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# Evaluating a User-Centered Environment-Friendly Mobile Phone App for Tourists and Residents Using Facial-Recognition Software

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**Abstract:** This study aims to examine a user-centered environment-friendly mobile phone app for tourists and residents in Saudi Arabia. To achieve this objective, a new fuzzy decision-making model is constructed. In this scope, by considering a detailed literature examination, eight criteria are identified. Facial expression-based quantum spherical DEMATEL with golden cuts are taken into consideration to examine the possible impact and directions among these criteria. The main contribution of this study is that priority factors in the development of the environment-friendly tourism mobile application can be identified. Moreover, facial expressions of the decision-makers are considered in the fuzzy decision-making analysis. This situation helps us to achieve more appropriate results. The findings demonstrate that user-centeredness is the most significant environment-friendly mobile application performance criterion of the tourism industry. Additionally, functionality is another important determinant with respect to this situation. It is of great importance to ensure customer satisfaction for the mobile applications used in the development of tourism to be successful. Thus, user feedback should be taken into consideration for them to work more effectively. Furthermore, tourism applications should provide users with fast and accurate information. In this context, mobile applications should offer customized offers to users to increase customer satisfaction.

**Keywords:** sustainability; tourism industry; sustainable mobile applications; environmental issues



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## 1. Introduction

Mobile applications play an important role in the tourism sector and contribute to the development of tourism. They offer tourists a wide range of information about the region [1]. Tourists will be able to have information on many important issues about places to visit, route suggestions and restaurants on these platforms [2]. This situation will significantly contribute to the development of tourism as it will facilitate the travel of tourists significantly [3]. Mobile applications also facilitate the transportation and accommodation of tourists [4]. With their help, tourists can more effectively manage their hotel reservations and flight-ticket purchasing processes [5]. On the other hand, it is possible for visitors to access useful information about local public transport facilities and services. Mobile applications also enable tourists to have information about places to visit. Hence, tourists can access news and views about the places [6]. In addition, some mobile applications enable users to access real-time information about these places.

Environment-friendly mobile applications involve both trying to develop the tourism sector while also being aimed at minimizing negative environmental impact. Because the tourism sector may have negative impacts on environmental issues, the popularity of these environment-friendly applications increases [7]. Within this framework, these apps support eco-friendly activities for the customers. In this context, guidance is provided to

the users of the application to increase the level of awareness regarding environmental issues [8]. Within this scope, data management should be provided more effectively. This condition helps to optimize energy consumption. Environment-friendly mobile applications also support the economic sustainability of tourism businesses. On the other hand, environment-friendly mobile apps help preserve and support local cultures and communities [9]. Owing to mobile applications, tourists can be informed about the importance of environmental issues in tourism activities. This issue can include environmentally friendly activities, protecting natural areas, and supporting local cultures and communities. Moreover, mobile applications can encourage users to act environmentally responsibly. In this context, application users can purchase digital tickets to reduce paper usage [10]. In addition, these apps can provide users with guidance, including recycling points and waste management information.

Therefore, it is necessary to address key issues around sustainability. The sustainability of the mobile application for the tourism sector refers to its ability to sustain its long-term success and impact in terms of environmental, economic, and social aspects. First, it is important that these practices are compatible with country practices. In addition, this application needs to meet the expectations of the users. Otherwise, they will not be preferred, and this will reduce the usability of the application [11]. On the other hand, this app should be functional. In this framework, it should offer many different feelings to the users. For this application to be successful, the technical infrastructure must also be sufficient. Also, it is necessary to ensure the financial profitability of this application. Otherwise, the long-term sustainability of the unprofitable application is not possible. Improvements need to be made to create a sustainable tourism mobile application. However, the costs will increase while making new improvements [12]. Therefore, it may not be financially possible to take many actions. It is necessary to conduct a priority analysis among these variables.

Accordingly, the purpose of this study is to evaluate a user-centered environment-friendly mobile phone app for tourists and residents in Saudi Arabia. The main reason for selecting this country is that the COVID-19 pandemic has also had a huge impact on the country's tourism industry. Due to this pandemic, the country's citizens have turned to local tourism rather than international travel. Within this framework, tourists visit famous landmarks throughout the country. On the other hand, tourism activities in this process are carried out through word-of-mouth communication or advertisements on social media. This situation is not sufficient for the effective development of tourism in the country. In other words, tourists cannot access enough information to make informed choices about many local tourism facilities and restaurants. This situation creates a significant barrier to the development of tourism activities.

Within this framework, a novel fuzzy decision-making model is constructed to achieve this objective. In this context, eight criteria are defined based on a detailed literature examination. These criteria are analyzed with facial expression-based quantum spherical DEMATEL with golden cuts to examine the possible impact and directions among them. The main contribution of this study is that priority factors in the development of the tourism mobile application will be determined. On the other hand, the proposed model also makes significant contributions to the literature. Firstly, by considering the facial expressions of the decision-makers, the uncertainties in the analysis process can be minimized. Additionally, while using the DEMATEL technique to weigh the determinants, the causal directions of these items can be taken into consideration. This condition makes a powerful contribution to achieving more effective findings.

## 2. Literature Review

This section consists of two different parts: an exploration of the literature on determinants of environment-friendly mobile applications and the literature review results. The summary table of the literature review can be found in the appendices (Table A1).

### *2.1. Literature on Determinants of Environment-Friendly Mobile Applications*

It is of great importance to comply with the legal regulations for the environment-friendly mobile applications used in the development of tourism to be successful. The data pool of these mobile applications contains the personal information of the users [13]. Therefore, the protection of personal data on this platform is of vital importance. Otherwise, these data may be stolen by third parties. Carvalho et al. [14] identified that this situation undermines the confidence of users in the application. On the other hand, there may be very high financial penalties for not complying with these legal regulations. Thong et al. [15] posed that tourism mobile applications must comply with relevant consumer protection laws to protect the rights of consumers. In this context, it is necessary to inform consumers accurately, especially about prices [16]. If this cannot be achieved, there is a risk that the application's owner company may encounter some legal problems. Moreover, Thananchana et al. [17] concluded that mobile applications must comply with competition rules. In this context, the details of competition law in the country of use should be thoroughly understood. Furthermore, Kotsyuba et al. [18] mentioned that tourism apps must act in accordance with legal and ethical standards. Encouraging or supporting illegal activities can lead to legal problems.

For the mobile applications used in the development of tourism to be successful, customer satisfaction should be ensured. In this context, mobile applications should be designed to be easy to use [19]. Users may encounter some glitches while transacting with the application. In this context, Mendes et al. [20] identified that some measures should be taken to solve customers' problems quickly and accurately. Therefore, user feedback needs to be taken into consideration [21]. This feedback demonstrates what kind of problems there are in the application. Furthermore, according to Yu et al. [22], to increase customer satisfaction, mobile applications must be able to provide personalized experiences to users. In this context, this application company is required to conduct a comprehensive data analysis of customers. Ortega et al. [23] suggested that based on the historical data of the customers, special offers should be made to these people. This ensures that customer expectations can be met to a significant extent. Additionally, Oliveira et al. [24] stated that more effective communication with customers is required. It is necessary to provide an easy and effective communication channel where customers can convey their complaints.

Technical infrastructure plays a crucial role in the effectiveness of environment-friendly mobile applications used in the development of tourism. One of the biggest expectations of users from environment-friendly mobile applications is fast and uninterrupted performance [25]. In this context, Kim et al. [26] mentioned that the application should be opened easily and the steps in the application should be performed quickly. If the transactions cannot be performed quickly, and the application freezes constantly, this reduces the satisfaction of customers. On the other hand, Botilias et al. [27] noted that tourism applications should be able to work on different mobile platforms. Otherwise, some operator users will not be able to benefit from this application. Environment-friendly tourism applications should include the necessary security measures to ensure the security and data protection of users [28]. Users share their credit card information while purchasing tickets on these mobile applications. Therefore, it should be ensured that the risks in this process are minimized by taking the necessary security measures [29]. Additionally, according to Salido et al. [30], it is important to constantly update and support the technical infrastructure. It may be necessary to add new services to environment-friendly tourism applications. In addition, some updates may be required to fix the encountered system errors. In this way, it is possible to increase customer satisfaction more easily.

Mobile applications used in the development of tourism should be functional. The success of an environment-friendly tourism application depends on meeting the needs of the users [31]. With this application, users can perform different operations such as travel planning and ticket purchase. Alauddin et al. [32] determined that the biggest expectation of the users in this process is that they can perform these transactions easily and quickly. The fact that users can use the application without difficulty and unnecessary complexity is

one of the key elements of success. According to Bessouat and Haller [33], for users from different countries to benefit from the environment-friendly mobile tourism application, it should be possible to operate in different languages. Otherwise, the application will not be able to serve some segments, and this will hinder the development of tourism. On the other hand, Hassan and Avi [34] stated that tourism applications should be able to integrate with other related services and platforms. The application's combination of various services makes travel planning more efficient for users. Manggopa et al. [35] mentioned that it is important to consider user feedback and reviews to ensure functionality. In this context, an interface should be developed where user experiences can be shared [36]. In this way, it is possible to develop the application by making continuous improvements [37].

### *2.2. Literature on Fuzzy Decision-Making Models in Mobile Applications*

The important points that affect the effectiveness of mobile applications are evaluated by fuzzy decision-making models in many different studies. Arif et al. [38] focused on Android mobile malware detection. In this process, important indicators are weighted by using fuzzy AHP methodology. Oztaysi et al. [39] created a fuzzy pricing model regarding mobile advertisements. For this purpose, the AHP approach is taken into consideration with spherical fuzzy sets. Pandey et al. [40] prioritized different issues in wearable apps by using the fuzzy DEMATEL methodology. With this issue, the causal directions between these factors can be considered. Peng et al. [41] conducted an analysis of mobile edge-caching-scheme preferences using a q-Rung orthopair fuzzy decision-making framework. On the other hand, Madasi et al. [42] used n-cubic q-rung orthopair fuzzy sets to examine the use of a mobile app in the education sector. Similarly, Tang et al. [43] performed an evaluation regarding mobile medical applications with q-rung orthopair fuzzy sets. Anitha and Padma [44] examined the resources of mobile devices with a neuro-fuzzy hybrid framework.

### *2.3. Literature Review Results*

The main results of the literature review are indicated below. The tourism industry plays a key role in the economic and social development of countries. For the effectiveness of the tourism industry, necessary importance should be given to marketing and promotional activities. A mobile application can make a positive contribution to the improvement of the tourism industry. Necessary actions should be taken to increase the effectiveness of environment-friendly mobile applications related to the tourism industry. There are lots of indicators that affect the performance of environment-friendly mobile tourism applications. However, each action has an increasing impact on costs. Therefore, it may not be financially possible to make lots of improvements at the same time. Thus, it is necessary to conduct a priority analysis among these variables and to make improvements to the more important issues in the first place.

The results of the literature review indicate that the main issue is the limited number of studies focusing on the indicators of the effectiveness of environment-friendly mobile applications. While considering these results of the literature examination, this study aims to examine key issues of the environment-friendly mobile application performance of the tourism industry in Saudi Arabia. By conducting this evaluation, we aimed to fill this gap in the literature. Within this context, eight factors are evaluated by facial expression-based quantum spherical DEMATEL with golden cuts (described below) to understand the possible impact and directions among them.

