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ORIGINAL RESEARCH

Modified interval EDAS approach for the multi-criteria ranking problem in banking sector of Iran

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Abstract
In this study an important real-world multi-criteria problem in banking sector is focused. The aim of this problem is to rank some branches of a bank in Iran subject to some economic criteria under interval type uncertainty. The problem is complex because of its multi-criteria nature and also its interval type data. A new solution procedure is proposed for this problem. In the proposed procedure first the criteria are weighted as interval values according to an effective method which combines experts' opinions and the Shannon's entropy approach. Then, as a novelty, the classical EDAS multi-criteria solution approach is newly modified for interval type data in order to overcome the shortcomings of the interval EDAS approaches of the literature. Finally, using the data obtained from the case study, an extensive computational study is performed by the proposed solution procedure. The sensitivity of the proposed approach also is analyzed by changing its parameters and a comparative study was done by some other approaches.

Keywords Banks ranking problem · Multi-criteria optimization · EDAS approach · Interval number

1 Introduction

As banking sector plays a crucial role in developing the countries, recently the ranking problem of this sector has become one of the most important optimization problems. This problem is a significant bridge between economics and mathematical sciences. In order to rank a set of given banks, a set of evaluating criteria should be considered. The criteria such as income, cost, efficiency, etc. are of main criteria to evaluate banking sector. Due to the variety of these criteria in most of cases this ranking problem is defined as a multi-criteria decision making problem. The difficulty of this problem arises from some aspects e.g. (1) criteria selection, (2) data collection, (3) uncertain nature of the data, (4) criteria weights determination, (5) multi-criteria solution approach selection, etc.

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First the criteria selection which is the basis of the ranking problem of banking sector is reviewed here. In the literature, many of the studies consider some traditional criteria such as return on asset, liquidity, capital, etc. to evaluate the banking sector. The most significant studies considering these factors are Kumbirai and Webb (2010), Said and Tumin (2011) and Bičo and Ganić (2012), etc. Further than the traditional criteria, a set of criteria named CAMEL criteria are used to evaluate banking sector (these criteria will be more detailed in the next section of this paper). These criteria are more detailed than the traditional set of criteria and considered by many studies of the literature. The studies of Wang et al. (2012, 2013), Maghyereh and Awartani (2014), Betz et al. (2014), Wanke et al. (2016) and Gavurova et al. (2017), etc. apply the CAMEL based criteria for assessing banking sector.

In addition to criteria used to evaluate banking sector, the multi-criteria approaches applied to perform the evaluation procedure are also of interest. There is a variety of such solution approaches in the literature of operations research and optimization theory. As the most famous and popular multi-criteria solution approaches, the approaches e.g. AHP, TOPSIS, ELECTRE, PROMETHEE, SAW, MULTIMOORA, etc. can be mentioned (see Hadi-Vencheh 2014; Hadi-Vencheh and Mohamadghasemi 2015; Chen et al.

2018a, b; Qiao et al. 2019; Zhang et al. 2018, etc.). The SAW method was used by Niroomand et al. (2019a, b) for credit ranking problem of the countries. This problem is similar to the banks ranking problem as some of the criteria in both are the same. Kosmidou and Zopounidis (2008) applied the PROMETHEE approach to evaluate the performance of commercial and cooperative banks. The Lithuanian banks are analyzed and evaluated by Brauers et al. (2014) using CAMEL based criteria and MULTIMOORA solution approach. The assessment problem of banks also was considered by Ginevičius and Podviezko (2013). They applied the multi-criteria solution approaches such as SAW, TOPSIS, PROMETHEE, etc. to perform their analysis. Bilbao-Terol et al. (2014) used TOPSIS for assessing the sustainability of government bond funds. Doumpos and Zopounidis (2010) introduced a multi-criteria decision support system for bank rating. Hemmati et al. (2013) applied DEA and TOPSIS approaches to measure the relative performance of banking industry. Mandic et al. (2014) used fuzzy AHP and TOPSIS approaches for analyzing the financial parameters of Serbian banks. On the other hand hybrid versions of the classical MCDM approaches have been used in the studies related to banking sector. A fuzzy MCDM approach combining AHP approach with SAW, TOPSIS, and VIKOR approaches was introduced by Wu et al. (2009) for evaluating banking performance. Shaverdi et al. (2011) combined fuzzy MCDM with BSC approach in performance evaluation of Iranian private banking sector. Beheshtinia and Omidi (2017) proposed a hybrid MCDM approach for performance evaluation in the banking industry. They integrated AHP and modified digital logic approaches with TOPSIS and VIKOR.

In this study a typical multi-criteria decision making problem is considered to rank some bank branches in Iran. The contribution of the study is highlighted by the followings,

- The criteria of this problem are selected according to the strategy of CAMEL criteria by the experts of the bank.
- The complexity of the problem is of high degree as the decision matrix of the problem is constructed in an uncertain environment with interval type values.
- A novel weight determination approach which integrates Shannon's entropy method and opinions of the experts is proposed to find the importance weights of the criteria of the problem in interval form.
- In order to solve the problem and rank the bank branches, a novel modification of the EDAS multi-criteria solution approach [first introduced by Keshavarz Ghorabaee et al. (2015)] is proposed. This modification considers the interval EDAS approach proposed by Ren and Toniolo (2018) and fixes its core weaknesses.

At the end, the case study is solved by the proposed interval EDAS approach and its performance and sensitivity analysis are studied in details. Also a comparative study with the approaches of the literature is done.

The remainder of this paper is organized by four sections. Section 2, describes the problem characteristics, its criteria, and its alternatives. Section 3, represents the proposed criteria weighting approach and the proposed interval EDAS multi-criteria solution approach. Section 4, deals with the computational study of the proposed solution approach and its sensitivity analysis. The paper ends with Sect. 5 which represents some concluding remarks.

2 The multi-criteria assessment problem of banking sector

The multi-criteria assessment problem of this study is developed for the Keshavarzi bank of Iran. For this aim some branches of this bank in a province of Iran is considered and ranked based on their performances in some selected criteria over the past years. In the rest of this section, the problem is described by presenting the details of the branches, the selected criteria, the decision matrix, etc.

2.1 The branches of Keshavarzi bank

In this study 51 branches of Keshavarzi bank in Sistan-Baloochestan province of Iran are considered to be assessed and ranked according to some given criteria. These branches are shown by Table 1.

