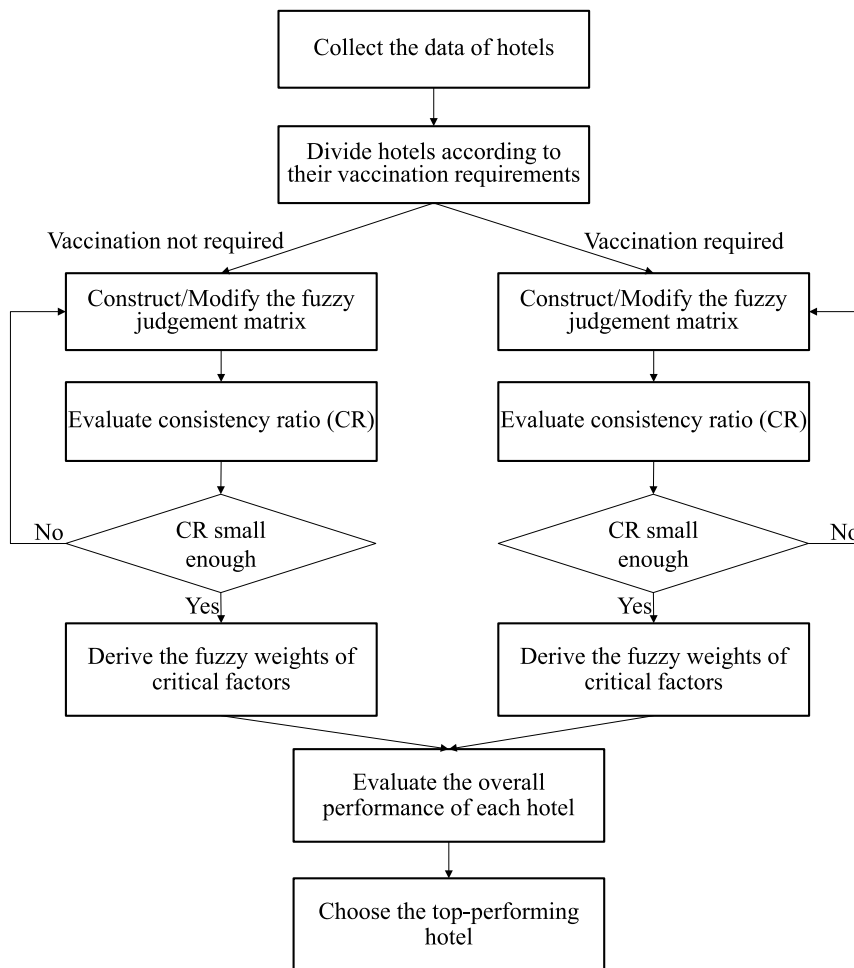


Fig. 1. Procedure of the proposed methodology.

		Hotels	
		Vaccination required	Vaccination not required
Traveler	Fully vaccinated	Yes	Yes
	Not fully vaccinated	No	Yes

Fig. 2. Types of hotels considered by travelers.

Table 1 Linguistic terms for comparing the relative priorities.

Symbol	Linguistic term	Triangular fuzzy number
L1	As important as	(1, 1, 3)
L2	As important as or weakly more important than	(1, 2, 4)
L3	Weakly more important than	(1, 3, 5)
L4	Weakly or strongly more important than	(2, 4, 6)
L5	Strongly more important than	(3, 5, 7)
L6	Strongly or very strongly more important than	(4, 6, 8)
L7	Very strongly more important than	(5, 7, 9)
L8	Very or absolutely strongly more important than	(6, 8, 9)
L9	Absolutely more important than	(7, 9, 9)

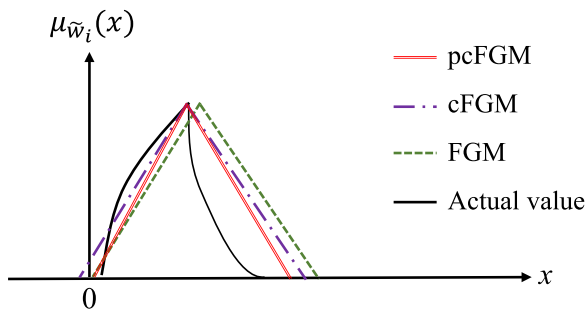


Fig. 3. Comparison of the fuzzy weights derived using various methods (pcFGM: proportionally calibrated fuzzy geometric mean; cFGM: calibrated fuzzy geometric mean; FGM: fuzzy geometric mean).

$\tilde{A}(v)$ meets the following requirements [28]:

$$\det(\tilde{A}(v) - \tilde{\lambda}(v)\mathbf{I}) = 0 \tag{1}$$

$$(\tilde{A}(v) - \tilde{\lambda}(v)\mathbf{I})(\times)\tilde{x}(v) = 0 \tag{2}$$

where $(-)$ and (\times) denote fuzzy subtraction and multiplication, respectively. $\det()$ is the determinant function. \mathbf{I} is the identity matrix. $\tilde{\lambda}(v)$ is the fuzzy eigenvalue; $\tilde{x}(v)$ is the fuzzy eigenvector.