## 3. Methodology

A novel fuzzy decision-making model is proposed in this study to identify key determinants of the effectiveness of the environment-friendly mobile application for the tourism industry. This proposed model has two different parts. Firstly, the criteria are selected based on the literature review results. After that, the weights of these items are computed by using the DEMATEL technique with facial expression-based quantum spherical fuzzy

sets. The methods considered in the proposed model are explained under the following subheadings. All equations are provided in the appendices of the manuscript.

### *3.1. Decision-Making with Facial Expressions*

The performance of the decision-making methodology depends on certain critical issues, such as the quality of the decision-makers. Hence, the expert team should consist of people who have necessary and sufficient knowledge of the subject. However, these people may not be sure of the answers to some questions. In this process, the facial expressions of these people can reach more appropriate solutions [45]. The Facial Action Coding System (FACS) considers the nonverbal behaviors of people by using action units (AUs) [46]. In other words, AUs refer to a set of fundamental motions of the facial muscles. The coding of each facial expression involves identifying the specific AUs. Considering the facial expressions of the experts who make evaluations during the analysis process is beneficial in many ways. Experts may experience uneasiness when answering some questions. In this context, the issue can be considered in the analysis process by considering the facial expressions of the experts. Within this scope, online meetings are conducted with the decision-makers while obtaining the evaluations. In this process, with respect to the facial expression technology, the emotions of the decision-makers making evaluations are taken into consideration. This enables more effective analysis results to be achieved.

### *3.2. Quantum-Based Fuzzy Sets with Golden Ratio*

Quantum theory (Q) considers different probabilities. Because of this advantage, in this proposed model, this theory is integrated with the fuzzy decision-making logic [47]. Equations (A1)–(A3) provide details about the quantum theory. In these equations, $\varsigma$ represents a collection of events while $u$ gives information about the events [48]. In this process, events give information about the elements of the function. In addition, $\varphi^2$ explains amplitude-based results for the probability and $\theta$ indicates the phase angle. Spherical fuzzy sets ($\widetilde{A}_S$) provide a comprehensive representation of uncertainty in decision-making problems. They consider membership, non-membership, and hesitancy degrees ($\mu_{\widetilde{A}_S}$, $v_{\widetilde{A}_S}$, $h_{\widetilde{A}_S}$) in the analysis process [49]. They are detailed in Equations (A4) and (A5). The integration of these sets with quantum theory is detailed in Equations (A6)–(A8). In this proposed model, the degrees are computed with a golden ratio ($G$), where $b$ and $a$ refer to the high and low values [50,51]. These issues are detailed in Equations (A9)–(A17). While calculating the degrees of spherical fuzzy sets with the golden ratio, it is possible to minimize the uncertainty in the analysis process. Thus, more effective and reliable solutions can be reached.

### *3.3. The Extended Approach to DEMATEL*

The DEMATEL technique is used to find the weights of different factors. With the help of this technique, it is possible to understand the most significant ones [52]. The DEMATEL method has some advantages. The indicators of the environment-friendly tourism mobile application can have effects on each other. Therefore, the causality relationship between these factors should be taken into consideration to perform a more accurate analysis. Therefore, the use of the DEMATEL technique provides benefits in many ways. In this study, this technique is used with quantum spherical fuzzy sets. Firstly, the evaluations are obtained from the expert team. After that, Equation (A18) is considered to create a fuzzy relation matrix [53]. Next, the aggregated values are identified with Equation (A19). In the following step, the values are defuzzified by Equation (A20). A direct relation matrix is created by Equations (A21) and (A22). Equation (A23) is used to generate the total relation matrix. Equations (A24) and (A25) are taken into consideration to calculate the cause factors *(D)* and the effect factors *(E)*, respectively. Their total is used to compute the weights. Finally, the threshold value *(a)* is used to generate causal directions, as in Equation (A26).

## 4. The Results of the Analysis

This study evaluates a user-centered environment-friendly mobile phone app for tourists and residents in Saudi Arabia. Firstly, the dataset is collected by using the observation of facial expressions. For this purpose, an expert team is constructed with six different people. These people have the necessary qualifications related to the tourism industry, sustainability, mobile applications, and environmental issues. Two of these people are users. These people have master's degrees. The opinions of two different state officials are also taken into consideration. They work as the top managers in their departments. Finally, the other two are service providers. They have a minimum of 23 years of working experience. While conducting online meetings, the evaluations are obtained from the decision-makers. With respect to the data collection, the Delphi technique is taken into consideration. In this context, expert opinions are systematically provided. Thus, the hesitation problem faced by experts can be minimized. In this context, first, the problem must be clearly defined. Following this, an expert group on the subject is formed. In the third stage, experts share their opinions on these determined questions. These evaluations are then analyzed, and the results are sent back to the experts. In this process, experts are advised to reconsider their opinions. These second results are taken into consideration to make an evaluation.

For this purpose, in this study, the meetings with the experts are conducted online. First, individual interviews are held with experts, and their opinions on the questions are obtained. Details of these opinions are shared in Table A2. After this, all different opinions are shared with experts. Later, a group meeting is held with experts. In this meeting, experts discussed these issues together. Following this, a specific interview is conducted with the experts again, and new expert evaluations are obtained. Details of these second-round evaluations are shown in Table A3. It is understood that during this process, some changes are made in the evaluations of each expert. Moreover, these new evaluations are shared with the experts again, and a group meeting is held with the experts for the second time. In this meeting, experts are again given the opportunity to discuss the issue together. Moreover, the experts are interviewed for the third time, and their final opinions are provided. These final opinions are presented in Table A4. During this process, it was determined that there were some changes in the opinions of experts 1, 2, 3, and 5. On the other hand, there was no change in the opinions of experts 4 and 6. In this framework, the values in Table 1 are taken into consideration.

**Table 1.** Emotional Expressions and AU Combinations.

| Emotions | AUs | Pair Combinations | Scales | Degrees | Quantum Spherical Fuzzy Numbers |
|---|---|---|---|---|---|
| Contempt (Disdain) | 7,10,14,15 | (7, 10); (7, 14); (7, 15); (10, 14); (10, 15); (14,15) | No influence (n) | 0.40 | $\begin{bmatrix} \sqrt{0.16}e^{j2\pi.0.4}, \\ \sqrt{0.10}e^{j2\pi.0.25}, \\ \sqrt{0.74}e^{j2\pi.0.35} \end{bmatrix}$ |
| Intermediate Emotion | 1 AU of Contempt +1 AU of Surprise | (7, 1); (7, 2); (7, 5); (7, 27); (10, 1); (10, 2); (10, 5); (10, 27); (14, 1); (14, 2); (14, 5); (14, 27); (15, 1); (15, 2); (15, 5); (15, 27) | somewhat influence (s) | 0.45 | $\begin{bmatrix} \sqrt{0.20}e^{j2\pi.0.45}, \\ \sqrt{0.13}e^{j2\pi.0.28}, \\ \sqrt{0.67}e^{j2\pi.0.27} \end{bmatrix}$ |

**Table 1.** *Cont.*

| Emotions | AUs | Pair Combinations | Scales | Degrees | Quantum Spherical Fuzzy Numbers |
|---|---|---|---|---|---|
| Surprise | 1,2,5,27<br><br>1 AU of Contempt +1 AU of Happy | (1, 2); (1, 5); (1, 27); (2, 5); (2, 27); (5, 27); (7, 6); (7, 12); (7, 25); (7, 26); (10, 6); (10, 12); (10, 25); (10, 26); (14, 6); (14, 12); (14, 25); (14, 26); (15, 6); (15, 12); (15, 25); (15,26) | medium influence (m) | 0.50 | $\begin{bmatrix}\sqrt{0.25}e^{j2\pi.0.50},\\ \sqrt{0.15}e^{j2\pi.0.31},\\ \sqrt{0.60}e^{j2\pi.0.19}\end{bmatrix}$ |
| Intermediate Emotion | 1 AU of Surprise +1 AU of Happy | (1, 6); (1, 12); (1, 25), (1, 26); (2, 6); (2, 12); (2, 25); (2, 26); (5, 6); (5, 12); (5, 25); (5, 26); (27, 6); (27, 12); (27, 25); (27, 26) | high influence (h) | 0.55 | $\begin{bmatrix}\sqrt{0.30}e^{j2\pi.0.55},\\ \sqrt{0.19}e^{j2\pi.0.34},\\ \sqrt{0.51}e^{j2\pi.0.11}\end{bmatrix}$ |
| Happiness | 6,12,25,26 | (6, 12); (6, 25); (6, 26), (12, 25); (12, 26); (25, 26) | very high influence (vh) | 0.60 | $\begin{bmatrix}\sqrt{0.36}e^{j2\pi.0.6},\\ \sqrt{0.22}e^{j2\pi.0.37},\\ \sqrt{0.42}e^{j2\pi.0.03}\end{bmatrix}$ |

Pair combinations give information about the combinations of different AUs. Additionally, Table 1 demonstrates that experts use five different scales to answer the questions created by the criteria set. Moreover, five degrees are also used based on these scales in the analysis process. For this purpose, eight criteria are defined based on a detailed literature examination. In this process, the results of the studies evaluated in the literature review are taken into consideration. They are detailed in Table 2.

**Table 2.** Mobile application performance criteria of the tourism industry.

| Criteria | Definition | References |
|---|---|---|
| Relevance (RLVC) | To what extent does the mobile application align with the principles of environment-friendly tourism and circular economy in Saudi Arabia? | [5] |
| User-centeredness (UCTD) | How well does the mobile application cater to the needs and preferences of the local users in Saudi Arabia? | [1] |
| Functionality (FTLY) | How well does the mobile application perform its intended functions and provide a satisfactory user experience? | [10] |
| Technical feasibility (TFBY) | Is the mobile application technically feasible to develop and implement in Saudi Arabia, given its infrastructure and resources? | [12] |
| Economic viability (EVBY) | Will the benefits of the mobile application outweigh its costs in terms of both financial and environmental impacts? | [16] |
| Social impact (SMPC) | What are the potential positive and negative social impacts of the mobile application on the local communities in Saudi Arabia? | [18] |
| Environmental impact (EVMC) | What are the potential positive and negative environmental impacts of the mobile application, and how well does it support circular economy principles? | [7] |
| Cultural authenticity (CAUY) | To what extent does the mobile application reflect the authentic cultural and historical values of Saudi Arabia and promote cultural sustainability? | [32] |

The Relevance criterion provides information about to what extent the mobile application aligns with the principles of environment-friendly tourism. Moreover, User-centeredness refers to how well the mobile application satisfies the needs and preferences of the local users. This situation attracts the attention of the users so that environment-friendly tourism can be improved. Additionally, Functionality shows how well the mobile application performs its intended functions and provides a satisfactory user experience. This situation makes a positive contribution to the usage of environment-friendly mobile applications. Furthermore, there should be Technical feasibility to increase the quality of mobile applications. With the help of this situation, interruptions in the applications can be minimized. Economic viability explains whether the benefits of the mobile application outweigh its costs in terms of both financial and environmental impacts. The applications should also have powerful Social and Environment impact to have greater performance. Finally, this application should reflect the authentic Cultural (and historical) values of the places.