2.2 Criteria selection

In order to assess and rank the bank branches of previous sub-section, some criteria should be selected. For this aim, first the important criteria of the literature of banking related researches is reviewed. In the literature, the most important criteria are the CAMEL based criteria. The CAMEL methodology is a well-known method to select the important criteria for assessing banking sector. This methodology has been used to perform many researches such as Cole and Gunther (1995, 1998), Zhao et al. (2009), Secme et al. (2009), Doumpos and Zopounidis (2010), Wang et al. (2012, 2013), Maghyereh and Awartani (2014), Betz et al. (2014), Wanke et al. (2016) and Gavurova et al. (2017), etc. In this method four main criteria of capital, asset quality, management, earnings, and liquidity are considered. Obviously, each of these criteria could be represented by one or more detailed criteria. In this study, considering the abovementioned studies of the literature and also the experts introduced by Keshavarzi bank the criteria of Table 2 are selected. In this table also each criteria is explained. It is

Table 1 The branches of the Keshavarzi bank in Sistan-Baloochestan province of Iran

Branch code	Detailed name	Branch code	Detailed name
B-1	Zahedan—Ziba City	B-27	Pishin
B-2	Zabol—Yaghoob Leys	B-28	Jakigoor
B-3	Iranshahr	B-29	Parood
B-4	Iranshaht—Tarebar Square	B-30	Zaboli
B-5	Chabahar	B-31	Jalegh
B-6	Khash	B-32	Saravan—Tarebar Square
B-7	Khash—Emam Khomeyni Street	B-33	Bent
B-8	Zabol	B-34	Nobandiyan
B-9	Ramshar—Zahak Four Way	B-35	Konarak County
B-10	Zahedan	B-36	Dalgan
B-11	Mirjaveh	B-37	Ashar
B-12	Saravan	B-38	Bonjar
B-13	Sooran	B-39	Hamoon
B-14	Sarbaz	B-40	Jazink
B-15	Nasirabad	B-41	Zahedan—Shareeati Street
B-16	Nikshahr	B-42	Zahedan—Rasooli Four Way
B-17	Espakeh	B-43	Chabahar—Shilat
B-18	Fanooj	B-44	Chabahar—Rooz Bazaar
B-19	Hirmand	B-45	Danesh Three Way
B-20	Ghasreghand	B-46	Chabahar—Free Zone
B-21	Sarbook	B-47	Zabol—Jahad Square
B-22	Zahak	B-48	Lale
B-23	Mohammadabad	B-49	zabol—Bazaar
B-24	Zahedan—Jahade Keshavarzi Organization	B-50	Taftan
B-25	Zahedan—Emam Khomeyni Street	B-51	Adimi
B-26	Rask		

Table 2 The criteria selected for the proposed multi-criteria ranking problem

Criterion code	Description	Type
C-1	Total amount of deposits	Positive
C-2	Total amount of low-interest deposits	Positive
C-3	Ratio of C-2 to C-1	Positive
C-4	Total amount of loans	Positive
C-5	Ratio of the amount of loans which their due is passed to C-4	Negative
C-6	Total amount of interest paid to the deposits	Negative
C-7	Total amount of operational expenses	Negative
C-8	Total amount of expenses	Negative
C-9	Ratio of C-7 to C-8	Negative
C-10	Total amount of interest earned by the loans	Positive
C-11	Total amount of wage earned for the provided banking services	Positive
C-12	Total amount of incomes (C-11 and C-12)	Positive
C-13	Ratio of C-12 to C-8	Positive
C-14	The amount of capital borrowed from the central branch of the bank	Negative
C-15	Liquidity	Positive
C-16	Marginal benefit (the difference between rate of C-10 and C-6	Positive

notable to mention that for a positive criterion higher values are favored and for a negative criterion lower values are favored.

2.3 Decision matrix

The decision matrix of the presented multi-criteria problem of the above sub-sections is a matrix with m rows and n columns. The notation m shows the number of branches of the bank and the notation n shows the number of criteria. For the case of this study $m = 51$ and $n = 16$. A parametric presentation of this decision matrix is as follow,

$$A = \begin{bmatrix} \tilde{a}_{11} & \cdots & \tilde{a}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{a}_{m1} & \cdots & \tilde{a}_{mn} \end{bmatrix} \quad (1)$$

where $\tilde{a}_{ij} = \left[a^l_{ij}, a^u_{ij}\right]$ denotes the interval value of the performance of branch i in criterion j.

In order to cope with the uncertainty which appear in real life problems, and also not only considering the recent year performance for assessing the branches, the values of the decision matrix of the problem is considered to be of interval numbers. In order to obtain the interval values of the decision matrix, the performances of the branches over last 5 years are considered and according to these performances the minimum and maximum values for the performance of each branch in each criterion are obtained and the associated interval value is estimated easily. The performance values are obtained from the central branch of the Keshavarzi bank in Sistan-Baloochestan province of Iran. The decision matrix is represented in the Appendix of the paper.

3 Solution methodology

As mentioned earlier, the assessment problem of this study aims to evaluate and rank some branches of the Keshavarzi bank of Iran according to some given criteria with interval values. For this aim an assessment methodology consisting of below phases is proposed in this section,

- **Phase 1:** In this phase an approach is proposed to calculate the importance weight of each criterion.
- **Phase 2:** In this phase a multi-criteria solution approach is proposed to evaluate the branches and rank them. For this aim, the EDAS approach (Keshavarz Ghorabaee et al. 2015) of the literature is modified by a new method for interval data.

These phases are explained in the rest of this section.

3.1 Phase 1: Weight determination

Usually, the importance weights of the criteria are different from decision maker (DM) point of view. Therefore, these weight values should be determined prior to evaluating the branches. The weight determination methods are classified in three general groups, (1) using experts' ideas as an exogenous method (see the study of Krylovas et al. 2014), (2) using decision matrix and applying optimization techniques for this aim as endogenous methods (see the studies of Hadi-Vencheh 2010; Niroomand et al. 2018;; Niroomand et al. 2019a, b, etc.), and (3) using a mix of exogenous and endogenous methods.

As the data of the decision matrix of this study is of interval values, it would be more effective to determine the importance weights of the criteria as interval values too. For this aim, in this study a mix of exogenous and endogenous methods is proposed to obtain the importance weights. The exogenous method uses the ideas of the experts of the field to obtain the weights (called external weight). The endogenous method uses the data of the decision matrix to obtain the weights (called internal weights). The obtained external and internal weights are used together to find the final importance weights. This procedure is represented by the flowchart of Fig. 1.

In order to obtain the external weights a typical expert examination method is used here. The following steps describe this method.

Step 1. A number of experts (say s) from the banking sector (from the bank under study) are selected.

Step 2. The experts are requested to score the importance of each criterion from 1 to 10 where 10 means the highest importance.

Step 3. The external importance weight of each criterion (denoted by w^{ex}_j) is calculated by $w^{ex}_j = \frac{\sum_{p=1}^{s} sc_{pj}}{\sum_{p=1}^{s}\sum_{j=1}^{n} sc_{pj}}$ (where sc_{pj} demonstrates the score given by the expert p to the criterion j. Then).