Eqs. (1) and (2) involve fuzzy multiplication and therefore are computationally intensive to solve [29]. Fuzzy geometric mean (FGM) is a prevalent method to approximate the solution [26]. However, the accuracy of deriving the fuzzy priorities of criteria using FGM is not always high. To solve this problem, Chen and Wang [13] proposed the calibrated FGM (cFGM) method to improve the accuracy in an efficient manner. However, a calibrated fuzzy priority may be negative, which is infeasible. To maintain the feasibility of a calibrated fuzzy priority, the pcFGM approach is proposed. A comparison of the fuzzy weights derived using various methods is provided in Fig. 3. In this figure, the x -axis and y -axis are the value and membership of \tilde{w}_i , respectively. Obviously, the fuzzy weight derived using pcFGM is closer to the actual value.

The procedure of the pcFGM method is as follows:

(1) Approximate the fuzzy priority of criterion i using FGM as [30]

$$\tilde{w}_i(v) \cong (w_{i1}(v), w_{i2}(v), w_{i3}(v)) \tag{3}$$

where

$$w_{i1}(v) = \frac{1}{1 + \sum_{m \neq i} \frac{\sqrt[n]{\prod_{j=1}^n a_{mj3}(v)}}{\sqrt[n]{\prod_{j=1}^n a_{ij1}(v)}}} \tag{4}$$

$$w_{i2}(v) \cong \frac{1}{1 + \sum_{m \neq i} \frac{\sqrt[n]{\prod_{j=1}^n a_{mj2}(v)}}{\sqrt[n]{\prod_{j=1}^n a_{ij2}(v)}}} \tag{5}$$

$$w_{i3}(v) \cong \frac{1}{1 + \sum_{m \neq i} \frac{\sqrt[n]{\prod_{j=1}^n a_{mj1}(v)}}{\sqrt[n]{\prod_{j=1}^n a_{ij3}(v)}}} \tag{6}$$

\tilde{w}_i is the fuzzy priority of criterion i .

(2) Derive the priority of criterion i from the crisp judgment matrix $\mathbf{A}^c(v) = [a_{ij2}(v)]$ using an eigen analysis [28]

$$\det(\mathbf{A}^c(v) - \lambda^c(v)\mathbf{I}) = 0 \tag{7}$$

$$(\mathbf{A}^c(v) - \lambda^c(v)\mathbf{I})\mathbf{x}^c(v) = 0 \tag{8}$$

The derived priorities are indicated with $\{w_i^c(v)\}$.

(3) Calibrate the fuzzy priority of criterion i in the following way:

$$w_{i1}(v) = w_{i1}(v) \cdot \frac{w_i^c(v)}{w_{i2}(v)} \tag{9}$$

$$w_{i2}(v) = w_i^c(v) \tag{10}$$

$$w_{i3}(v) = w_{i3}(v) \cdot \frac{w_i^c(v)}{w_{i2}(v)} \tag{11}$$

Since $w_{i1}(v)$, $w_{i2}(v)$, and $w_i^c(v)$ are all positive, the calibrated $w_{i1}(v)$ will not be negative.

3.3. Steps 4 to 6

Subsequently, the fuzzy consistency ratio of $\tilde{A}(v)$, $\widetilde{CR}(\tilde{A}(v))$, can be evaluated as [30]

$$CR_1(\tilde{A}(v)) = \frac{1 - n + \frac{1}{n} \sum_{i=1}^n \sum_{j \neq i} \frac{a_{ij1}(v)w_{j1}(v)}{w_{i3}(v)}}{(n-1)RI} \tag{12}$$

$$CR_2(\tilde{A}(v)) = \frac{1 - n + \frac{1}{n} \sum_{i=1}^n \sum_{j \neq i} \frac{a_{ij2}(v)w_{j2}(v)}{w_{i2}(v)}}{(n-1)RI} \tag{13}$$

$$CR_3(\tilde{A}(v)) = \frac{1 - n + \frac{1}{n} \sum_{i=1}^n \sum_{j \neq i} \frac{a_{ij3}(v)w_{j3}(v)}{w_{i1}(v)}}{(n-1)RI} \tag{14}$$

RI denotes the random consistency index [28]. Basically, $\tilde{A}(v)$ is consistent if $\widetilde{CR}(\tilde{A}(v)) \leq 0.1 \sim 0.3$ (for a large or complicated decision-making problem) [28,31,32]; otherwise, the fuzzy judgment matrix needs to be modified.

If $\tilde{A}(v)$ is consistent, the fuzzy priorities of criteria derived using pcFGM can be applied to evaluate the overall performances of hotels as follows.

3.4. Steps 7 to 8

Subsequently, the fuzzy VIKOR method [24] is applied to evaluate the overall performance of a hotel. The fuzzy VIKOR method comprises the following steps:

(1) Determine the best and worst values of each criterion:

$$\begin{aligned} \tilde{p}_i^* &= \max_h \tilde{p}_{hi} \\ &= (\max_h p_{hi1}, \max_h p_{hi2}, \max_h p_{hi3}) \end{aligned} \tag{15}$$

$$\begin{aligned} \tilde{p}_i^- &= \min_h \tilde{p}_{hi} \\ &= (\min_h p_{hi1}, \min_h p_{hi2}, \min_h p_{hi3}) \end{aligned} \tag{16}$$

where \tilde{p}_{hi} is the performance of hotel h in optimizing criterion i ; $h = 1 \sim H$. \tilde{p}_i^* and \tilde{p}_i^- indicate the best and worst values of criterion i , respectively.