Aggregated values are computed in the following stage, as in Table A5. In the following process, these values are defuzzified. In other words, the fuzzy numbers are converted into real numbers. Defuzzified values are calculated in the next step, as in Table A6. These values are created by using Equation (A20). Next, the values are normalized in Table A7. Normalization helps to conduct an analysis more effectively. In this framework, Equations (A21) and (A22) are taken into consideration. After that, Equation (A23) is used to generate a total relation matrix. By using the values in this matrix, the weights of the items can be identified. Table A8 gives information about the total relation matrix. Later, Equations (A24) and (A25) are taken into consideration to calculate the cause factors ($D$) and the effect factors ($E$), respectively. The sum of these items is used to compute the weights of the items. The weights of the criteria are computed, and the results are provided in Table 3.

**Table 3.** Weights.

| | **Overall** | | **User** | | **Government** | | **Service Provider** | |
|---|---|---|---|---|---|---|---|---|
| | **Weights** | **Priorities** | **Weights** | **Priorities** | **Weights** | **Priorities** | **Weights** | **Priorities** |
| RLVC | 0.1259 | 5 | 0.1294 | 3 | 0.1245 | 4 | 0.1237 | 6 |
| UCTD | 0.1322 | 1 | 0.1344 | 1 | 0.1332 | 1 | 0.1296 | 3 |
| FTLY | 0.1291 | 2 | 0.1315 | 2 | 0.1300 | 2 | 0.1261 | 4 |
| TFBY | 0.1269 | 3 | 0.1199 | 7 | 0.1288 | 3 | 0.1319 | 1 |
| EVBY | 0.1130 | 8 | 0.1119 | 8 | 0.1141 | 8 | 0.1131 | 8 |
| SMPC | 0.1267 | 4 | 0.1252 | 5 | 0.1238 | 5 | 0.1314 | 2 |
| EVMC | 0.1210 | 7 | 0.1202 | 6 | 0.1228 | 6 | 0.1192 | 7 |
| CAUY | 0.1251 | 6 | 0.1275 | 4 | 0.1227 | 7 | 0.1249 | 5 |

The weights of the determinants are also illustrated in Figure 1.

Both Table 3 and Figure 1 aim to identify the weights of different criteria. With the help of this situation, it is possible to understand more significant factors. It is concluded that User-centeredness is the most critical environment-friendly mobile application performance criterion of the tourism industry. Functionality is also another critical issue regarding this situation. Technical feasibility also plays an essential role in this condition. Nevertheless, Environmental impact and Economic viability have the lowest weights.

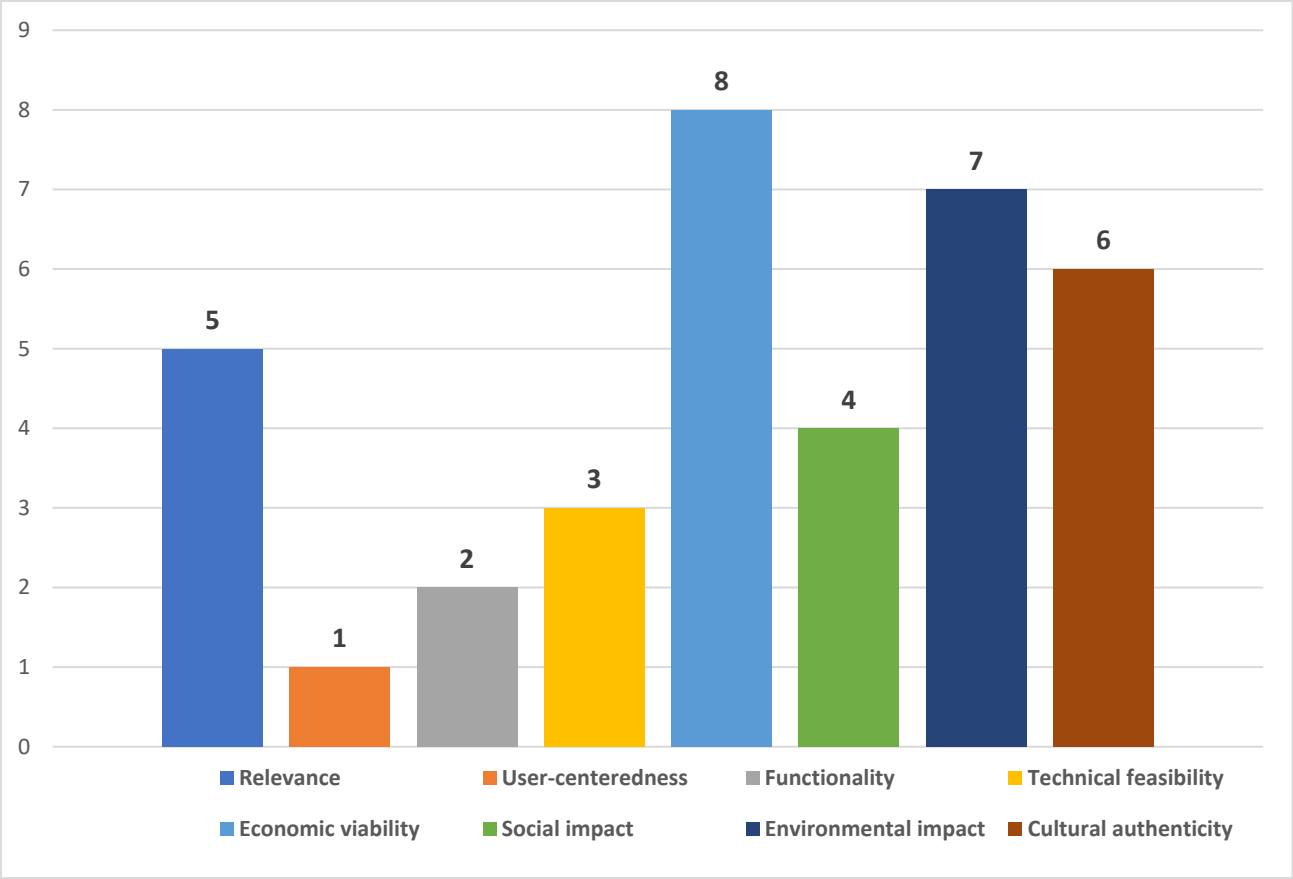


**Figure 1.** Weights of the Determinants.

## 5. Discussion

For the mobile applications used in the development of tourism to be successful, it is of great importance to ensure customer satisfaction. Therefore, user feedback should be taken into consideration for them to work more effectively. In this context, it is possible to detect the problems that arise regarding the application early. This enables quick action to solve problems. Thus, it will be possible to increase customer satisfaction, and this increases the usability of mobile applications. Juliana et al. [54], Anand et al. [55] and Preziosi et al. [56] also concluded that customer expectations should be met effectively for the improvement of tourism services. On the other hand, Camilleri and Filieri [57], Ioannou et al. [58] and Tiganis et al. [59] mentioned that tourism applications should provide users with fast and accurate information. In this context, care should be taken to ensure that the information in the application is up to date. Otherwise, customer satisfaction will decrease significantly. Moreover, to increase customer satisfaction, mobile applications should offer customized offers to users. According to Mainardes et al. [60] and Li et al. [61], this situation also contributes to increasing customer satisfaction. To increase customer satisfaction, mobile applications should consider user feedback and make continuous improvements. Kucukoglu [62] and Windasari et al. [63] also highlighted that tourism companies should provide quick solutions to the problems of the customers.

Ensuring customer satisfaction is of great importance in improving the performance of mobile applications related to the tourism sector. This also contributes to the support of these mobile applications for environment-friendly tourism. Thanks to meeting customer expectations, these people will be able to use this application more. In this way, it is possible to reach more people and increase environmental awareness in certain activities. Tourism activities can harm the natural environment and ecosystems in various ways. For example, the excessive use of water in tourism activities or the pollution of water

resources can cause significant damage to the environment [64]. To prevent this problem, it is important to increase the environmental awareness of customers. As a result of customers giving importance to these issues, businesses may be more sensitive in this regard [65]. Thus, thanks to the mobile application, the tourism sector will be able to develop, and environmental problems will be minimized in this process [66]. Xu et al. [67] conducted a methodological review of sustainable tourism and emphasized that mobile applications can be helpful in this situation. Similarly, Salido et al. [30] focused on the sustainable tourism industry in Boracay Island and underlined the importance of mobile applications in this regard. Kimutai et al. [68] evaluated the sustainable tourism industry in the East Africa region. They demonstrated that an effective mobile application is necessary to improve sustainability in the tourism industry.

## 6. Theoretical and Practical Implications

Being user-friendly is of great importance in the success of environmentally friendly mobile applications. This allows users to use these applications regularly. The complexity of the interface makes these applications not preferred. In this context, a document should be created within the application to support users. Thanks to these documents, it is possible to direct users to certain steps. In addition to this, unnecessary screens should not be created, so that applications can run quickly. Moreover, users should be offered the opportunity to give feedback. In this way, customer satisfaction can be achieved and problems can be understood more easily. Thus, necessary steps can be taken to continuously improve the application. On the other hand, menus should be designed to be easy to use. Users should be able to easily access the topics they want to access via the menu.

## 7. Conclusions

In this study, we aimed to evaluate the environment-friendly mobile application performance of the tourism industry in Saudi Arabia. Within this scope, eight criteria are defined based on a detailed literature examination. These factors are analyzed with facial expression-based quantum spherical DEMATEL with golden cuts to examine the possible impact and directions among them. We identified that User-centeredness is the most significant mobile application performance criterion of the tourism industry. Moreover, Functionality is also another important determinant with respect to this situation. Additionally, Technical feasibility also plays an essential role in this condition. On the other side, Environmental impact and Economic viability have the lowest weights.

The main contribution of this study is that priority factors in the development of the tourism mobile application can be identified. With the help of this situation, the appropriate strategies can be implemented without incurring high costs. Similarly, the DEMATEL method provides some advantages. The indicators of the environment-friendly tourism mobile application can have an influence on each other. Hence, the causality relationship between these factors should be taken into consideration to perform a more accurate analysis. As a result, the use of the DEMATEL technique provides benefits in many ways. In addition, considering the facial expressions of the experts who make evaluations during the analysis process is beneficial. Thus, this issue can be considered in the analysis process, owing to the consideration of the facial expressions of the experts. This situation enables more effective analysis results to be achieved.

The main limitation of this study is that this evaluation is conducted in Saudi Arabia. However, the effectiveness of the tourism industry is also crucial for other countries. For this purpose, developing or developed country groups can be evaluated in subsequent studies. The analysis results can help to present appropriate investment strategies for the improvement of the tourism industry. Also, this evaluation is performed only for the tourism industry. In terms of future research directions, different industries can be examined, such as banking or textiles. Similarly, in future studies, the proposed methodology can be improved. While ranking different country groups based on the performance of tourism mobile applications, TOPSIS or VIKOR techniques can be considered. Furthermore, consid-

ering expert opinions in the analysis process can be accepted as another limitation. Hence, in the following studies, econometric models can be created based on numerical data.