The internal weights of the criteria are determined by a well-known approach in this sub-section. For this aim, an effective method of the literature say interval Shannon's entropy introduced by Lotfi and Fallahnejad (2010)

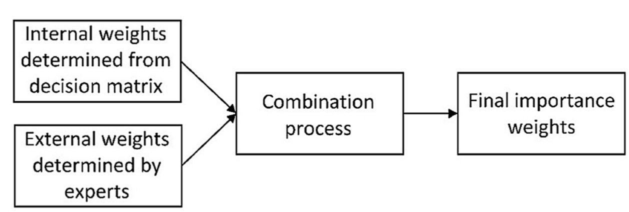

Fig. 1 Summary of the proposed importance weight determination procedure

is applied to find these importance weights endogenously. The steps of this method are given below,

Step 1. The decision matrix A is normalized by the following relations,

$$r^l_{ij} = \frac{a^l_{ij}}{\sum_{k=1}^{m} a^l_{kj}} \quad \forall i,j \tag{2}$$

$$r^u_{ij} = \frac{a^u_{ij}}{\sum_{k=1}^{m} a^u_{kj}} \quad \forall i,j \tag{3}$$

Step 2. The lower bound (h^l_j) and the upper bound (h^u_i) of the interval entropy are calculated as follow,

$$h^l_j = \min\left\{ -h_0 \sum_{i=1}^{m} r^l_{ij} \ln r^l_{ij}, -h_0 \sum_{i=1}^{m} r^u_{ij} \ln r^u_{ij} \right\} \quad \forall j \tag{4}$$

$$h^u_j = \max\left\{ -h_0 \sum_{i=1}^{m} r^l_{ij} \ln r^l_{ij}, -h_0 \sum_{i=1}^{m} r^u_{ij} \ln r^u_{ij} \right\} \quad \forall j \tag{5}$$

where $h_0 = (\ln m)^{-1}$, $r^l_{ij} = 0 \Rightarrow r^l_{ij} \ln r^l_{ij} = 0$, and $r^u_{ij} = 0 \Rightarrow r^u_{ij} \ln r^u_{ij} = 0$.

Step 3. The interval value for degree of diversification of criterion j ($\left[d^l_j, d^u_j\right]$) is obtained as follow,

$$\left[d^l_j, d^u_j\right] = \left[1 - h^u_j, 1 - h^l_j\right] \quad \forall j \tag{6}$$

Step 4. The internal interval weight of each criterion (denoted by $\left[w^{in,l}_j, w^{in,u}_j\right]$) is calculated as follow,

$$\left[w^{in,l}_j, w^{in,u}_j\right] = \left[\frac{d^l_j}{\sum_{k=1}^{n} d^u_k}, \frac{d^u_j}{\sum_{k=1}^{n} d^l_k}\right] \quad \forall j \tag{7}$$

The final importance weights in an interval form (denoted by $\left[w^l_j, w^u_j\right]$) are obtained from a combination process which mixes the obtained internal and external weights. For this aim a summation operator is proposed which sums up the weighted internal and external weights. The formula for this process is $\left[w^l_j, w^u_j\right] = \lambda w^{ex}_j + (1-\lambda)\left[w^{in,l}_j, w^{in,u}_j\right]$ which is summarized as $\left[w^l_j, w^u_j\right] = \left[(1-\lambda)w^{in,l}_j + \lambda w^{ex}_j, (1-\lambda)w^{in,u}_j + \lambda w^{ex}_j\right]$. The value of λ is between 0 and 1. It is determined by decision maker and shows the importance of the internal and external weights.

3.2 Phase 2: Interval EDAS approach

In this section a new modification of the EDAS approach for interval type data is proposed to solve the problem of Sect. 2. In this section, first the classical EDAS approach is explained and then the proposed new interval EDAS approach is presented.

The EDAS approach first was introduced by Keshavarz Ghorabaee et al. (2015). This method ranks the alternatives based on the distance from the average solution (AV). To achieve such ranking the measures like positive distance from average (PDA) and negative distance from average (NDA) are defined for each alternative which reflect the difference of the alternatives from the AV. For details of the EDAS approach, the study of Keshavarz Ghorabaee et al. (2015) can be referred.

In the case of uncertain decision matrix, the classical EDAS approach has been extended in many studies such as Ghorabaee et al. (2017), Kahraman et al. (2017) and Ren and Toniolo (2018), etc.

In the rest of this section, we propose an extension of the classical EDAS approach to uncertain environment with interval type data. For this aim a procedure is proposed in order to convert all steps of the classical EDAS approach to their equivalent interval form. This procedure uses some simple concepts of interval numbers theory while it modifies the interval EDAS approach introduced by Ren and Toniolo (2018). This new interval EDAS approach is summarized in the following steps where some of its steps are similar to Ren and Toniolo (2018).

Step 1. Define the alternatives (indexed by $i \in \{1,2,\ldots,m\}$), the criteria (indexed by $j \in \{1,2,\ldots,n\}$), and the interval decision matrix $A = \left[\left[a^l_{ij}, a^u_{ij}\right]\right]_{m\times n}$.

Step 2. Normalize the decision matrix as $R = \left[\left[r^l_{ij}, r^u_{ij}\right]\right]_{m\times n}$ using the following formulas. These formulas are also used by Ren and Toniolo (2018).

$$\left[r^l_{ij}, r^u_{ij}\right] = \left[\frac{a^l_{ij} - \min_i\left\{a^l_{ij}\right\}}{\max_i\left\{a^u_{ij}\right\} - \min_i\left\{a^l_{ij}\right\}}, \frac{a^u_{ij} - \min_i\left\{a^l_{ij}\right\}}{\max_i\left\{a^u_{ij}\right\} - \min_i\left\{a^l_{ij}\right\}}\right] \text{for positive criteria} \tag{8}$$

$$\left[r_{ij}^l, r_{ij}^u\right] = \left[\frac{\max_i \left\{a_{ij}^u\right\} - a_{ij}^u}{\max_i \left\{a_{ij}^u\right\} - \min_i \left\{a_{ij}^l\right\}}, \frac{\max_i \left\{a_{ij}^u\right\} - a_{ij}^l}{\max_i \left\{a_{ij}^u\right\} - \min_i \left\{a_{ij}^l\right\}}\right] \text{for negative criteria} \tag{9}$$

Step 3. The average solution of each criterion (AV) should be calculated in this step. The interval EDAS approach proposed by Ren and Toniolo (2018) applies the formula $AV_j = \frac{\sum_{i=1}^m \left(r_{ij}^l + r_{ij}^u\right)}{2m}$. This formula gives a crisp value for each average solution. Instead for this crisp formula, a new formula is proposed here to obtain interval value for the average solutions. This formula is as follow,

$$\left[AV_j^l, AV_j^u\right] = \left[\frac{\sum_{i=1}^m r_{ij}^l}{m}, \frac{\sum_{i=1}^m r_{ij}^u}{m}\right] \tag{10}$$

Step 4. According to Ren and Toniolo (2018) the interval values for positive and negative distances from the average ($\left[PDA_{ij}^l, PDA_{ij}^u\right]$ and $\left[NDA_{ij}^l, NDA_{ij}^u\right]$) is calculated for each alternative in each criterion by the following formulas.