(2) Compute the normalized fuzzy distance between each hotel and the best performance in each hotel type:

$$\begin{aligned} \tilde{d}_{hi}(v) &= \frac{\tilde{p}_i^*(v) - \tilde{p}_{hi}(v)}{\tilde{p}_{i3}^*(v) - \tilde{p}_{i1}^-(v)} \\ &= \left(\frac{\max(p_{i1}^*(v) - p_{hi3}(v), 0)}{p_{i3}^*(v) - p_{i1}^-(v)}, \frac{p_{i2}^*(v) - p_{hi2}(v)}{p_{i3}^*(v) - p_{i1}^-(v)}, \frac{p_{i3}^*(v) - p_{hi1}(v)}{p_{i3}^*(v) - p_{i1}^-(v)} \right) \end{aligned} \tag{17}$$

(3) Compute the values of $\tilde{S}_h(v)$ and $\tilde{R}_h(v)$ as [33]

$$\begin{aligned} \tilde{S}_h &= \sum_{i=1}^n (\tilde{w}_i(v) \times \tilde{d}_{hi}(v)) \\ &\cong \left(\sum_{i=1}^n w_{i1}(v)d_{hi1}(v), \sum_{i=1}^n w_{i2}(v)d_{hi2}(v), \sum_{i=1}^n w_{i3}(v)d_{hi3}(v) \right) \end{aligned} \tag{18}$$

$$\begin{aligned} \tilde{R}_h &= \max_i (\tilde{w}_i(v) \times \tilde{d}_{hi}(v)) \\ &= (\max_i w_{i1}(v)d_{hi1}(v), \max_i w_{i2}(v)d_{hi2}(v), \max_i w_{i3}(v)d_{hi3}(v)) \end{aligned} \tag{19}$$

\tilde{S}_h considers the performances of hotel h in all aspects, while \tilde{R}_h highlights the performance of the hotel in the most important aspect or the aspect with the worse performance.

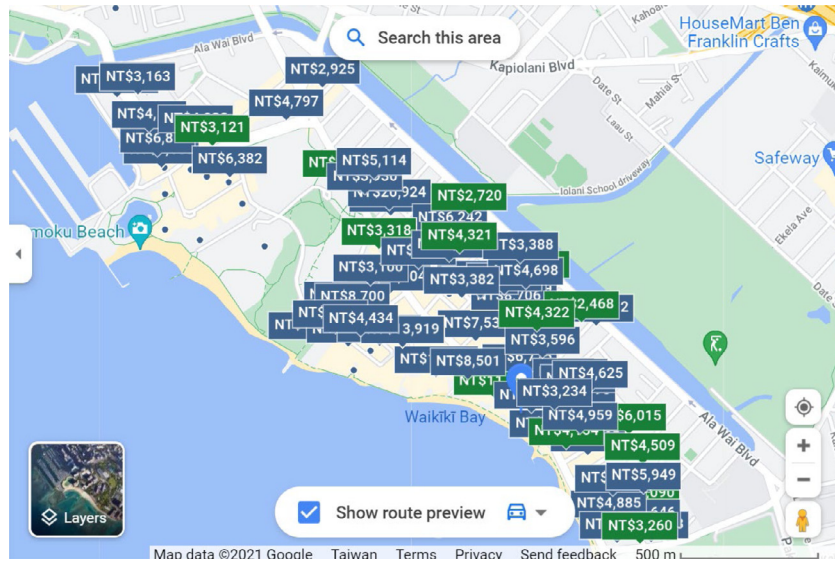


Fig. 4. Experimental region.

(4) Calculate the value of $\tilde{Q}_h(v)$ as [33]

$$\tilde{Q}_h = \omega \cdot \frac{\tilde{S}_h(-) \min_r \tilde{S}_r}{\max_r S_{r3} - \min_r S_{r1}} + (1 - \omega) \cdot \frac{\tilde{R}_h(-) \min_r \tilde{R}_r}{\max_r R_{r3} - \min_r R_{r1}}$$

$$= (\omega \cdot \frac{S_{h1} - \min_r S_{r3}}{\max_r S_{r3} - \min_r S_{r1}} + (1 - \omega) \cdot \frac{R_{h1} - \min_r R_{r3}}{\max_r R_{r3} - \min_r R_{r1}}, \quad (20)$$

$$\omega \cdot \frac{S_{h2} - \min_r S_{r2}}{\max_r S_{r3} - \min_r S_{r1}} + (1 - \omega) \cdot \frac{R_{h2} - \min_r R_{r2}}{\max_r R_{r3} - \min_r R_{r1}},$$

$$\omega \cdot \frac{S_{h3} - \min_r S_{r1}}{\max_r S_{r3} - \min_r S_{r1}} + (1 - \omega) \cdot \frac{R_{h3} - \min_r R_{r1}}{\max_r R_{r3} - \min_r R_{r1}})$$

where $\omega \in [0, 1]$ is a prespecified weight for the maximum group utility [33].

(5) Defuzzify \tilde{S}_h , \tilde{R}_h and \tilde{Q}_h as follows [33]:

$$D(\tilde{S}_h) = \frac{S_{h1} + 2S_{h2} + S_{h3}}{4} \quad (21)$$

$$D(\tilde{R}_h) = \frac{R_{h1} + 2R_{h2} + R_{h3}}{4} \quad (22)$$

$$D(\tilde{Q}_h) = \frac{Q_{h1} + 2Q_{h2} + Q_{h3}}{4} \quad (23)$$

(6) Rank hotels by their $D(\tilde{S}_h)$, $D(\tilde{R}_h)$, and $D(\tilde{Q}_h)$ values from the smallest to the largest. The decision maker will have three ranking results, giving him/her high flexibility, which is an advantage of fuzzy VIKOR over FTOPSIS. Assuming the top two hotels that minimize $D(\tilde{Q}_h)$ are indicated with hotels $h_{(1)}$ and $h_{(2)}$, respectively. Then,

- (i) If $D(\tilde{Q}_{h_{(2)}}) - D(\tilde{Q}_{h_{(1)}}) \geq \frac{1}{H-1}$ and $D(\tilde{S}_{h_{(1)}}) = \min_r D(\tilde{S}_r)$ or $D(\tilde{R}_{h_{(1)}}) = \min_r D(\tilde{R}_r)$ [33], recommend hotel $h_{(1)}$ to the traveler.
- (ii) Otherwise, if $\omega > 0.5$, recommend the one of the two hotels that minimizes $D(\tilde{S}_h)$ to the traveler.
- (iii) Otherwise, recommend the one of the two hotels that minimizes $D(\tilde{R}_h)$ to the traveler.