**Author Contributions:** Methodology, L.S.K. and S.Y.; Software, L.S.K.; Validation, L.S.K.; Formal analysis, L.S.K., S.Y. and H.D.; Investigation, L.S.K. and S.Y.; Data curation, H.D.; Writing—original draft, H.D.; Writing—review & editing, H.D. All authors have read and agreed to the published version of the manuscript.

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## Appendix A. Literature Review Results

**Table A1.** Literature Review Results.

| Studies | Results |
|---|---|
| Carvalho et al. [14] | Legal regulations play a crucial role for the environment-friendly mobile applications used in the development of tourism to be successful |
| Thong et al. [15] | |
| Thananchana et al. [17] | |
| Kotsyuba et al. [18] | |
| Mendes et al. [20] | It is of great importance to ensure customer satisfaction for the mobile applications used in the development of tourism to be successful |
| Yu et al. [22] | |
| Ortega e al. [23] | |
| Oliveira et al. [24] | |
| Kim et al. [26] | Technical infrastructure plays a crucial role for the effectiveness of the environment-friendly mobile applications used in the development of tourism |
| Botilias et al. [27] | |
| Salido et al. [30] | |
| Alauddin et al. [32] | Mobile applications used in the development of tourism should be functional |
| Bessouat and Haller [33] | |
| Hassan and Avi [34] | |
| Manggopa et al. [35] | |

## Appendix B. Equations

$$Q(|u>) = \varphi e^{j\theta} \tag{A1}$$

$$|\varsigma> = \{|u_1>, |u_2>, \ldots, |u_n>\} \tag{A2}$$

$$\sum_{|u>\subseteq|\varsigma>} |Q(|u>)| = 1 \tag{A3}$$

$$\widetilde{A}_S = \left\{ \langle u, \left( \mu_{\widetilde{A}_S}(u), v_{\widetilde{A}_S}(u), h_{\widetilde{A}_S}(u) \right) | u \in U \right\} \tag{A4}$$

$$0 \leq \mu^2_{\widetilde{A}_S}(u) + v^2_{\widetilde{A}_S}(u) + h^2_{\widetilde{A}_S}(u) \leq 1, \ \forall_u \in U \tag{A5}$$

$$\left| \varsigma_{\widetilde{A}_S} > = \left\{ \langle u, \left( \varsigma_{\mu_{\widetilde{A}_S}}(u), \varsigma_{v_{\widetilde{A}_S}}(u), \varsigma_{h_{\widetilde{A}_S}}(u) \right) | u \in 2^{|\varsigma_{\widetilde{A}_S}>} \right\} \right. \tag{A6}$$

$$\varsigma = \left[ \varsigma_\mu . e^{j2\pi.\alpha}, \varsigma_v . e^{j2\pi.\gamma}, \varsigma_h . e^{j2\pi.\beta} \right] \tag{A7}$$

$$\varphi^2 = \left| \varsigma_\mu (|u_i>) \right| \tag{A8}$$

$$\varsigma_v = \frac{\varsigma_\mu}{G} \tag{A9}$$

$$\varsigma_h = 1 - \varsigma_\mu - \varsigma_v \tag{A10}$$

$$\alpha = \left| \varsigma_\mu (|u_i>) \right| \tag{A11}$$

$$\gamma = \frac{\alpha}{G} \tag{A12}$$

$$\beta = 1 - \alpha - \gamma \tag{A13}$$

$$\lambda \times \widetilde{A}_\varsigma = \left\{ \left( 1 - \left( 1 - \varsigma_{\mu_{\widetilde{A}}}{}^2 \right)^\lambda \right)^{\frac{1}{2}} e^{j2\pi.(1-(1-(\frac{\alpha_{\widetilde{A}}}{2\pi})^2)^\lambda)^{\frac{1}{2}}}, \varsigma_{v_{\widetilde{A}}}{}^\lambda e^{j2\pi.(\frac{\gamma_{\widetilde{A}}}{2\pi})^\lambda}, \right.$$
$$\left. \left( \left( 1 - \varsigma_{h_{\widetilde{A}}}{}^2 \right)^\lambda - \left( 1 - \varsigma_{\mu_{\widetilde{A}}}{}^2 - \varsigma_{h_{\widetilde{A}}}{}^2 \right)^\lambda \right)^{\frac{1}{2}} e^{j2\pi.((1-(\frac{\beta_{\widetilde{A}}}{2\pi})^2)^\lambda - (1-(\frac{\alpha_{\widetilde{A}}}{2\pi})^2 - (\frac{\beta_{\widetilde{A}}}{2\pi})^2)^\lambda)^{\frac{1}{2}}} \right\}, \tag{A14}$$
$$\lambda > 0$$

$$\widetilde{A}_\varsigma{}^\lambda = \left\{ \varsigma_{\mu_{\widetilde{A}}}{}^\lambda e^{j2\pi.(\frac{\alpha_{\widetilde{A}}}{2\pi})^\lambda}, \left( 1 - \left( 1 - \varsigma_{v_{\widetilde{A}}}{}^2 \right)^\lambda \right)^{\frac{1}{2}} e^{j2\pi.(1-(1-(\frac{\gamma_{\widetilde{A}}}{2\pi})^2)^\lambda)^{\frac{1}{2}}}, \right.$$
$$\left. \left( \left( 1 - \varsigma_{v_{\widetilde{A}}}{}^2 \right)^\lambda - \left( 1 - \varsigma_{v_{\widetilde{A}}}{}^2 - \varsigma_{h_{\widetilde{A}}}{}^2 \right)^\lambda \right)^{\frac{1}{2}} e^{j2\pi.((1-(\frac{\gamma_{\widetilde{A}}}{2\pi})^2)^\lambda - (1-(\frac{\gamma_{\widetilde{A}}}{2\pi})^2 - (\frac{\beta_{\widetilde{A}}}{2\pi})^2)^\lambda)^{\frac{1}{2}}} \right\}, \tag{A15}$$
$$\lambda > 0$$

$$\begin{aligned} &\widetilde{A}_\varsigma \oplus \widetilde{B}_\varsigma \\ &= \left\{ \left( \varsigma_{\mu_{\widetilde{A}}}{}^2 + \varsigma_{\mu_{\widetilde{B}}}{}^2 - \varsigma_{\mu_{\widetilde{A}}}{}^2 \varsigma_{\mu_{\widetilde{B}}}{}^2 \right)^{\frac{1}{2}} e^{j2\pi.((\frac{\alpha_{\widetilde{A}}}{2\pi})^2 + (\frac{\alpha_{\widetilde{B}}}{2\pi})^2 - (\frac{\alpha_{\widetilde{A}}}{2\pi})^2 (\frac{\alpha_{\widetilde{B}}}{2\pi})^2)^{\frac{1}{2}}}, \right. \\ &\varsigma_{v_{\widetilde{A}}} \varsigma_{v_{\widetilde{B}}} e^{j2\pi.((\frac{\gamma_{\widetilde{A}}}{2\pi})(\frac{\gamma_{\widetilde{B}}}{2\pi}))}, \left( \left( 1 - \varsigma_{\mu_{\widetilde{B}}}{}^2 \right) \varsigma_{h_{\widetilde{A}}}{}^2 + \left( 1 - \varsigma_{\mu_{\widetilde{A}}}{}^2 \right) \varsigma_{h_{\widetilde{B}}}{}^2 \right. \\ &\left. \left. - \varsigma_{h_{\widetilde{A}}}{}^2 \varsigma_{h_{\widetilde{B}}}{}^2 \right)^{\frac{1}{2}} e^{j2\pi.((1-(\frac{\alpha_{\widetilde{B}}}{2\pi})^2)(\frac{\beta_{\widetilde{A}}}{2\pi})^2 + (1-(\frac{\alpha_{\widetilde{A}}}{2\pi})^2)(\frac{\beta_{\widetilde{B}}}{2\pi})^2 - (\frac{\beta_{\widetilde{A}}}{2\pi})^2 (\frac{\beta_{\widetilde{B}}}{2\pi})^2)^{\frac{1}{2}}} \right\} \end{aligned} \tag{A16}$$

$$\begin{aligned}&\widetilde{\boldsymbol{A}}_{\boldsymbol{\varsigma}} \otimes \widetilde{\boldsymbol{B}}_{\boldsymbol{\varsigma}}\\&= \left\{ \begin{array}{l} \boldsymbol{\varsigma_{\mu_{\widetilde{A}}}\varsigma_{\mu_{\widetilde{B}}}} \boldsymbol{e^{j2\pi.\left(\frac{\alpha_{\widetilde{A}}}{2\pi}\right)\left(\frac{\alpha_{\widetilde{B}}}{2\pi}\right)}}, \left(\boldsymbol{\varsigma_{v_{\widetilde{A}}}{}^2 + \varsigma_{v_{\widetilde{B}}}{}^2}\right.\\ \left.\boldsymbol{- \varsigma_{v_{\widetilde{A}}}{}^2\varsigma_{v_{\widetilde{B}}}{}^2}\right)^{\frac{1}{2}} \boldsymbol{e^{j2\pi.\left(\left(\frac{\gamma_{\widetilde{A}}}{2\pi}\right)^2+\left(\frac{\gamma_{\widetilde{B}}}{2\pi}\right)^2-\left(\frac{\gamma_{\widetilde{A}}}{2\pi}\right)^2\left(\frac{\gamma_{\widetilde{B}}}{2\pi}\right)^2\right)^{\frac{1}{2}}}}, \\ \left(\left(\boldsymbol{1 - \varsigma_{v_{\widetilde{B}}}{}^2}\right)\boldsymbol{\varsigma_{h_{\widetilde{A}}}{}^2 + \left(1 - \varsigma_{v_{\widetilde{A}}}{}^2\right)\varsigma_{h_{\widetilde{B}}}{}^2}\right.\\ \left.\boldsymbol{- \varsigma_{h_{\widetilde{A}}}{}^2\varsigma_{h_{\widetilde{B}}}{}^2}\right)^{\frac{1}{2}} \boldsymbol{e^{j2\pi.\left(\left(1-\left(\frac{\gamma_{\widetilde{B}}}{2\pi}\right)^2\right)\left(\frac{\beta_{\widetilde{A}}}{2\pi}\right)^2+\left(1-\left(\frac{\gamma_{\widetilde{A}}}{2\pi}\right)^2\right)\left(\frac{\beta_{\widetilde{B}}}{2\pi}\right)^2-\left(\frac{\beta_{\widetilde{A}}}{2\pi}\right)^2\left(\frac{\beta_{\widetilde{B}}}{2\pi}\right)^2\right)^{\frac{1}{2}}}} \end{array} \right\}\end{aligned} \tag{A17}$$

$$\varsigma_k = \begin{bmatrix} 0 & \varsigma_{12} & \cdots & \cdots & \varsigma_{1n} \\ \varsigma_{21} & 0 & \cdots & \cdots & \varsigma_{2n} \\ \vdots & \vdots & \ddots & \cdots & \cdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \varsigma_{n1} & \varsigma_{n2} & \cdots & \cdots & 0 \end{bmatrix} \tag{A18}$$