$$\left[PDA_{ij}^l, PDA_{ij}^u\right] = \left[\max\left\{0, \min\left\{\frac{r_{ij}^l - AV_j^l}{AV_j^l}, \frac{r_{ij}^u - AV_j^u}{AV_j^u}\right\}\right\}, \max\left\{0, \max\left\{\frac{r_{ij}^l - AV_j^l}{AV_j^l}, \frac{r_{ij}^u - AV_j^u}{AV_j^u}\right\}\right\}\right] \quad \forall i,j \tag{11}$$

$$\left[NDA_{ij}^l, NDA_{ij}^u\right] = \left[\max\left\{0, \min\left\{\frac{AV_j^l - r_{ij}^l}{AV_j^l}, \frac{AV_j^u - r_{ij}^u}{AV_j^u}\right\}\right\}, \max\left\{0, \max\left\{\frac{AV_j^l - r_{ij}^l}{AV_j^l}, \frac{AV_j^u - r_{ij}^u}{AV_j^u}\right\}\right\}\right] \quad \forall i,j \tag{12}$$

Step 5. The weighted sum of positive and negative distances ($\left[SP_i^l, SP_i^u\right]$ and $\left[SN_i^l, SN_i^u\right]$) for each alternative is calculated by the following formulas.

$$\left[SP_i^l, SP_i^u\right] = \sum_{j=1}^n \left[w_j^l, w_j^u\right]\left[PDA_{ij}^l, PDA_{ij}^u\right] = \left[\sum_{j=1}^n w_j^l PDA_{ij}^l, \sum_{j=1}^n w_j^u PDA_{ij}^u\right] \quad \forall i \tag{13}$$

$$\left[SN_i^l, SN_i^u\right] = \sum_{j=1}^n \left[w_j^l, w_j^u\right]\left[NDA_{ij}^l, NDA_{ij}^u\right] = \left[\sum_{j=1}^n w_j^l NDA_{ij}^l, \sum_{j=1}^n w_j^u NDA_{ij}^u\right] \quad \forall i \tag{14}$$

The difference of these formulas with those of Ren and Toniolo (2018) is that, here the weights of criteria is of interval type values. So that, using concepts of interval numbers, the interval weights are multiplied by the obtained distances of Step 4.

Step 6. The weighted sum distances of Sect. 5 is normalized by the following equations proposed by Ren and Toniolo (2018).

$$\left[NSP_i^l, NSP_i^u\right] = \left[\frac{SP_i^l}{\max_i \left\{SP_i^u\right\}}, \frac{SP_i^u}{\max_i \left\{SP_i^u\right\}}\right] \quad \forall i \tag{15}$$

$$\left[NSN_i^l, NSN_i^u\right] = \left[\frac{\max_i \left\{SN_i^u\right\} - SN_i^u}{\max_i \left\{SN_i^u\right\}}, \frac{\max_i \left\{SN_i^u\right\} - SN_i^l}{\max_i \left\{SN_i^u\right\}}\right] \quad \forall i \tag{16}$$

In these formulas $\left[NSP_i^l, NSP_i^u\right]$ is the interval value of the normalized weighted sum of positive distance for alternative i, and $\left[NSN_i^l, NSN_i^u\right]$ is the interval value of the normalized weighted sum of negative distance for alternative i.

Step 7. The interval value for appraisal score of each alternative ($\left[AS_i^l, AS_i^u\right]$) is calculated by the following formula (Ren and Toniolo 2018).

$$\left[AS_i^l, AS_i^u\right] = \left[\frac{NSP_i^l + NSN_i^l}{2}, \frac{NSP_i^u + NSN_i^u}{2}\right] \quad \forall i \tag{17}$$

Step 8. According to Ren and Toniolo (2018) the interval appraisal scores are compared by an interval comparison method proposed by Shui and Li (2003). In this method the probability of the order relation of two interval appraisal scores is defined as follow,

$$P_{ik} = P\left(\left[AS_i^l, AS_i^u\right] \geq \left[AS_k^l, AS_k^u\right]\right) = \max\left\{1 - \frac{AS_k^u - AS_i^l}{AS_i^u - AS_i^l + AS_k^u - AS_k^l}, 0\right\} \quad (18)$$

So that, P_{ik} is the probability that the interval $\left[AS_i^l, AS_i^u\right]$ be greater than or equal to the interval $\left[AS_k^l, AS_k^u\right]$. Therefore, the probability matrix of the alternatives is defined as $P = \left[P_{ik}\right]_{m\times m}$, where its values are calculated by formula (18). Then, the integrated priority of each alternative (shown by IP_i) is calculated by the following equation.

$$IP_i = \frac{\sum_{k=1}^{m} P_{ik} + \frac{m}{2} - 1}{m(m-1)} \quad \forall i \quad (19)$$

The alternatives are ranked according to the decreasing order of IP_i values. It means that the smaller IP_i value, the worse the alternative is.

The main weakness of the comparison procedure of Ren and Toniolo (2018) is that the IP_i values may result in wrong ranking. For this aim a simple numerical example is given here. If three intervals of $\left[AS_1^l, AS_1^u\right] = [0.04,0.12]$, $\left[AS_2^l, AS_2^u\right] = [0.46,0.60]$, and $\left[AS_3^l, AS_3^u\right] = [0.41,0.42]$ are considered, using the method of Ren and Toniolo (2018) the integrated priority values of $IP_1 = 0.0098$, $IP_2 = 0.0113$, and $IP_3 = 0.0115$ are calculated. According to the integrated priority values the ranking of 3, 2, and 1 is obtained while the intervals can be easily compared directly and the order of 2, 3, and 1 is obtained.

In order to overcome the above-mentioned weakness of the method of Ren and Toniolo (2018) a new comparison procedure is proposed here. A new probability relation is defined as below,

$$P_{ik} = P\left(\left[AS_i^l, AS_i^u\right] \geq \left[AS_k^l, AS_k^u\right]\right) = \frac{AS_k^u - AS_i^l}{AS_{\max}^u - AS_{\min}^l} \quad (20)$$

where, $AS_{min}^l = \min_i\left\{AS_i^l\right\}$ and $AS_{max}^u = \max_i\left\{AS_i^u\right\}$. Actually this probability value is a relative distance of the intervals. Then, the integrated priority of each alternative is calculated by the following equation.

$$IP_i = \sum_{k=1}^{m} P_{ik} \quad \forall i \quad (21)$$

Using Eqs. (20) and (21) for the above-mentioned intervals of $\left[AS_1^l, AS_1^u\right] = [0.04,0.12]$, $\left[AS_2^l, AS_2^u\right] = [0.46,0.60]$, and $\left[AS_3^l, AS_3^u\right] = [0.41,0.42]$, the integrated priority values of $IP_1 = -0.9821$, $IP_2 = 1.5893$, and $IP_3 = 0.626$ are calculated. According to the integrated priority values, the ranking of 2, 3, and 1 is obtained which is the same with the case that the intervals are compared directly and the order of 2, 3, and 1 is obtained.

The solution methodology proposed in this section is summarized in the flowchart of Fig. 2.

3.3 Advantages of the proposed solution methodology

Some important advantages of the proposed solution methodology is summarized as below,

- Interval value based decision matrix is considered.
- Interval value based importance weights are obtained.
- The decision matrix is considered for criteria weights determination.
- Experts' ideas are considered for criteria weights determination.
- Ranking procedure is done based on interval calculations.
- Comparing to the literature, a more logical ranking step is proposed.