4. Case study

4.1. Background

The proposed methodology has been applied to assist twelve foreign travelers in selecting suitable hotels to stay near Waikiki Beach. Although all foreign travelers must be fully vaccinated before they can enter the United States, not all U.S. travelers are fully vaccinated. Therefore, there may be travelers with different vaccination statuses

Table 2

Factors considered when choosing hotels of various categories.

Hotel category	Considerations
Full vaccination required	<ul style="list-style-type: none"> • Room rate • Hotel rating • Hotel ranking • Number of reviews • Quality of service
Full vaccination not required	<ul style="list-style-type: none"> • Number of COVID-19 prevention measures • Hotel rating • Room rate • Number of reviews • Quality of service

in a hotel. The requirements of hotels on whether or not travelers are vaccinated are also different.

The experimental region had an area of 4.9 km², as shown in Fig. 4. There were more than ninety hotels in the experimental region. Choosing the most suitable one from so many hotels was a challenging task. Some hotels required that a traveler had to be fuzzy vaccinated, while others did not. Foreign travelers had been fully vaccinated, and therefore could choose both categories of hotels. However, when choosing different categories of hotels, travelers' considerations were different. To solve this problem, the proposed methodology was applied. In the following, the first traveler was used to illustrate the application of the proposed methodology.

4.2. Application of the proposed methodology

The traveler first listed his top five factors considered when choosing hotels of various categories, which are summarized in Table 2. Some hotels required travelers to be fully vaccinated (or have a negative PCR COVID-19 test result). When all hotel guests were fully vaccinated, the cleanliness of the hotel was more realistic than the number of COVID-19 prevention measures. In contrast, other hotels did not require the proof of full vaccination. As a compensation for this, a number of COVID-19 pandemic prevention measures were widely adopted in these hotels. When choosing hotels of this category, the room rate of a hotel was far more important than the ranking.

The traveler then compared these factors in pairs. The results are summarized in Table 3.

Table 3
Pairwise comparison results.

Full vaccination required	Full vaccination not required
<ul style="list-style-type: none"> Room rate is weakly more important than hotel rating Room rate is strongly more important than hotel ranking Room rate is strongly more important than number of reviews Quality of service is weakly more important than room rate Hotel rating is strongly more important than hotel ranking Hotel rating is weakly more important than number of reviews Quality of service is weakly more important than hotel rating Number of reviews is weakly more important than hotel ranking Quality of service is strongly more important than hotel ranking Number of reviews is as important as quality of service 	<ul style="list-style-type: none"> Number of COVID-19 prevention measures is strongly more important than hotel rating Number of COVID-19 prevention measures is weakly more important than room rate Number of COVID-19 prevention measures is strongly more important than number of reviews Number of COVID-19 prevention measures is weakly more important than quality of service Room rate is strongly more important than hotel rating Hotel rating is weakly more important than number of reviews Quality of service is strongly more important than hotel rating Room rate is strongly more important than number of reviews Room rate is strongly more important than quality of service Quality of service is strongly more important than number of reviews

The pairwise comparison results are summarized in the following two fuzzy judgment matrixes:

$$\tilde{A}(1) = \begin{bmatrix} 1 & (1, 3, 5) & (3, 5, 7) & (3, 5, 7) & 1/(1, 3, 5) \\ 1/(1, 3, 5) & 1 & (3, 5, 7) & (1, 3, 5) & 1/(1, 3, 5) \\ 1/(3, 5, 7) & 1/(3, 5, 7) & 1 & 1/(1, 3, 5) & 1/(3, 5, 7) \\ 1/(3, 5, 7) & 1/(1, 3, 5) & (1, 3, 5) & 1 & (1, 1, 3) \\ (1, 3, 5) & (1, 3, 5) & (3, 5, 7) & 1/(1, 1, 3) & 1 \end{bmatrix}$$

$$\tilde{A}(2) = \begin{bmatrix} 1 & (3, 5, 7) & (1, 3, 5) & (3, 5, 7) & (1, 3, 5) \\ 1/(3, 5, 7) & 1 & 1/(3, 5, 7) & (1, 3, 5) & 1/(3, 5, 7) \\ 1/(1, 3, 5) & (3, 5, 7) & 1 & (3, 5, 7) & (3, 5, 7) \\ 1/(3, 5, 7) & 1/(1, 3, 5) & 1/(3, 5, 7) & 1 & 1/(3, 5, 7) \\ 1/(1, 3, 5) & (3, 5, 7) & 1/(3, 5, 7) & (3, 5, 7) & 1 \end{bmatrix}$$

The fuzzy priorities of the factors were derived from the fuzzy judgment matrix using the pcFGM approach. The results are presented in Fig. 5. When choosing hotels requiring full vaccination, the most critical factor was quality of service. In contrast, the most critical factor in choosing hotels without full vaccination was the number of COVID-19 prevention measures.