$$\begin{aligned}&\boldsymbol{\varsigma}\\&= \left\{ \begin{array}{l} \left[\boldsymbol{1 - \prod_{i=1}^{k}\left(1 - \varsigma_{\mu_i}{}^2\right)^{\frac{1}{k}}}\right]^{\frac{1}{2}} \boldsymbol{e^{2\pi.\left[1-\prod_{i=1}^{k}\left(1-\left(\frac{\alpha_i}{2\pi}\right)^2\right)^{\frac{1}{k}}\right]^{\frac{1}{2}}}}, \boldsymbol{\prod_{i=1}^{k}\varsigma_{v_i}{}^{\frac{1}{k}}\, e^{2\pi.\prod_{i=1}^{k}\left(\frac{\gamma_i}{2\pi}\right)^{\frac{1}{k}}}}, \left[\boldsymbol{\prod_{i=1}^{k}\left(1 - \varsigma_{\mu_i}{}^2\right)^{\frac{1}{k}}}\right. \\ \left.\boldsymbol{- \prod_{i=1}^{k}\left(1 - \varsigma_{\mu_i}{}^2 - \varsigma_{h_i}{}^2\right)^{\frac{1}{k}}}\right]^{\frac{1}{2}} \boldsymbol{e^{2\pi.\left[\prod_{i=1}^{k}\left(1-\left(\frac{\alpha_i}{2\pi}\right)^2\right)^{\frac{1}{k}}-\prod_{i=1}^{k}\left(1-\left(\frac{\alpha_i}{2\pi}\right)^2-\left(\frac{\beta_i}{2\pi}\right)^2\right)^{\frac{1}{k}}\right]^{\frac{1}{2}}}} \end{array} \right\}\end{aligned} \tag{A19}$$

$$\boldsymbol{Def\varsigma_i} = \varsigma_{\mu_i} + \left(\frac{\varsigma_{\mu_i}}{\varsigma_{\mu_i} + \varsigma_{h_i} + \varsigma_{v_i}}\right) + \left(\frac{\boldsymbol{\alpha_i}}{2\pi}\right) + \left(\frac{\left(\frac{\alpha_i}{2\pi}\right)}{\left(\frac{\alpha_i}{2\pi}\right) + \left(\frac{\gamma_i}{2\pi}\right) + \left(\frac{\beta_i}{2\pi}\right)}\right) \tag{A20}$$

$$\boldsymbol{B} = \frac{\varsigma}{\boldsymbol{max}_{1 \le i \le n}\sum_{j=1}^{n}\varsigma_{ij}} \tag{A21}$$

$$0 \le \boldsymbol{b_{ij}} \le 1 \tag{A22}$$

$$C = \lim_{k\to\infty}\left(B + B^2 + \ldots + B^k\right) = B(I - B)^{-1} \quad \text{(A23)}$$

$$D = \left[\sum_{j=1}^{n} e_{ij}\right]_{nx1} \quad \text{(A24)}$$

$$E = \left[\sum_{i=1}^{n} e_{ij}\right]_{1xn} \quad \text{(A25)}$$

$$\alpha = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}\left[e_{ij}\right]}{N} \quad \text{(A26)}$$

## Appendix C. Tables in the Analysis Process

**Table A2.** The expert evaluations for the first round.

| **Expert 1 (User)** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **RLVC** | **UCTD** | **FTLY** | **TFBY** | **EVBY** | **SMPC** | **EVMC** | **CAUY** |
| RLVC | | (25, 26) | (12, 25) | (27, 25) | (12, 25) | (12, 25) | (15, 5) | (25, 26) |
| UCTD | (14, 12) | | (14, 2) | (12, 25) | (7, 6) | (12, 25) | (10, 14) | (27, 25) |
| FTLY | (7, 6) | (12, 25) | | (12, 25) | (7, 6) | (14, 12) | (27, 25) | (25, 26) |
| TFBY | (7, 6) | (25, 26) | (5, 26) | | (14, 2) | (7, 10) | (14, 2) | (10, 14) |
| EVBY | (14, 2) | (14, 2) | (14, 2) | (10, 14) | | (15, 5) | (7, 6) | (15, 5) |
| SMPC | (14, 12) | (25, 26) | (27, 25) | (5, 26) | (27, 25) | | (5, 26) | (7, 6) |
| EVMC | (12, 25) | (12, 25) | (15, 5) | (10, 14) | (7, 10) | (14, 2) | | (25, 26) |
| CAUY | (7, 6) | (7, 6) | (14, 12) | (5, 26) | (15, 5) | (5, 26) | (12, 25) | |
| **Expert 2 (User)** | | | | | | | | |
| | **RLVC** | **UCTD** | **FTLY** | **TFBY** | **EVBY** | **SMPC** | **EVMC** | **CAUY** |
| RLVC | | (10, 5) | (25, 26) | (27, 25) | (27, 25) | (27, 25) | (14, 12) | (5, 26) |
| UCTD | (27, 25) | | (25, 26) | (27, 25) | (14, 12) | (25, 26) | (15, 2) | (27, 25) |
| FTLY | (14, 12) | (12, 25) | | (27, 25) | (27, 25) | (7, 6) | (27, 25) | (12, 25) |
| TFBY | (14, 12) | (25, 26) | (5, 26) | | (14, 2) | (10, 5) | (10, 5) | (7, 6) |
| EVBY | (10, 5) | (10, 5) | (10, 5) | (7, 10) | | (14, 2) | (14, 12) | (15, 5) |
| SMPC | (14, 12) | (12, 25) | (5, 26) | (14, 12) | (5, 26) | | (5, 26) | (12, 25) |
| EVMC | (25, 26) | (25, 26) | (7, 6) | (10, 14) | (10, 14) | (10, 5) | | (12, 25) |
| CAUY | (7, 6) | (5, 26) | (5, 26) | (5, 26) | (7, 6) | (14, 2) | (27, 25) | |
| **Expert 3 (Government)** | | | | | | | | |
| | **RLVC** | **UCTD** | **FTLY** | **TFBY** | **EVBY** | **SMPC** | **EVMC** | **CAUY** |
| RLVC | | (7, 6) | (27, 25) | (1, 2) | (27, 25) | (27, 25) | (10, 14) | (27, 25) |
| UCTD | (15, 5) | | (25, 26) | (25, 26) | (14, 12) | (27, 25) | (15, 5) | (25, 26) |
| FTLY | (27, 25) | (27, 25) | | (12, 25) | (14, 12) | (27, 25) | (12, 25) | (14, 12) |
| TFBY | (27, 25) | (7, 6) | (25, 26) | | (14, 12) | (10, 5) | (14, 12) | (10, 5) |
| EVBY | (15, 5) | (12, 25) | (10, 14) | (15, 5) | | (7, 6) | (7, 6) | (10, 5) |
| SMPC | (15, 5) | (5, 26) | (14, 12) | (5, 26) | (7, 6) | | (7, 6) | (7, 6) |
| EVMC | (27, 25) | (7, 6) | (15, 5) | (12, 25) | (15, 5) | (1, 2) | | (15, 5) |
| CAUY | (10, 5) | (7, 6) | (15, 5) | (7, 6) | (15, 5) | (15, 5) | (15, 5) | |

**Table A2.** *Cont.*

| Expert 4 (Government) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **RLVC** | **UCTD** | **FTLY** | **TFBY** | **EVBY** | **SMPC** | **EVMC** | **CAUY** |
| RLVC | | (27, 25) | (27, 25) | (6, 25) | (5, 26) | (27, 25) | (10, 14) | (7, 6) |
| UCTD | (7, 6) | | (27, 25) | (25, 26) | (5, 26) | (27, 25) | (14, 12) | (25, 26) |
| FTLY | (5, 26) | (14, 12) | | (12, 25) | (14, 12) | (27, 25) | (5, 26) | (7, 6) |
| TFBY | (12, 25) | (14, 12) | (25, 26) | | (14, 12) | (15, 5) | (7, 6) | (10, 5) |
| EVBY | (7, 10) | (12, 25) | (10, 14) | (10, 5) | | (1, 2) | (14, 12) | (7, 6) |
| SMPC | (10, 5) | (5, 26) | (7, 6) | (5, 26) | (7, 6) | | (14, 12) | (5, 26) |
| EVMC | (5, 26) | (12, 25) | (14, 12) | (6, 25) | (10, 5) | (1, 2) | | (10, 5) |
| CAUY | (27, 25) | (12, 25) | (14, 12) | (1, 2) | (14, 12) | (14, 12) | (1, 2) | |
| **Expert 5 (Service provider)** | | | | | | | | |
| | **RLVC** | **UCTD** | **FTLY** | **TFBY** | **EVBY** | **SMPC** | **EVMC** | **CAUY** |
| RLVC | | (10, 5) | (12, 25) | (7, 6) | (25, 26) | (5, 26) | (25, 26) | (5, 26) |
| UCTD | (15, 5) | | (12, 25) | (25, 26) | (7, 6) | (25, 26) | (10, 5) | (12, 25) |
| FTLY | (15, 5) | (15, 5) | | (25, 26) | (10, 1) | (27, 25) | (25, 26) | (25, 26) |
| TFBY | (27, 25) | (7, 6) | (25, 26) | | (27, 25) | (27, 25) | (14, 12) | (14, 12) |
| EVBY | (7, 10) | (15, 5) | (10, 14) | (7, 6) | | (7, 6) | (10, 14) | (10, 5) |
| SMPC | (14, 12) | (25, 26) | (12, 25) | (12, 25) | (7, 6) | | (10, 5) | (7, 6) |
| EVMC | (10, 14) | (27, 25) | (10, 5) | (7, 6) | (15, 5) | (6, 12) | | (7, 6) |
| CAUY | (7, 6) | (27, 25) | (10, 5) | (5, 26) | (7, 10) | (5, 26) | (7, 6) | |
| **Expert 6 (Service provider)** | | | | | | | | |
| | **RLVC** | **UCTD** | **FTLY** | **TFBY** | **EVBY** | **SMPC** | **EVMC** | **CAUY** |
| RLVC | | (27, 25) | (27, 25) | (27, 25) | (27, 25) | (27, 25) | (27, 25) | (7, 6) |
| UCTD | (14, 12) | | (25, 26) | (7, 6) | (7, 6) | (7, 6) | (10, 1) | (25, 26) |
| FTLY | (14, 12) | (14, 12) | | (12, 25) | (10, 1) | (27, 25) | (12, 25) | (25, 26) |
| TFBY | (27, 25) | (14, 12) | (12, 25) | | (5, 26) | (7, 6) | (14, 12) | (14, 12) |
| EVBY | (14, 12) | (10, 1) | (15, 5) | (7, 6) | | (7, 6) | (14, 12) | (14, 12) |
| SMPC | (14, 12) | (12, 25) | (7, 6) | (12, 25) | (7, 6) | | (10, 1) | (5, 26) |
| EVMC | (10, 1) | (15, 5) | (10, 1) | (14, 12) | (10, 1) | (25, 26) | | (14, 12) |
| CAUY | (7, 6) | (15, 5) | (15, 5) | (5, 26) | (10, 1) | (5, 26) | (7, 6) | |