Furthermore, a comparison of the proposed solution approach and other ranking problems of banking sector is presented by Table 3, where the completeness of the proposed approach can be realized easily.

4 Results and discussion

The proposed interval EDAS approach of Sect. 3 is applied for a simple example and the case study explained by Sect. 2. The required calculations are done by MS Excel software.

4.1 A simple example

A simple example with three alternatives and three criteria are used here to show the calculations of the phases of the proposed solution methodology. In this example all criteria are of positive type. The calculations are detailed in Tables 4 and 5 by showing the formula used in each step of the calculations.

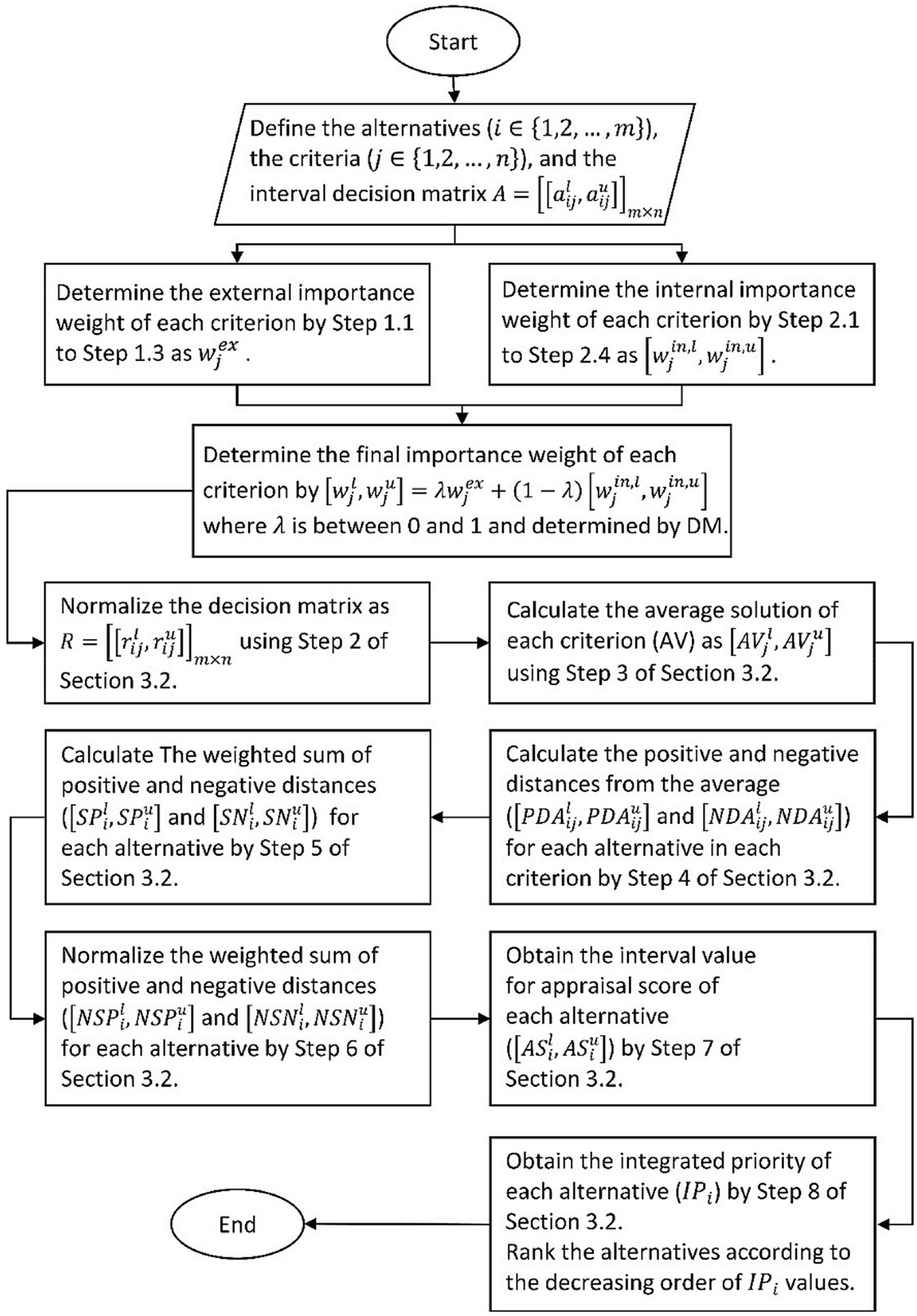

Fig. 2 The flowchart of the proposed solution methodology

4.2 Case study

In order to apply the proposed Interval EDAS approach to the case study of Sect. 2, the following values are considered for the parameters of this approach.

- The number of alternatives (branches of bank) is 51 ($m = 51$).
- The number of criteria is 16 ($n = 16$).
- The number of experts for determining the external weights is 10 ($s = 10$).
- In order to calculate final interval weights, the importance of the external weights is set to 0.8, therefore, the importance of the internal weights is 0.2 ($\lambda = 0.8$).

The results obtained for the weight determination stage is calculated by the proposed approach of Sect. 3.1 and the

Table 3 Comparison of the proposed solution methodology and the ranking problems of banking sector of the literature

Study	Uncertainty type			Importance weight determination		Sensitivity analysis	Case study
	Interval	Fuzzy	Others	Internal	External		
Aleskerov et al. (2004)					•		•
Minh et al. (2012)							
Jakšić et al. (2011)					•		•
				•		•	•
Chitnis and Vaidya (2016)				•		•	•
Esmaili Dooki et al. (2017)		•			•		•
Proposed approach of this study	•			•	•	•	•