In order to screen for hotels worthy of consideration from a large number of options, the traveler set the following conditions:

- Hotel-related information could be fully obtained from travel websites;
- Rooms were available during the period of stay;
- Free wifi;
- Room rate was within the range [3000, 5000] NTD per night.

As a result, 13 hotels, indicated with Hotels #1 to #13 were considered. The details of these hotels are summarized in Table 4. It is worth noting that only a few (i.e., 2) hotels required travelers to be fully vaccinated in advance.

Among the factors, only “room rate” was the-lower-the-better (LTB) performance, whereas the others were the-higher-the-better (HTB) performances. The performances were evaluated as follows:

LTB performances:

$$\tilde{p}_{hi}(x_{hi}) = \left(\max\left(\frac{\max_r x_{ri} - x_{hi}}{\max_r x_{ri} - \min_r x_{ri}} \cdot 4, 1\right), \frac{\max_r x_{ri} - x_{hi}}{\max_r x_{ri} - \min_r x_{ri}} \cdot 4 + 1, \min\left(\frac{\max_r x_{ri} - x_{hi}}{\max_r x_{ri} - \min_r x_{ri}} \cdot 4 + 2, 5\right) \right) \quad (24)$$

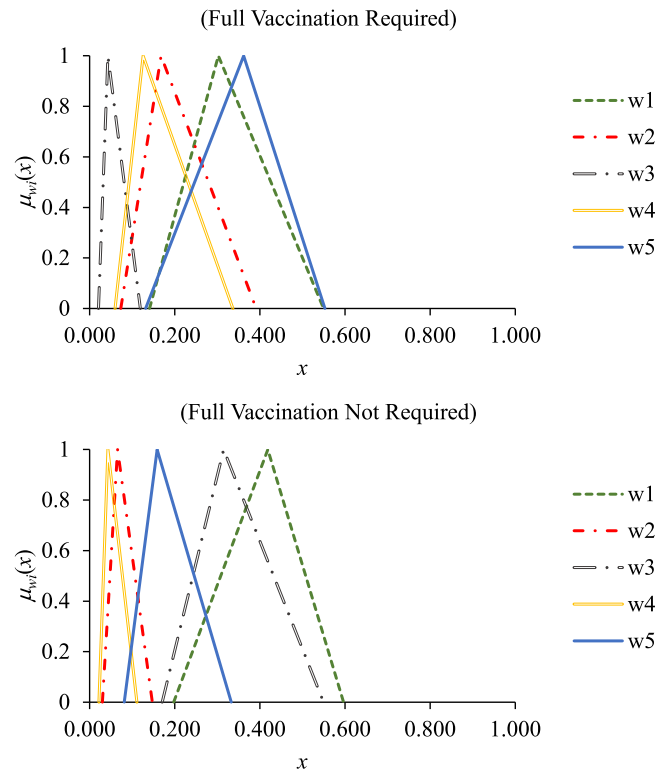


Fig. 5. Priorities of the factors.

HTB performances:

$$\tilde{p}_{hi}(x_{hi}) = \left(\max\left(\frac{x_{hi} - \min_r x_{ri}}{\max_r x_{ri} - \min_r x_{ri}} \cdot 4, 1\right), \frac{x_{hi} - \min_r x_{ri}}{\max_r x_{ri} - \min_r x_{ri}} \cdot 4 + 1, \min\left(\frac{x_{hi} - \min_r x_{ri}}{\max_r x_{ri} - \min_r x_{ri}} \cdot 4 + 2, 5\right) \right) \quad (25)$$

where $\tilde{p}_{hi}(x_{hi})$ is the performance of hotel h in optimizing factor i . $\tilde{p}_{hi}(x_{hi}) \in [1, 5]$. The evaluation results are summarized in Table 5.

Subsequently, for hotels of either category, the best and worst performances in optimizing each criterion were determined. The results are shown in Table 6.

The normalized fuzzy distance between each hotel and the best performance of the category it belonged to was measured. The measurement results are summarized in Table 7.

Table 4
Details of hotels considered by the traveler.
Source: Google Maps, Expedia, and Tripadvisor.

<i>h</i>	Room rate	Number of stars	Rating	Number of Reviews	Hotel ranking	Full vaccination required	Number of COVID-19 prevention measures	Quality of service
1	4684	3	4.1	107	17	No	10	4.3
2	4563	4	4.1	2422	54	No	13	4
3	4031	3	4	710	51	Yes	16	4.5
4	3292	3	4	1209	44	No	15	4.2
5	4434	3	4.3	825	46	No	4	4.1
6	3382	3	4.1	542	23	No	9	4.4
7	4698	3	3.7	495	26	No	16	4.5
8	3909	2	3.3	1127	83	No	13	3.6
9	4625	3	4.4	698	14	No	4	4.6
10	4003	3	4	642	50	No	15	4
11	4959	3	4	1248	25	No	20	4.2
12	3090	2	3.5	429	69	No	12	4
13	4885	4	4.1	3707	64	Yes	14	4.3

Table 5
Evaluated performances.