**Table A3.** The expert evaluations for the second round.

| Expert 1 (User) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **RLVC** | **UCTD** | **FTLY** | **TFBY** | **EVBY** | **SMPC** | **EVMC** | **CAUY** |
| RLVC | | (25, 26) | (12, 25) | (27, 25) | (12, 25) | (12, 25) | (15, 5) | (25, 26) |
| UCTD | (14, 12) | | (14, 2) | (12, 25) | (7, 6) | (12, 25) | (10, 14) | (27, 25) |
| FTLY | (14, 12) | (12, 25) | | (12, 25) | (7, 6) | (14, 12) | (27, 25) | (25, 26) |
| TFBY | (7, 6) | (25, 26) | (5, 26) | | (14, 2) | (7, 10) | (14, 2) | (10, 14) |
| EVBY | (14, 2) | (14, 2) | (14, 2) | (10, 14) | | (15, 5) | (7, 6) | (15, 5) |
| SMPC | (14, 12) | (25, 26) | (27, 25) | (14, 12) | (27, 25) | | (5, 26) | (7, 6) |
| EVMC | (12, 25) | (12, 25) | (15, 5) | (10, 14) | (7, 10) | (14, 2) | | (25, 26) |
| CAUY | (7, 6) | (5, 26) | (14, 12) | (5, 26) | (15, 5) | (14, 2) | (12, 25) | |

**Table A3.** *Cont.*

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Expert 2 (User)** | | | | | | | | |
| | **RLVC** | **UCTD** | **FTLY** | **TFBY** | **EVBY** | **SMPC** | **EVMC** | **CAUY** |
| RLVC | | (10, 5) | (25, 26) | (27, 25) | (12, 25) | (12, 25) | (14, 12) | (5, 26) |
| UCTD | (27, 25) | | (25, 26) | (12, 25) | (14, 12) | (25, 26) | (15, 2) | (27, 25) |
| FTLY | (14, 12) | (12, 25) | | (12, 25) | (27, 25) | (7, 6) | (27, 25) | (12, 25) |
| TFBY | (14, 12) | (25, 26) | (5, 26) | | (14, 2) | (10, 5) | (10, 5) | (7, 6) |
| EVBY | (10, 5) | (10, 5) | (10, 5) | (7, 10) | | (14, 2) | (14, 12) | (15, 5) |
| SMPC | (14, 12) | (12, 25) | (5, 26) | (14, 12) | (5, 26) | | (5, 26) | (12, 25) |
| EVMC | (25, 26) | (25, 26) | (7, 6) | (10, 14) | (10, 14) | (10, 5) | | (12, 25) |
| CAUY | (7, 6) | (5, 26) | (5, 26) | (5, 26) | (7, 6) | (14, 2) | (27, 25) | |
| **Expert 3 (Government)** | | | | | | | | |
| | **RLVC** | **UCTD** | **FTLY** | **TFBY** | **EVBY** | **SMPC** | **EVMC** | **CAUY** |
| RLVC | | (7, 6) | (27, 25) | (1, 2) | (27, 25) | (27, 25) | (10, 14) | (27, 25) |
| UCTD | (15, 5) | | (25, 26) | (25, 26) | (14, 12) | (27, 25) | (15, 5) | (25, 26) |
| FTLY | (27, 25) | (27, 25) | | (12, 25) | (14, 12) | (27, 25) | (12, 25) | (14, 12) |
| TFBY | (27, 25) | (7, 6) | (25, 26) | | (14, 12) | (10, 5) | (14, 12) | (10, 5) |
| EVBY | (15, 5) | (12, 25) | (10, 14) | (15, 5) | | (7, 6) | (7, 6) | (10, 5) |
| SMPC | (15, 5) | (5, 26) | (14, 12) | (5, 26) | (7, 6) | | (7, 6) | (7, 6) |
| EVMC | (27, 25) | (12, 25) | (14, 12) | (12, 25) | (15, 5) | (1, 2) | | (15, 5) |
| CAUY | (27, 25) | (12, 25) | (15, 5) | (7, 6) | (15, 5) | (15, 5) | (15, 5) | |
| **Expert 4 (Government)** | | | | | | | | |
| | **RLVC** | **UCTD** | **FTLY** | **TFBY** | **EVBY** | **SMPC** | **EVMC** | **CAUY** |
| RLVC | | (27, 25) | (27, 25) | (6, 25) | (5, 26) | (27, 25) | (10, 14) | (7, 6) |
| UCTD | (7, 6) | | (25, 26) | (25, 26) | (5, 26) | (27, 25) | (14, 12) | (25, 26) |
| FTLY | (5, 26) | (14, 12) | | (12, 25) | (14, 12) | (27, 25) | (5, 26) | (7, 6) |
| TFBY | (12, 25) | (14, 12) | (25, 26) | | (14, 12) | (15, 5) | (14, 12) | (10, 5) |
| EVBY | (7, 10) | (10, 5) | (10, 14) | (10, 5) | | (1, 2) | (14, 12) | (7, 6) |
| SMPC | (10, 5) | (5, 26) | (7, 6) | (5, 26) | (7, 6) | | (14, 12) | (5, 26) |
| EVMC | (5, 26) | (12, 25) | (14, 12) | (6, 25) | (10, 5) | (1, 2) | | (10, 5) |
| CAUY | (27, 25) | (12, 25) | (14, 12) | (1, 2) | (14, 12) | (14, 12) | (1, 2) | |
| **Expert 5 (Service provider)** | | | | | | | | |
| | **RLVC** | **UCTD** | **FTLY** | **TFBY** | **EVBY** | **SMPC** | **EVMC** | **CAUY** |
| RLVC | | (10, 5) | (27, 25) | (7, 6) | (25, 26) | (5, 26) | (25, 26) | (5, 26) |
| UCTD | (15, 5) | | (12, 25) | (25, 26) | (7, 6) | (25, 26) | (10, 5) | (12, 25) |
| FTLY | (15, 5) | (15, 5) | | (25, 26) | (10, 1) | (27, 25) | (25, 26) | (25, 26) |
| TFBY | (27, 25) | (7, 6) | (25, 26) | | (27, 25) | (27, 25) | (14, 12) | (14, 12) |
| EVBY | (7, 10) | (15, 5) | (10, 14) | (7, 6) | | (7, 6) | (10, 14) | (10, 5) |
| SMPC | (14, 12) | (25, 26) | (12, 25) | (12, 25) | (7, 6) | | (10, 5) | (7, 6) |
| EVMC | (10, 14) | (27, 25) | (10, 5) | (7, 6) | (15, 5) | (6, 12) | | (7, 6) |
| CAUY | (7, 6) | (27, 25) | (10, 5) | (5, 26) | (7, 10) | (5, 26) | (7, 6) | |

**Table A3.** *Cont.*

| Expert 6 (Service provider) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **RLVC** | **UCTD** | **FTLY** | **TFBY** | **EVBY** | **SMPC** | **EVMC** | **CAUY** |
| RLVC | | (27, 25) | (27, 25) | (27, 25) | (27, 25) | (27, 25) | (27, 25) | (7, 6) |
| UCTD | (14, 12) | | (25, 26) | (25, 26) | (7, 6) | (25, 26) | (10, 1) | (25, 26) |
| FTLY | (14, 12) | (14, 12) | | (12, 25) | (10, 1) | (27, 25) | (12, 25) | (25, 26) |
| TFBY | (27, 25) | (14, 12) | (12, 25) | | (5, 26) | (27, 25) | (14, 12) | (14, 12) |
| EVBY | (14, 12) | (10, 1) | (15, 5) | (7, 6) | | (7, 6) | (14, 12) | (14, 12) |
| SMPC | (14, 12) | (12, 25) | (7, 6) | (12, 25) | (7, 6) | | (10, 1) | (5, 26) |
| EVMC | (10, 1) | (27, 25) | (10, 1) | (14, 12) | (10, 1) | (25, 26) | | (14, 12) |
| CAUY | (7, 6) | (27, 25) | (15, 5) | (5, 26) | (10, 1) | (5, 26) | (7, 6) | |

**Table A4.** The expert evaluations for the third round.

| Expert 1 (User) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **RLVC** | **UCTD** | **FTLY** | **TFBY** | **EVBY** | **SMPC** | **EVMC** | **CAUY** |
| RLVC | | (25, 26) | (12, 25) | (27, 25) | (12, 25) | (12, 25) | (15, 5) | (25, 26) |
| UCTD | (14, 12) | | (25, 26) | (12, 25) | (7, 6) | (12, 25) | (10, 14) | (27, 25) |
| FTLY | (14, 12) | (12, 25) | | (12, 25) | (27, 25) | (14, 12) | (27, 25) | (25, 26) |
| TFBY | (7, 6) | (25, 26) | (5, 26) | | (14, 2) | (7, 10) | (14, 2) | (10, 14) |
| EVBY | (14, 2) | (14, 2) | (14, 2) | (10, 14) | | (15, 5) | (7, 6) | (15, 5) |
| SMPC | (14, 12) | (25, 26) | (27, 25) | (14, 12) | (27, 25) | | (5, 26) | (12, 25) |
| EVMC | (12, 25) | (12, 25) | (15, 5) | (10, 14) | (7, 10) | (14, 2) | | (25, 26) |
| CAUY | (7, 6) | (5, 26) | (14, 12) | (5, 26) | (15, 5) | (14, 2) | (12, 25) | |
| **Expert 2 (User)** | | | | | | | | |
| | **RLVC** | **UCTD** | **FTLY** | **TFBY** | **EVBY** | **SMPC** | **EVMC** | **CAUY** |
| RLVC | | (27, 25) | (25, 26) | (27, 25) | (12, 25) | (12, 25) | (14, 12) | (5, 26) |
| UCTD | (27, 25) | | (25, 26) | (12, 25) | (14, 12) | (25, 26) | (15, 2) | (27, 25) |
| FTLY | (14, 12) | (12, 25) | | (12, 25) | (27, 25) | (7, 6) | (27, 25) | (12, 25) |
| TFBY | (14, 12) | (25, 26) | (5, 26) | | (14, 2) | (10, 5) | (10, 5) | (7, 6) |
| EVBY | (10, 5) | (10, 5) | (10, 5) | (7, 10) | | (14, 2) | (14, 12) | (15, 5) |
| SMPC | (14, 12) | (12, 25) | (5, 26) | (14, 12) | (5, 26) | | (5, 26) | (12, 25) |
| EVMC | (25, 26) | (25, 26) | (7, 6) | (10, 14) | (10, 14) | (10, 5) | | (12, 25) |
| CAUY | (7, 6) | (5, 26) | (5, 26) | (5, 26) | (7, 6) | (14, 2) | (27, 25) | |
| **Expert 3 (Government)** | | | | | | | | |
| | **RLVC** | **UCTD** | **FTLY** | **TFBY** | **EVBY** | **SMPC** | **EVMC** | **CAUY** |
| RLVC | | (27, 25) | (27, 25) | (1, 2) | (27, 25) | (27, 25) | (10, 14) | (27, 25) |
| UCTD | (15, 5) | | (25, 26) | (25, 26) | (14, 12) | (27, 25) | (15, 5) | (25, 26) |
| FTLY | (27, 25) | (27, 25) | | (12, 25) | (14, 12) | (27, 25) | (12, 25) | (14, 12) |
| TFBY | (27, 25) | (7, 6) | (25, 26) | | (14, 12) | (10, 5) | (14, 12) | (10, 5) |
| EVBY | (7, 10) | (10, 5) | (10, 14) | (15, 5) | | (7, 6) | (14, 12) | (10, 5) |
| SMPC | (15, 5) | (5, 26) | (14, 12) | (5, 26) | (7, 6) | | (7, 6) | (7, 6) |
| EVMC | (27, 25) | (12, 25) | (14, 12) | (12, 25) | (15, 5) | (1, 2) | | (15, 5) |
| CAUY | (27, 25) | (12, 25) | (15, 5) | (7, 6) | (15, 5) | (15, 5) | (15, 5) | |