Table 4 Phase 1 calculations for the example

Alternative	Decision matrix ($\left[a_{ij}^{l}, a_{ij}^{u}\right]$)			Comment
	C1 ($j = 1$)	C2 ($j = 2$)	C3 ($j = 3$)	
A1 ($i = 1$)	[2, 3]	[8, 9]	[4, 4]	
A2 ($i = 2$)	[3, 4]	[5, 6]	[4,5]	
A3 ($i = 3$)	[3, 3]	[9, 10]	[5, 8]	
Alternative	Normalized decision matrix ($\left[r_{ij}^{l}, r_{ij}^{u}\right]$)			
	C1 ($j = 1$)	C1 ($j = 1$)	C1 ($j = 1$)	
A1 ($i = 1$)	[0.2, 0.3]	[0.32, 0.36]	[0.23, 0.23]	Obtained by Eqs. (2) and (3)
A2 ($i = 2$)	[0.3, 0.4]	[0.2, 0.24]	[0.23, 0.29]	
A3 ($i = 3$)	[0.3, 0.3]	[0.34, 0.4]	[0.29, 0.47]	
Variables	Internal weight calculation			
	C1 ($j = 1$)	C2 ($j = 2$)	C3 ($j = 3$)	
$\left[h_j^l, h_j^u\right]$	[0.95, 0.99]	[0.95, 0.98]	[0.94, 0.96]	Obtained by Eqs. (4) and (5)
$\left[d_j^l, d_j^u\right]$	[0.01, 0.04]	[0.01, 0.04]	[0.03, 0.05]	Obtained by Eq. (6)
$\left[w_j^{in,l}, w_j^{in,u}\right]$	[0.06, 0.72]	[0.13, 0.59]	[0.27, 0.77]	Obtained by Eq. (7)
Variables	Interval weight calculation			
	C1 ($j = 1$)	C2 ($j = 2$)	C3 ($j = 3$)	
Expert 1 ($p = 1$) scores	10	9	4	Asked from the expert
Expert 2 ($p = 2$) scores	8	8	5	Asked from the expert
w_j^{ex}	0.41	0.38	0.20	Obtained by equation $w_j^{ex} = \frac{\sum_{p=1}^{s} sc_{pj}}{\sum_{p=1}^{s}\sum_{j=1}^{n} sc_{pj}}$
Variables	Final importance weights (using $\lambda = 0.4$)			
	C1 ($j = 1$)	C2 ($j = 2$)	C3 ($j = 3$)	
$\left[w_j^l, w_j^u\right]$	[0.20, 0.59]	[0.23, 0.50]	[0.24, 0.54]	Obtained by equation $\left[w_j^l, w_j^u\right] = \left[(1-\lambda)w_j^{in,l} + \lambda w_j^{ex}, (1-\lambda)w_j^{in,u} + \lambda w_j^{ex}\right]$

results e.g. external weight values, internal weight values, and final interval weights are reported by Table 6.

In continue, using the obtained weights of the criteria shown by Table 6, the proposed interval EDAS approach of Sect. 3.2 is applied to the decision matrix of the case study explained by Sect. 2. The detailed results and the ranking obtained for the bank branches are demonstrated by Table 7. According to these results the branch B-5 obtains the best rank while the branch B-40 has the worst rank among all the 51 branches.

A very important parameter that affects the obtained results is the importance values of the external and internal

Table 5 Phase 2 calculations for the example

Alternative	Decision matrix ($\left[a_{ij}^{l}, a_{ij}^{u}\right]$)			Comment
	C1 (j = 1)	C2 (j = 2)	C3 (j = 3)	
A1 (i = 1)	[2, 3]	[8, 9]	[4, 4]	
A2 (i = 2)	[3, 4]	[5, 6]	[4,5]	
A3 (i = 3)	[3, 3]	[9, 10]	[5, 8]	
Alternative	Normalized decision matrix ($\left[r_{ij}^{l}, r_{ij}^{u}\right]$)			
	C1 (j = 1)	C1 (j = 1)	C1 (j = 1)	
A1 (i = 1)	[0.2, 0.3]	[0.32, 0.36]	[0.23, 0.23]	Obtained by Eqs. (8) and (9)
A2 (i = 2)	[0.3, 0.4]	[0.2, 0.24]	[0.23, 0.29]	
A3 (i = 3)	[0.3, 0.3]	[0.34, 0.4]	[0.29, 0.47]	
Variables	Average solution of each criterion			
	C1 (j = 1)	C2 (j = 2)	C3 (j = 3)	
$\left[AV_{j}^{l}, AV_{j}^{u}\right]$	[0.95, 0.99]	[0.95, 0.98]	[0.94, 0.96]	Obtained by Eq. (10)
Alternative	Positive distances from the average ($\left[PDA_{ij}^{l}, PDA_{ij}^{u}\right]$)			
	C1 (j = 1)	C2 (j = 2)	C3 (j = 3)	
A1 (i = 1)	[0, 0]	[0.20, 0.28]	[0, 0]	Obtained by Eq. (11)
A2 (i = 2)	[0.5, 0.5]	[0, 0]	[0, 0]	
A3 (i = 3)	[0, 0.5]	[0.5, 0.71]	[1.4, 2]	
Alternative	Negative distances from the average ($\left[NDA_{ij}^{l}, NDA_{ij}^{u}\right]$)			
	C1 (j = 1)	C2 (j = 2)	C3 (j = 3)	
A1 (i = 1)	[0.25, 1]	[0, 0]	[1, 1]	Obtained by Eq. (12)
A2 (i = 2)	[0, 0]	[0.7, 1]	[0.4, 1]	
A3 (i = 3)	[0, 0.25]	[0, 0]	[0, 0]	
Variables	Ranking related calculations			
	A1 (i = 1)	A2 (i = 2)	A3 (i = 3)	
$\left[SP_{i}^{l}, SP_{i}^{u}\right]$	[0.04, 0.14]	[0.10, 0.29]	[0.46, 1.75]	Obtained by Eq. (13)
$\left[SN_{i}^{l}, SN_{i}^{u}\right]$	[0.29, 1.14]	[0.26, 1.05]	[0, 0.14]	Obtained by Eq. (14)
$\left[NSP_{i}^{l}, NSP_{i}^{u}\right]$	[0.02, 0.08]	[0.05, 0.17]	[0.26, 1]	Obtained by Eq. (15)
$\left[NSN_{i}^{l}, NSN_{i}^{u}\right]$	[0, 0.73]	[0.07, 0.76]	[0.86, 1]	Obtained by Eq. (16)
$\left[AS_{i}^{l}, AS_{i}^{u}\right]$	[0.01, 0.41]	[0.06, 0.46]	[0.56, 1]	Obtained by Eq. (17)
Alternative	Interval appraisal scores (P_{ik})			
	A1 (k = 1)	A2 (k = 2)	A3 (k = 3)	
A1 (i = 1)	0.40	0.34	−0.15	Obtained by Eq. (20)
A2 (i = 2)	0.46	0.40	−0.10	
A3 (i = 3)	1	0.94	0.43	
Alternative	Integrated priority of each alternative (IP_i)			
A1 (i = 1)	0.59			Obtained by Eq. (21)
A2 (i = 2)	0.76			
A3 (i = 3)	2.37			

weights (denoted by λ and $1-\lambda$ respectively). To obtain the results of Tables 6 and 7, the value of λ is set to 0.8. In the rest of this section a detailed sensitivity analysis is done to study the effect of λ on the obtained results. For this aim, the value of λ is set to be from the set of values $\{0.0, 0.2, 0.4, 0.6, 0.8, 1.0\}$. By taking each of these values, the weight determination procedure of Sect. 3.1 is repeated and the final interval weights of Table 8 are obtained.