<i>h</i>	Room rate	Number of stars	Rating	Number of reviews	Hotel ranking	Number of COVID-19 prevention measures	Quality of service
1	(1, 1.59, 2.59)	(2, 3, 4)	(3.1, 4.1, 5)	(1, 1, 2)	(3.31, 4.31, 5)	(1.5, 2.5, 3.5)	(3.3, 4.3, 5)
2	(1, 1.85, 2.85)	(3, 4, 5)	(3.1, 4.1, 5)	(2.57, 3.57, 4.57)	(1.72, 2.72, 3.72)	(2.25, 3.25, 4.25)	(3, 4, 5)
3	(1.99, 2.99, 3.99)	(2, 3, 4)	(3, 4, 5)	(1, 1.67, 2.67)	(1.85, 2.85, 3.85)	(3, 4, 5)	(3.5, 4.5, 5)
4	(3.57, 4.57, 5)	(2, 3, 4)	(3, 4, 5)	(1.22, 2.22, 3.22)	(2.15, 3.15, 4.15)	(2.75, 3.75, 4.75)	(3.2, 4.2, 5)
5	(1.12, 2.12, 3.12)	(2, 3, 4)	(3.3, 4.3, 5)	(1, 1.8, 2.8)	(2.06, 3.06, 4.06)	(1, 1, 2)	(3.1, 4.1, 5)
6	(3.38, 4.38, 5)	(2, 3, 4)	(3.1, 4.1, 5)	(1, 1.48, 2.48)	(3.05, 4.05, 5)	(1.25, 2.25, 3.25)	(3.4, 4.4, 5)
7	(1, 1.56, 2.56)	(2, 3, 4)	(2.7, 3.7, 4.7)	(1, 1.43, 2.43)	(2.92, 3.92, 4.92)	(3, 4, 5)	(3.5, 4.5, 5)
8	(2.25, 3.25, 4.25)	(1, 2, 3)	(2.3, 3.3, 4.3)	(1.13, 2.13, 3.13)	(1, 1.47, 2.47)	(2.25, 3.25, 4.25)	(2.6, 3.6, 4.6)
9	(1, 1.71, 2.71)	(2, 3, 4)	(3.4, 4.4, 5)	(1, 1.66, 2.66)	(3.44, 4.44, 5)	(1, 1, 2)	(3.6, 4.6, 5)
10	(2.05, 3.05, 4.05)	(2, 3, 4)	(3, 4, 5)	(1, 1.59, 2.59)	(1.89, 2.89, 3.89)	(2.75, 3.75, 4.75)	(3, 4, 5)
11	(1, 1, 2)	(2, 3, 4)	(3, 4, 5)	(1.27, 2.27, 3.27)	(2.97, 3.97, 4.97)	(4, 5, 5)	(3.2, 4.2, 5)
12	(4, 5, 5)	(1, 2, 3)	(2.5, 3.5, 4.5)	(1, 1.36, 2.36)	(1.08, 2.08, 3.08)	(2, 3, 4)	(3, 4, 5)
13	(1, 1.16, 2.16)	(3, 4, 5)	(3.1, 4.1, 5)	(4, 5, 5)	(1.29, 2.29, 3.29)	(2.5, 3.5, 4.5)	(3.3, 4.3, 5)

Table 6
Best and worst performances in optimizing each criterion.

	Full vaccination required	Full vaccination not required
\tilde{p}_1^+	(1.99, 2.99, 3.99)	(4, 5, 5)
\tilde{p}_1^-	(1, 1.16, 2.16)	(1, 1, 2)
\tilde{p}_2^+	(3.1, 4.1, 5)	(3.4, 4.4, 5)
\tilde{p}_2^-	(3, 4, 5)	(2.3, 3.3, 4.3)
\tilde{p}_3^+	(1.85, 2.85, 3.85)	(4, 5, 5)
\tilde{p}_3^-	(1.29, 2.29, 3.29)	(1, 1, 2)
\tilde{p}_4^+	(4, 5, 5)	(2.57, 3.57, 4.57)
\tilde{p}_4^-	(1, 1.67, 2.67)	(1, 1, 2)
\tilde{p}_5^+	(3.5, 4.5, 5)	(3.6, 4.6, 5)
\tilde{p}_5^-	(3.3, 4.3, 5)	(2.6, 3.6, 4.6)

The values of \tilde{S}_h and \tilde{R}_h were then computed for each hotel. The results are shown in Table 8, based on which the value of \tilde{Q}_h was derived by setting ω to 0.5. The defuzzified values of these performance measures are summarized in Table 9. based on the defuzzification results, hotels were ranked, as shown in Table 10. Hotel #4 achieved the lowest value of \tilde{Q}_h , followed by Hotel #3. However, the superiority of Hotel #4 over Hotel #3 only met the second condition. Therefore, both hotels were recommended to the traveler for his consideration.

4.3. Discussion

Based on to the experimental results, the following discussion was made:

- (1) In the two recommended hotels, Hotel #3 required a traveler to be fully vaccinated, while Hotel #4 did not. This result gave the traveler space to consider which type of hotel to stay.
- (2) A parametric analysis on the value of ω was also conducted. To this end, various values of ω were tried to see whether the recommendation result changed. The results are summarized in

Table 11. When ω exceeded 0.8, Hotel #3 was replaced by Hotel #12, and both the recommended hotels did not require full vaccination. In addition, the ranking of other hotels changed as ω varied.

(3) It was interesting to know the recommendation result if all hotels were evaluated by considering the same factors regardless of their types. For example, if all hotels required full vaccination, the ranking result is shown Table 12. As a consequence, the top performing hotel changed to Hotel #6. Its advantage over the second performing hotel, Hotel #4, was not significant. Therefore, both hotels were recommended to the traveler.