**Table A4.** *Cont.*

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Expert 4 (Government)** | | | | | | | | |
| | **RLVC** | **UCTD** | **FTLY** | **TFBY** | **EVBY** | **SMPC** | **EVMC** | **CAUY** |
| RLVC | | (27, 25) | (27, 25) | (6, 25) | (5, 26) | (27, 25) | (10, 14) | (7, 6) |
| UCTD | (7, 6) | | (25, 26) | (25, 26) | (5, 26) | (27, 25) | (14, 12) | (25, 26) |
| FTLY | (5, 26) | (14, 12) | | (12, 25) | (14, 12) | (27, 25) | (5, 26) | (7, 6) |
| TFBY | (12, 25) | (14, 12) | (25, 26) | | (14, 12) | (15, 5) | (14, 12) | (10, 5) |
| EVBY | (7, 10) | (10, 5) | (10, 14) | (10, 5) | | (1, 2) | (14, 12) | (7, 6) |
| SMPC | (10, 5) | (5, 26) | (7, 6) | (5, 26) | (7, 6) | | (14, 12) | (5, 26) |
| EVMC | (5, 26) | (12, 25) | (14, 12) | (6, 25) | (10, 5) | (1, 2) | | (10, 5) |
| CAUY | (27, 25) | (12, 25) | (14, 12) | (1, 2) | (14, 12) | (14, 12) | (1, 2) | |
| **Expert 5 (Service provider)** | | | | | | | | |
| | **RLVC** | **UCTD** | **FTLY** | **TFBY** | **EVBY** | **SMPC** | **EVMC** | **CAUY** |
| RLVC | | (27, 25) | (27, 25) | (7, 6) | (25, 26) | (5, 26) | (25, 26) | (5, 26) |
| UCTD | (15, 5) | | (12, 25) | (25, 26) | (7, 6) | (25, 26) | (10, 5) | (12, 25) |
| FTLY | (15, 5) | (15, 5) | | (25, 26) | (10, 1) | (27, 25) | (25, 26) | (25, 26) |
| TFBY | (27, 25) | (7, 6) | (25, 26) | | (27, 25) | (27, 25) | (14, 12) | (14, 12) |
| EVBY | (7, 10) | (15, 5) | (10, 14) | (7, 6) | | (7, 6) | (10, 14) | (10, 5) |
| SMPC | (14, 12) | (25, 26) | (7, 6) | (12, 25) | (7, 6) | | (10, 5) | (5, 26) |
| EVMC | (10, 14) | (27, 25) | (10, 5) | (7, 6) | (15, 5) | (6, 12) | | (7, 6) |
| CAUY | (7, 6) | (27, 25) | (10, 5) | (5, 26) | (7, 10) | (5, 26) | (7, 6) | |
| **Expert 6 (Service provider)** | | | | | | | | |
| | **RLVC** | **UCTD** | **FTLY** | **TFBY** | **EVBY** | **SMPC** | **EVMC** | **CAUY** |
| RLVC | | (27, 25) | (27, 25) | (27, 25) | (27, 25) | (27, 25) | (27, 25) | (7, 6) |
| UCTD | (14, 12) | | (25, 26) | (25, 26) | (7, 6) | (25, 26) | (10, 1) | (25, 26) |
| FTLY | (14, 12) | (14, 12) | | (12, 25) | (10, 1) | (27, 25) | (12, 25) | (25, 26) |
| TFBY | (27, 25) | (14, 12) | (12, 25) | | (5, 26) | (27, 25) | (14, 12) | (14, 12) |
| EVBY | (14, 12) | (10, 1) | (15, 5) | (7, 6) | | (7, 6) | (14, 12) | (14, 12) |
| SMPC | (14, 12) | (12, 25) | (7, 6) | (12, 25) | (7, 6) | | (10, 1) | (5, 26) |
| EVMC | (10, 1) | (27, 25) | (10, 1) | (14, 12) | (10, 1) | (25, 26) | | (14, 12) |
| CAUY | (7, 6) | (27, 25) | (15, 5) | (5, 26) | (10, 1) | (5, 26) | (7, 6) | |

**Table A5.** The aggregated values.

| | **RLVC** | **UCTD** | **FTLY** | **TFBY** |
|---|---|---|---|---|
| RLVC | | $\begin{bmatrix}\sqrt{0.31}e^{j2\pi.0.55},\\ \sqrt{0.19}e^{j2\pi.0.34},\\ \sqrt{0.51}e^{j2\pi.0.13}\end{bmatrix}$ | $\begin{bmatrix}\sqrt{0.32}e^{j2\pi.0.56},\\ \sqrt{0.19}e^{j2\pi.0.34},\\ \sqrt{0.50}e^{j2\pi.0.11}\end{bmatrix}$ | $\begin{bmatrix}\sqrt{0.28}e^{j2\pi.0.52},\\ \sqrt{0.16}e^{j2\pi.0.31},\\ \sqrt{0.58}e^{j2\pi.0.19}\end{bmatrix}$ |
| UCTD | $\begin{bmatrix}\sqrt{0.25}e^{j2\pi.0.50},\\ \sqrt{0.15}e^{j2\pi.0.31},\\ \sqrt{0.60}e^{j2\pi.0.19}\end{bmatrix}$ | | $\begin{bmatrix}\sqrt{0.36}e^{j2\pi.0.60},\\ \sqrt{0.22}e^{j2\pi.0.37},\\ \sqrt{0.42}e^{j2\pi.0.03}\end{bmatrix}$ | $\begin{bmatrix}\sqrt{0.36}e^{j2\pi.0.60},\\ \sqrt{0.22}e^{j2\pi.0.37},\\ \sqrt{0.42}e^{j2\pi.0.03}\end{bmatrix}$ |
| FTLY | $\begin{bmatrix}\sqrt{0.26}e^{j2\pi..51},\\ \sqrt{0.15}e^{j2\pi..31},\\ \sqrt{0.60}e^{j2\pi..21}\end{bmatrix}$ | $\begin{bmatrix}\sqrt{0.29}e^{j2\pi.0.54},\\ \sqrt{0.18}e^{j2\pi.0.33},\\ \sqrt{0.53}e^{j2\pi.0.13}\end{bmatrix}$ | | $\begin{bmatrix}\sqrt{0.36}e^{j2\pi.0.60},\\ \sqrt{0.22}e^{j2\pi.0.37},\\ \sqrt{0.42}e^{j2\pi.0.03}\end{bmatrix}$ |