From the results of Table 8 the changes of the interval weights over the changes of λ can be seen easily. Two core conclusions can be drawn from these results, (1) by increasing the value of λ, the interval weights are either decreased

Table 6 The weight values obtained for the criteria (for $\lambda = 0.8$)

Criterion code	External weight determination		Internal weight determination		Final weight ($\left[w_j^l, w_j^u\right]$)	
	Scores given by the experts	External weight (w_j^{ex})	$\left[d_j^l, d_j^u\right]$	$\left[w_j^{in,l}, w_j^{in,u}\right]$	w_j^l	w_j^u
C-1	5 6 4 6 3 8 4 3 6 5	0.1190	[0.0469, 0.0580]	[0.0313, 0.0439]	0.1015	0.1040
C-2	1 5 4 5 3 5 3 2 1 1	0.0710	[0.0439, 0.0521]	[0.0293, 0.0394]	0.0630	0.0650
C-3	1 1 2 1 4 2 2 2 3 2	0.0480	[0.0088, 0.0171]	[0.0059, 0.0130]	0.0393	0.0407
C-4	7 3 7 8 5 3 2 3 6 6	0.1190	[0.2335, 0.2549]	[0.1558, 0.1929]	0.1264	0.1338
C-5	5 3 3 7 5 3 6 3 7 8	0.1190	[0.0531, 0.0703]	[0.0354, 0.0532]	0.1023	0.1059
C-6	3 2 2 1 2 1 3 2 2 2	0.0480	[0.1320, 0.1320]	[0.0881, 0.0999]	0.0557	0.0581
C-7	1 1 1 1 1 1 1 1 1 1	0.0240	[0.0518, 0.0518]	[0.0346, 0.0392]	0.0260	0.0269
C-8	2 2 4 1 1 2 3 2 2 1	0.0480	[0.1354, 0.1354]	[0.0903, 0.1025]	0.0562	0.0586
C-9	1 1 1 1 1 1 1 1 1 1	0.0240	[0.0261, 0.0261]	[0.0174, 0.0198]	0.0225	0.0230
C-10	1 1 1 1 1 1 1 1 1 1	0.0240	[0.2856, 0.2856]	[0.1905, 0.2161]	0.0572	0.0623
C-11	2 3 2 2 2 3 2 1 2 1	0.0480	[0.0677, 0.0677]	[0.0452, 0.0513]	0.0471	0.0483
C-12	2 3 2 1 1 4 1 3 1 2	0.0480	[0.1030, 0.1030]	[0.0687, 0.0780]	0.0518	0.0537
C-13	6 3 8 3 8 8 4 2 4 4	0.1190	[0.0153, 0.0153]	[0.0102, 0.0116]	0.0973	0.0976
C-14	1 1 1 1 1 1 1 1 1 1	0.0240	[0.0104, 0.0883]	[0.0070, 0.0668]	0.0204	0.0324
C-15	1 1 1 1 1 1 1 1 1 1	0.0240	[0.0958, 0.1255]	[0.0639, 0.0949]	0.0318	0.0380
C-16	2 6 4 3 3 4 5 6 3 4	0.0950	[0.0118, 0.0157]	[0.0079, 0.0119]	0.0778	0.0786

or increased (actually, it moves to the value of external weight), (2) by increasing the value of λ, the length of the interval weights are decreased to zero (because the external weights are of deterministic values). The results of Table 8 are depicted by Figs. 3 and 4.

In continue, for each of the set of the weight values of Table 8, the proposed interval EDAS approach of Sect. 3.2 is done and the rankings of Table 9 for the bank branches are obtained.

According to the results of Table 9, it can be concluded that the amount of λ and accordingly the amount of final interval weights directly influence the obtained ranking of the bank branches. For example the branch B-1 obtains the ranks 38, 41, 45, 46, 47, and 47 while the value of λ changes over the values 0, 0.2, 0.4, 0.6, 0.8, and 1. For more comparison among the rankings of Table 9, the Jaccard similarity index (Levandowsky and Winter 1971; Qian et al. 2011; Niroomand et al. 2018; Niroomand et al. 2019a, b) is used. This index takes a value between zero and one where its higher value shows more similarity between two ranking based sets of values. For any pair of the rankings of Table 9 the Jaccard similarity index is calculated and reported by Table 10.

The results of Table 10 demonstrate the similarities between any pair of rankings obtained in Table 9 in terms of Jaccard similarity index. As can be seen from these two

Table 7 Results obtained for ranking problem of the branches of the Keshavarzi bank by the proposed interval EDAS approach (for $\lambda = 0.8$)