(4) In contrast, if all hotels did not require full vaccination, the ranking result is shown Table 13. The recommendation result did not change. Both Hotels #4 and #3 were recommended to the traveler. However, the ranking of other hotels was affected. For example, the rank of Hotel #13 dropped from the 6th to the 10th.

(5) The performance of the proposed methodology is evaluated as follows. Ten out of the twelve travelers followed the recommendations. Therefore, the successful recommendation rate using the proposed methodology was 83%.

4.4. Comparison with an existing method

For comparison, the existing FGM-FTOPSIS method was also applied to make a recommendation. However, hotels of different types were compared separately. First, the priorities of factors were derived using FGM for the two types of hotels, as shown in Table 14. Taking $\tilde{w}_2(1)$ as an example. The values of this factor derived using FGM and pcFGM are compared in Fig. 6. There was some deviation between these two values, which might change the recommendation result. Subsequently, the overall performance of a hotel was evaluated using FTOPSIS. In FTOPSIS, data were normalized using distributive normalization, which was different from that in fuzzy VIKOR. The overall performances of

Table 7
Normalized fuzzy distance between each hotel and the best performance.

h	\tilde{d}_{h1}	\tilde{d}_{h2}	\tilde{d}_{h3}	\tilde{d}_{h4}	\tilde{d}_{h5}
1	(0.13, 0.63, 0.88)	(0, 0.11, 0.7)	(0.35, 0.85, 1)	(0.16, 0.72, 1)	(0, 0.13, 0.71)
2	(0, 0.44, 0.69)	(0, 0.11, 0.7)	(0.29, 0.79, 1)	(0, 0, 0.56)	(0, 0.25, 0.83)
3	(0, 0, 0.67)	(0, 0.05, 1)	(0, 0, 0.78)	(0.33, 0.83, 1)	(0, 0, 0.88)
4	(0, 0.31, 0.56)	(0, 0.15, 0.74)	(0, 0.11, 0.36)	(0, 0.38, 0.94)	(0, 0.17, 0.75)
5	(0.5, 1, 1)	(0, 0.04, 0.63)	(0.22, 0.72, 0.97)	(0, 0.5, 1)	(0, 0.21, 0.79)
6	(0.19, 0.69, 0.94)	(0, 0.11, 0.7)	(0, 0.16, 0.41)	(0.02, 0.58, 1)	(0, 0.08, 0.67)
7	(0, 0.25, 0.5)	(0, 0.26, 0.85)	(0.36, 0.86, 1)	(0.04, 0.6, 1)	(0, 0.04, 0.63)
8	(0, 0.44, 0.69)	(0, 0.41, 1)	(0, 0.44, 0.69)	(0, 0.4, 0.96)	(0, 0.42, 1)
9	(0.5, 1, 1)	(0, 0, 0.59)	(0.32, 0.82, 1)	(0, 0.54, 1)	(0, 0, 0.58)
10	(0, 0.31, 0.56)	(0, 0.15, 0.74)	(0, 0.49, 0.74)	(0, 0.55, 1)	(0, 0.25, 0.83)
11	(0, 0, 0.25)	(0, 0.15, 0.74)	(0.5, 1, 1)	(0, 0.37, 0.93)	(0, 0.17, 0.75)
12	(0, 0.5, 0.75)	(0, 0.33, 0.93)	(0, 0, 0.25)	(0.06, 0.62, 1)	(0, 0.25, 0.83)
13	(0, 0.61, 1)	(0, 0, 0.95)	(0, 0.22, 1)	(0, 0, 0.25)	(0, 0.12, 1)

Table 8
Values of \tilde{S}_h and \tilde{R}_h of each hotel.

h	\tilde{S}_h	\tilde{R}_h	\tilde{Q}_h
1	(0.09, 0.59, 1.52)	(0.06, 0.27, 0.55)	(0, 0.28, 0.91)
2	(0.05, 0.48, 1.4)	(0.05, 0.25, 0.55)	(0, 0.23, 0.88)
3	(0.02, 0.11, 1.68)	(0.02, 0.1, 0.49)	(0, 0, 0.91)
4	(0, 0.22, 0.99)	(0, 0.13, 0.34)	(0, 0.05, 0.58)
5	(0.14, 0.7, 1.6)	(0.1, 0.42, 0.6)	(0, 0.44, 0.98)
6	(0.04, 0.38, 1.22)	(0.04, 0.29, 0.56)	(0, 0.23, 0.83)
7	(0.06, 0.42, 1.29)	(0.06, 0.27, 0.55)	(0, 0.23, 0.85)
8	(0, 0.43, 1.37)	(0, 0.18, 0.41)	(0, 0.16, 0.75)
9	(0.15, 0.7, 1.54)	(0.1, 0.42, 0.6)	(0, 0.44, 0.96)
10	(0, 0.36, 1.24)	(0, 0.15, 0.41)	(0, 0.11, 0.71)
11	(0.09, 0.37, 1.16)	(0.09, 0.31, 0.55)	(0, 0.25, 0.81)
12	(0, 0.3, 1.11)	(0, 0.21, 0.45)	(0, 0.14, 0.71)
13	(0, 0.24, 1.68)	(0, 0.19, 0.55)	(0, 0.1, 0.96)

Table 9
Defuzzification results.

h	$D(\tilde{S}_h)$	$D(\tilde{R}_h)$	$D(\tilde{Q}_h)$
1	0.696	0.287	0.368
2	0.602	0.274	0.334
3	0.480	0.179	0.227
4	0.357	0.149	0.171
5	0.784	0.383	0.464
6	0.505	0.293	0.325
7	0.551	0.288	0.328
8	0.559	0.194	0.269
9	0.773	0.383	0.459
10	0.488	0.178	0.235
11	0.494	0.316	0.328
12	0.426	0.217	0.248
13	0.538	0.231	0.293

Table 11
Parametric analysis results.