**Table A5.** *Cont.*

| | **RLVC** | **UCTD** | **FTLY** | **TFBY** |
|---|---|---|---|---|
| TFBY | $\begin{bmatrix}\sqrt{0.30}e^{j2\pi..55},\\ \sqrt{0.19}e^{j2\pi..34},\\ \sqrt{0.51}e^{j2\pi..11}\end{bmatrix}$ | $\begin{bmatrix}\sqrt{0.29}e^{j2\pi.0.54},\\ \sqrt{0.18}e^{j2\pi.0.33},\\ \sqrt{0.53}e^{j2\pi.0.13}\end{bmatrix}$ | $\begin{bmatrix}\sqrt{0.34}e^{j2\pi.0.58},\\ \sqrt{0.20}e^{j2\pi.0.35},\\ \sqrt{0.47}e^{j2\pi.0.11}\end{bmatrix}$ | |
| EVBY | $\begin{bmatrix}\sqrt{0.19}e^{j2\pi..44},\\ \sqrt{0.12}e^{j2\pi..27},\\ \sqrt{0.70}e^{j2\pi..30}\end{bmatrix}$ | $\begin{bmatrix}\sqrt{0.20}e^{j2\pi.0.45},\\ \sqrt{0.13}e^{j2\pi.0.28},\\ \sqrt{0.67}e^{j2\pi.0.27}\end{bmatrix}$ | $\begin{bmatrix}\sqrt{0.18}e^{j2\pi.0.43},\\ \sqrt{0.11}e^{j2\pi.0.26},\\ \sqrt{0.71}e^{j2\pi.0.31}\end{bmatrix}$ | $\begin{bmatrix}\sqrt{0.21}e^{j2\pi.0.45},\\ \sqrt{0.12}e^{j2\pi.0.28},\\ \sqrt{0.68}e^{j2\pi.0.28}\end{bmatrix}$ |
| SMPC | $\begin{bmatrix}\sqrt{0.24}e^{j2\pi.0.48},\\ \sqrt{0.14}e^{j2\pi.0.30},\\ \sqrt{0.62}e^{j2\pi.0.22}\end{bmatrix}$ | $\begin{bmatrix}\sqrt{0.34}e^{j2\pi.0.58},\\ \sqrt{0.20}e^{j2\pi.0.35},\\ \sqrt{0.47}e^{j2\pi.0.11}\end{bmatrix}$ | $\begin{bmatrix}\sqrt{0.27}e^{j2\pi.0.51},\\ \sqrt{0.16}e^{j2\pi.0.31},\\ \sqrt{0.59}e^{j2\pi.0.20}\end{bmatrix}$ | $\begin{bmatrix}\sqrt{0.31}e^{j2\pi.0.55},\\ \sqrt{0.19}e^{j2\pi.0.34},\\ \sqrt{0.51}e^{j2\pi.0.13}\end{bmatrix}$ |
| EVMC | $\begin{bmatrix}\sqrt{0.29}e^{j2\pi.0.54},\\ \sqrt{0.18}e^{j2\pi.0.33},\\ \sqrt{0.53}e^{j2\pi.0.13}\end{bmatrix}$ | $\begin{bmatrix}\sqrt{0.34}e^{j2\pi.0.58},\\ \sqrt{0.20}e^{j2\pi.0.35},\\ \sqrt{0.47}e^{j2\pi.0.11}\end{bmatrix}$ | $\begin{bmatrix}\sqrt{0.23}e^{j2\pi.0.48},\\ \sqrt{0.14}e^{j2\pi.0.29},\\ \sqrt{0.64}e^{j2\pi.0.23}\end{bmatrix}$ | $\begin{bmatrix}\sqrt{0.27}e^{j2\pi.0.51},\\ \sqrt{0.16}e^{j2\pi.0.31},\\ \sqrt{0.59}e^{j2\pi.0.20}\end{bmatrix}$ |
| CAUY | $\begin{bmatrix}\sqrt{0.27}e^{j2\pi.0.51},\\ \sqrt{0.16}e^{j2\pi.0.31},\\ \sqrt{0.59}e^{j2\pi.0.20}\end{bmatrix}$ | $\begin{bmatrix}\sqrt{0.32}e^{j2\pi.0.56},\\ \sqrt{0.19}e^{j2\pi.0.34},\\ \sqrt{0.50}e^{j2\pi.0.11}\end{bmatrix}$ | $\begin{bmatrix}\sqrt{0.24}e^{j2\pi.0.48},\\ \sqrt{0.14}e^{j2\pi.0.30},\\ \sqrt{0.62}e^{j2\pi.0.22}\end{bmatrix}$ | $\begin{bmatrix}\sqrt{0.29}e^{j2\pi.0.54},\\ \sqrt{0.18}e^{j2\pi.0.33},\\ \sqrt{0.53}e^{j2\pi.0.13}\end{bmatrix}$ |
| | **EVBY** | **SMPC** | **EVMC** | **CAUY** |
| RLVC | $\begin{bmatrix}\sqrt{0.33}e^{j2\pi.0.58},\\ \sqrt{0.20}e^{j2\pi.0.36},\\ \sqrt{0.47}e^{j2\pi.0.08}\end{bmatrix}$ | $\begin{bmatrix}\sqrt{0.32}e^{j2\pi.0.56},\\ \sqrt{0.19}e^{j2\pi.0.34},\\ \sqrt{0.50}e^{j2\pi.0.11}\end{bmatrix}$ | $\begin{bmatrix}\sqrt{0.25}e^{j2\pi.0.50},\\ \sqrt{0.15}e^{j2\pi.0.31},\\ \sqrt{0.60}e^{j2\pi.0.19}\end{bmatrix}$ | $\begin{bmatrix}\sqrt{0.30}e^{j2\pi..55},\\ \sqrt{0.19}e^{j2\pi..34},\\ \sqrt{0.51}e^{j2\pi..11}\end{bmatrix}$ |
| UCTD | $\begin{bmatrix}\sqrt{0.26}e^{j2\pi..51},\\ \sqrt{0.15}e^{j2\pi..31},\\ \sqrt{0.60}e^{j2\pi..21}\end{bmatrix}$ | $\begin{bmatrix}\sqrt{0.34}e^{j2\pi.0.58},\\ \sqrt{0.20}e^{j2\pi.0.35},\\ \sqrt{0.47}e^{j2\pi.0.11}\end{bmatrix}$ | $\begin{bmatrix}\sqrt{0.21}e^{j2\pi.0.45},\\ \sqrt{0.12}e^{j2\pi.0.28},\\ \sqrt{0.68}e^{j2\pi.0.28}\end{bmatrix}$ | $\begin{bmatrix}\sqrt{0.34}e^{j2\pi.0.58},\\ \sqrt{0.20}e^{j2\pi.0.35},\\ \sqrt{0.47}e^{j2\pi.0.11}\end{bmatrix}$ |
| FTLY | $\begin{bmatrix}\sqrt{0.26}e^{j2\pi..51},\\ \sqrt{0.15}e^{j2\pi..31},\\ \sqrt{0.60}e^{j2\pi..21}\end{bmatrix}$ | $\begin{bmatrix}\sqrt{0.29}e^{j2\pi.0.54},\\ \sqrt{0.18}e^{j2\pi.0.33},\\ \sqrt{0.53}e^{j2\pi.0.13}\end{bmatrix}$ | $\begin{bmatrix}\sqrt{0.33}e^{j2\pi.0.58},\\ \sqrt{0.20}e^{j2\pi.0.36},\\ \sqrt{0.47}e^{j2\pi.0.08}\end{bmatrix}$ | $\begin{bmatrix}\sqrt{0.33}e^{j2\pi.0.58},\\ \sqrt{0.20}e^{j2\pi.0.36},\\ \sqrt{0.47}e^{j2\pi.0.08}\end{bmatrix}$ |
| TFBY | $\begin{bmatrix}\sqrt{0.26}e^{j2\pi..51},\\ \sqrt{0.15}e^{j2\pi..31},\\ \sqrt{0.60}e^{j2\pi..21}\end{bmatrix}$ | $\begin{bmatrix}\sqrt{0.24}e^{j2\pi.0.48},\\ \sqrt{0.14}e^{j2\pi.0.30},\\ \sqrt{0.62}e^{j2\pi.0.22}\end{bmatrix}$ | $\begin{bmatrix}\sqrt{0.24}e^{j2\pi.0.48},\\ \sqrt{0.14}e^{j2\pi.0.30},\\ \sqrt{0.62}e^{j2\pi.0.22}\end{bmatrix}$ | $\begin{bmatrix}\sqrt{0.22}e^{j2\pi..47},\\ \sqrt{0.13}e^{j2\pi..29},\\ \sqrt{0.65}e^{j2\pi..25}\end{bmatrix}$ |
| EVBY | | $\begin{bmatrix}\sqrt{0.24}e^{j2\pi.0.48},\\ \sqrt{0.14}e^{j2\pi.0.30},\\ \sqrt{0.62}e^{j2\pi.0.22}\end{bmatrix}$ | $\begin{bmatrix}\sqrt{0.24}e^{j2\pi.0.48},\\ \sqrt{0.14}e^{j2\pi.0.30},\\ \sqrt{0.62}e^{j2\pi.0.22}\end{bmatrix}$ | $\begin{bmatrix}\sqrt{0.22}e^{j2\pi..47},\\ \sqrt{0.13}e^{j2\pi..29},\\ \sqrt{0.65}e^{j2\pi..25}\end{bmatrix}$ |
| SMPC | $\begin{bmatrix}\sqrt{0.27}e^{j2\pi.0.51},\\ \sqrt{0.16}e^{j2\pi.0.31},\\ \sqrt{0.59}e^{j2\pi.0.20}\end{bmatrix}$ | | $\begin{bmatrix}\sqrt{0.26}e^{j2\pi..51},\\ \sqrt{0.15}e^{j2\pi..31},\\ \sqrt{0.60}e^{j2\pi..21}\end{bmatrix}$ | $\begin{bmatrix}\sqrt{0.32}e^{j2\pi.0.56},\\ \sqrt{0.19}e^{j2\pi.0.34},\\ \sqrt{0.50}e^{j2\pi.0.11}\end{bmatrix}$ |
| EVMC | $\begin{bmatrix}\sqrt{0.19}e^{j2\pi..44},\\ \sqrt{0.12}e^{j2\pi..27},\\ \sqrt{0.70}e^{j2\pi..30}\end{bmatrix}$ | $\begin{bmatrix}\sqrt{0.28}e^{j2\pi.0.52},\\ \sqrt{0.16}e^{j2\pi.0.31},\\ \sqrt{0.58}e^{j2\pi.0.19}\end{bmatrix}$ | | $\begin{bmatrix}\sqrt{0.28}e^{j2\pi.0.52},\\ \sqrt{0.16}e^{j2\pi.0.31},\\ \sqrt{0.58}e^{j2\pi.0.19}\end{bmatrix}$ |
| CAUY | $\begin{bmatrix}\sqrt{0.21}e^{j2\pi.0.45},\\ \sqrt{0.12}e^{j2\pi.0.28},\\ \sqrt{0.68}e^{j2\pi.0.28}\end{bmatrix}$ | $\begin{bmatrix}\sqrt{0.25}e^{j2\pi.0.50},\\ \sqrt{0.15}e^{j2\pi.0.31},\\ \sqrt{0.60}e^{j2\pi.0.19}\end{bmatrix}$ | $\begin{bmatrix}\sqrt{0.27}e^{j2\pi.0.51},\\ \sqrt{0.16}e^{j2\pi.0.31},\\ \sqrt{0.59}e^{j2\pi.0.20}\end{bmatrix}$ | |

**Table A6.** The defuzzified values.

| | **RLVC** | **UCTD** | **FTLY** | **TFBY** | **EVBY** | **SMPC** | **EVMC** | **CAUY** |
|---|---|---|---|---|---|---|---|---|
| RLVC | 0.000 | 1.741 | 1.776 | 1.604 | 1.811 | 1.776 | 1.468 | 1.674 |
| UCTD | 1.474 | 0.000 | 1.920 | 1.920 | 1.535 | 1.846 | 1.311 | 1.846 |
| FTLY | 1.540 | 1.649 | 0.000 | 1.920 | 1.509 | 1.638 | 1.811 | 1.778 |

**Table A6.** *Cont.*

| | RLVC | UCTD | FTLY | TFBY | EVBY | SMPC | EVMC | CAUY |
|---|---|---|---|---|---|---|---|---|
| TFBY | 1.674 | 1.646 | 1.846 | 0.000 | 1.509 | 1.421 | 1.437 | 1.377 |
| EVBY | 1.252 | 1.305 | 1.216 | 1.316 | 0.000 | 1.437 | 1.441 | 1.373 |
| SMPC | 1.437 | 1.846 | 1.570 | 1.710 | 1.570 | 0.000 | 1.509 | 1.743 |
| EVMC | 1.625 | 1.846 | 1.405 | 1.537 | 1.246 | 1.588 | 0.000 | 1.588 |
| CAUY | 1.570 | 1.776 | 1.443 | 1.638 | 1.344 | 1.479 | 1.579 | 0.000 |

**Table A7.** The normalized relation matrix.

| | RLVC | UCTD | FTLY | TFBY | EVBY | SMPC | EVMC | CAUY |
|---|---|---|---|---|---|---|---|---|
| RLVC | 0.000 | 0.147 | 0.150 | 0.135 | 0.153 | 0.150 | 0.124 | 0.141 |
| UCTD | 0.124 | 0.000 | 0.162 | 0.162 | 0.130 | 0.156 | 0.111 | 0.156 |
| FTLY | 0.130 | 0.139 | 0.000 | 0.162 | 0.127 | 0.138 | 0.153 | 0.150 |
| TFBY | 0.141 | 0.139 | 0.156 | 0.000 | 0.127 | 0.120 | 0.121 | 0.116 |
| EVBY | 0.106 | 0.110 | 0.103 | 0.111 | 0.000 | 0.121 | 0.122 | 0.116 |
| SMPC | 0.121 | 0.156 | 0.132 | 0.144 | 0.132 | 0.000 | 0.127 | 0.147 |
| EVMC | 0.137 | 0.156 | 0.119 | 0.130 | 0.105 | 0.134 | 0.000 | 0.134 |
| CAUY | 0.132 | 0.150 | 0.122 | 0.138 | 0.113 | 0.125 | 0.133 | 0.000 |

**Table A8.** Total relation matrix.

| | RLVC | UCTD | FTLY | TFBY | EVBY | SMPC | EVMC | CAUY |
|---|---|---|---|---|---|---|---|---|
| RLVC | 1.813 | 2.125 | 2.039 | 2.097 | 1.937 | 2.034 | 1.918 | 2.059 |
| UCTD | 1.928 | 2.002 | 2.053 | 2.123 | 1.922 | 2.043 | 1.912 | 2.074 |
| FTLY | 1.929 | 2.120 | 1.909 | 2.118 | 1.916 | 2.025 | 1.941 | 2.065 |
| TFBY | 1.815 | 1.985 | 1.916 | 1.845 | 1.796 | 1.884 | 1.795 | 1.909 |
| EVBY | 1.562 | 1.715 | 1.636 | 1.699 | 1.458 | 1.648 | 1.570 | 1.668 |
| SMPC | 1.860 | 2.064 | 1.961 | 2.037 | 1.859 | 1.839 | 1.859 | 1.997 |
| EVMC | 1.804 | 1.990 | 1.879 | 1.952 | 1.770 | 1.886 | 1.678 | 1.915 |
| CAUY | 1.797 | 1.981 | 1.877 | 1.954 | 1.773 | 1.875 | 1.792 | 1.792 |

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