ω	Recommended hotels
0	Hotel #4, Hotel #3
0.1	Hotel #4, Hotel #3
0.2	Hotel #4, Hotel #3
0.3	Hotel #4, Hotel #3
0.4	Hotel #4, Hotel #3
0.5	Hotel #4, Hotel #3
0.6	Hotel #4, Hotel #3
0.7	Hotel #4, Hotel #3
0.8	Hotel #4, Hotel #12
0.9	Hotel #4, Hotel #12
1.0	Hotel #4, Hotel #12

Table 10
Ranking of hotels.

h	Rank
1	11
2	10
3	2
4	1
5	13
6	7
7	9
8	5
9	12
10	3
11	8
12	4
13	6

Table 12
Ranking result if all hotels required full vaccination.

h	Rank
1	11
2	9
3	4
4	2
5	8
6	1
7	12
8	6
9	7
10	5
11	13
12	3
13	10

hotels were defuzzified using the centroid of gravity (COG) method and then ranked. The ranking results, for the two types of hotels, are shown in Tables 15 and 16, respectively. Finally, Hotels #13 and #6 were the top performing hotels of the two types, which was different from the

result using the proposed methodology. In addition, it was unknown whether to recommend the top hotels of the two types or the top two of the larger type (i.e., full vaccination not required).

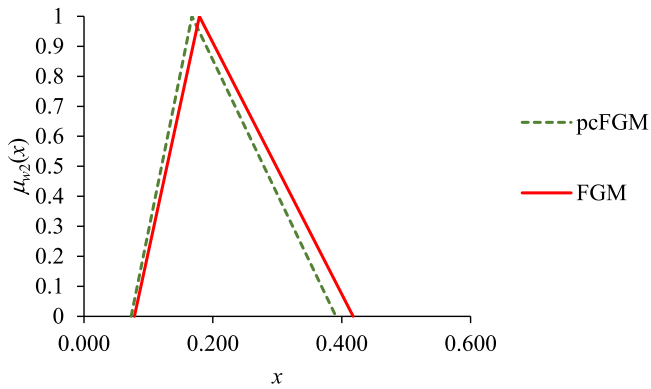


Fig. 6. Values of $\tilde{w}_2(x)$ derived using various methods.

Table 13
Ranking result if all hotels required full vaccination.

<i>h</i>	Rank
1	11
2	9
3	2
4	1
5	13
6	6
7	8
8	5
9	12
10	3
11	7
12	4
13	10

Table 14
Priorities of factors derived using fuzzy geometric mean.

	Full vaccination required	Full vaccination not required
\tilde{w}_1	(0.143, 0.308, 0.559)	(0.2, 0.425, 0.606)
\tilde{w}_2	(0.078, 0.179, 0.417)	(0.031, 0.068, 0.153)
\tilde{w}_3	(0.024, 0.049, 0.137)	(0.164, 0.303, 0.53)
\tilde{w}_4	(0.055, 0.117, 0.315)	(0.022, 0.044, 0.114)
\tilde{w}_5	(0.126, 0.346, 0.53)	(0.081, 0.159, 0.334)

Table 15
Ranking of hotels with full vaccination.

Hotel #	Rank
3	2
13	1

Table 16
Ranking of hotels without full vaccination.

Hotel #	Rank
1	7
2	11
4	2
5	8
6	1
7	9
8	5
9	6
10	4
11	10
12	3

5. Conclusions

In the latter stages of the COVID-19 pandemic, the tourism industry has also gradually recovered as borders are gradually being opened up. However, despite the growing popularity of COVID-19 vaccinations, the pandemic remains bleak in some regions. Faced with this impact, hotels have responded differently. Some hotels require all travelers to be fully vaccinated against the COVID-19 pandemic, while others are implementing enhanced pandemic prevention or cleaning measures without restrictions. Travelers must consider these factors when choosing a hotel, which leads to a novel problem of hotel selection and recommendation. To address this issue, this study proposes the pcFGM-fuzzy VIKOR method for hotel recommendation considering COVID-19 vaccination requirements. The proposed methodology begins by classifying hotels into two types based on their COVID-19 vaccination requirements. The key factors in choosing these two types of hotels are different. The pcFGM method is proposed to derive the priority of factors. Subsequently, a cross-type fuzzy VIKOR method is designed to evaluate and compare the overall performances of hotels.

A real hotel selection case illustrates the applicability of the proposed methodology. According to the experimental results,

- (1) Most hotels did not require travelers to be fully vaccinated.
- (2) The most critical factor in choosing a suitable hotel that required comprehensive vaccination was service quality. In contrast, the most critical factor in choosing a suitable hotel without vaccination requirements was the number of COVID-19 precautions.
- (3) The recommendation results using the proposed methodology were different from those using the existing FGM-FTOPSIS method. Nonetheless, hotels recommended using the proposed methodology also rank high (i.e., second place) in the ranking result using the FGM-FTOPSIS method.

One development to watch is whether the number of hotels requiring travelers to be fully vaccinated will continue to increase or decrease. Furthermore, this study modifies the existing fuzzy VIKOR method to make recommendations across hotel types. In the future, other fuzzy multi-objective decision-making methods can also be modified in a similar way to achieve the same goal.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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