Branch	SP_i^l	SP_i^u	SN_i^l	SN_i^u	NSP_i^l	NSP_i^u	NSN_i^l	NSN_i^u	AS_i^l	AS_i^u	IP_i	Rank
B-1	0.06283	0.10345	0.46625	0.52888	0.02039	0.03357	0.06909	0.17934	0.04474	0.10645	0.05743	47
B-2	0.06892	0.10973	0.47699	0.51347	0.02236	0.03560	0.09622	0.16043	0.05929	0.09802	0.04410	49
B-3	1.08469	1.19076	0.22717	0.29352	0.35195	0.38637	0.48336	0.60014	0.41765	0.49325	0.66847	4
B-4	0.07288	0.08497	0.30485	0.33518	0.02365	0.02757	0.41003	0.46343	0.21684	0.24550	0.27708	31
B-5	2.62408	3.08196	0.33734	0.42475	0.85143	1.00000	0.25238	0.40623	0.55191	0.70312	1.00000	1
B-6	0.26453	0.33198	0.11665	0.15154	0.08583	0.10772	0.73326	0.79469	0.40955	0.45120	0.60204	8
B-7	0.07218	0.10093	0.40013	0.44746	0.02342	0.03275	0.21241	0.29571	0.11791	0.16423	0.14870	39
B-8	0.97916	1.20558	0.27735	0.31919	0.31771	0.39117	0.43818	0.51183	0.37794	0.45150	0.60251	7
B-9	0.08463	0.14223	0.44403	0.48573	0.02746	0.04615	0.14505	0.21844	0.08626	0.13229	0.09825	44
B-10	1.23950	1.56302	0.23834	0.30129	0.40218	0.50715	0.46968	0.58049	0.43593	0.54382	0.74835	3
B-11	0.10775	0.13927	0.40459	0.44298	0.03496	0.04519	0.22030	0.28786	0.12763	0.16652	0.15232	38
B-12	0.19450	0.21674	0.11561	0.16266	0.06311	0.07033	0.71369	0.79651	0.38840	0.43342	0.57395	10
B-13	0.07774	0.09227	0.15091	0.18222	0.02523	0.02994	0.67926	0.73438	0.35224	0.38216	0.49297	17
B-14	0.19129	0.21411	0.15128	0.20316	0.06207	0.06947	0.64241	0.73372	0.35224	0.40160	0.52367	14
B-15	0.21739	0.23275	0.31616	0.37985	0.07054	0.07552	0.33141	0.44352	0.20097	0.25952	0.29923	28
B-16	0.20022	0.22191	0.09340	0.11806	0.06497	0.07200	0.79220	0.83561	0.42859	0.45381	0.60615	6
B-17	0.14638	0.16467	0.29403	0.33241	0.04750	0.05343	0.41491	0.48246	0.23120	0.26794	0.31254	27
B-18	0.09201	0.11491	0.14466	0.21013	0.02985	0.03728	0.63014	0.74538	0.32999	0.39133	0.50746	15
B-19	0.38875	0.46273	0.14364	0.18354	0.12614	0.15014	0.67694	0.74718	0.40154	0.44866	0.59802	9
B-20	0.08432	0.10689	0.23080	0.34576	0.02736	0.03468	0.39141	0.59376	0.20938	0.31422	0.38565	24
B-21	0.20209	0.23693	0.39662	0.41835	0.06557	0.07688	0.26364	0.30190	0.16461	0.18939	0.18844	36
B-22	0.48442	0.57462	0.19376	0.22363	0.15718	0.18645	0.60639	0.65895	0.38178	0.42270	0.55701	12
B-23	0.17555	0.20452	0.17988	0.24311	0.05696	0.06636	0.57209	0.68338	0.31452	0.37487	0.48146	18
B-24	0.55321	0.73548	0.27905	0.30205	0.17950	0.23864	0.46835	0.50883	0.32392	0.37373	0.47966	19
B-25	0.05466	0.07043	0.47083	0.51188	0.01774	0.02285	0.09901	0.17127	0.05838	0.09706	0.04259	50
B-26	0.14975	0.16788	0.15712	0.19290	0.04859	0.05447	0.66047	0.72344	0.35453	0.38896	0.50371	16
B-27	0.15493	0.20460	0.25936	0.35061	0.05027	0.06638	0.38287	0.54349	0.21657	0.30494	0.37098	26
B-28	0.26064	0.36314	0.38338	0.43225	0.08457	0.11783	0.23918	0.32520	0.16188	0.22151	0.23919	32
B-29	0.11701	0.15898	0.38403	0.42225	0.03797	0.05158	0.25677	0.32406	0.14737	0.18782	0.18597	37
B-30	0.11745	0.13001	0.23304	0.28261	0.03811	0.04219	0.50257	0.58982	0.27034	0.31600	0.38846	23
B-31	0.40197	0.54634	0.25196	0.31535	0.13043	0.17727	0.44493	0.55652	0.28768	0.36689	0.46886	20
B-32	0.13153	0.18413	0.45965	0.48902	0.04268	0.05974	0.13926	0.19096	0.09097	0.12535	0.08728	45
B-33	0.25640	0.31427	0.16338	0.21067	0.08319	0.10197	0.62919	0.71243	0.35619	0.40720	0.53253	13
B-34	0.29836	0.32967	0.23521	0.26648	0.09681	0.10697	0.53096	0.58600	0.31388	0.34648	0.43661	22
B-35	0.73911	0.84011	0.08740	0.13384	0.23982	0.27259	0.76442	0.84617	0.50212	0.55938	0.77293	2
B-36	0.23139	0.28470	0.07740	0.10545	0.07508	0.09237	0.81439	0.86377	0.44473	0.47807	0.64448	5
B-37	0.43641	0.47948	0.30141	0.32077	0.14160	0.15558	0.43541	0.46947	0.28850	0.31253	0.38297	25
B-38	0.06202	0.08574	0.45136	0.50595	0.02012	0.02782	0.10945	0.20553	0.06479	0.11668	0.07358	46
B-39	0.05872	0.08759	0.46942	0.53102	0.01905	0.02842	0.06533	0.17375	0.04219	0.10109	0.04895	48
B-40	0.06693	0.10175	0.50724	0.56814	0.02172	0.03301	0.00000	0.10719	0.01086	0.07010	0.00000	51
B-41	0.03633	0.04715	0.34567	0.40541	0.01179	0.01530	0.28642	0.39156	0.14911	0.20343	0.21063	33
B-42	0.05253	0.08736	0.35488	0.38551	0.01704	0.02834	0.32144	0.37536	0.16924	0.20185	0.20813	35
B-43	0.06155	0.10377	0.43283	0.45926	0.01997	0.03367	0.19163	0.23815	0.10580	0.13591	0.10396	43
B-44	0.15344	0.22140	0.21024	0.23060	0.04979	0.07184	0.59411	0.62995	0.32195	0.35090	0.44358	21
B-45	0.70446	0.91024	0.24706	0.28336	0.22858	0.29534	0.50124	0.56514	0.36491	0.43024	0.56893	11
B-46	0.11329	0.39020	0.34586	0.50481	0.03676	0.12661	0.11146	0.39125	0.07411	0.25893	0.29829	29
B-47	0.06513	0.08409	0.39733	0.45040	0.02113	0.02728	0.20723	0.30064	0.11418	0.16396	0.14827	40
B-48	0.06533	0.08343	0.42807	0.48356	0.02120	0.02707	0.14887	0.24654	0.08503	0.13681	0.10538	42
B-49	0.04571	0.10737	0.30002	0.37673	0.01483	0.03484	0.33691	0.47192	0.17587	0.25338	0.28953	30

Table 7 (continued)

Branch	SP_i^l	SP_i^u	SN_i^l	SN_i^u	NSP_i^l	NSP_i^u	NSN_i^l	NSN_i^u	AS_i^l	AS_i^u	IP_i	Rank
B-50	0.05911	0.09757	0.41589	0.44990	0.01918	0.03166	0.20811	0.26798	0.11365	0.14982	0.12593	41
B-51	0.06140	0.08085	0.35356	0.45854	0.01992	0.02623	0.19291	0.37768	0.10641	0.20196	0.20830	34

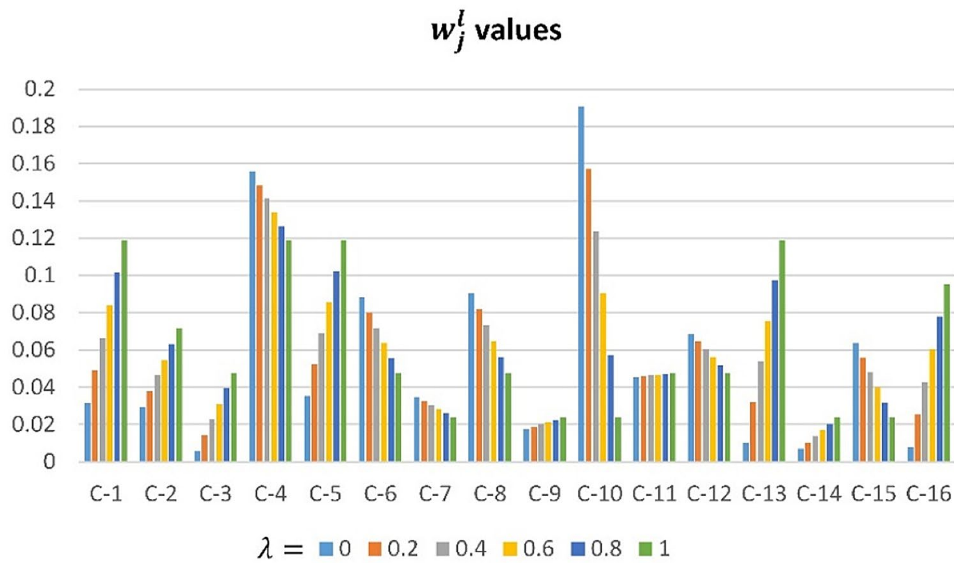

Fig. 3 The lower values of the importance weights for different λ values

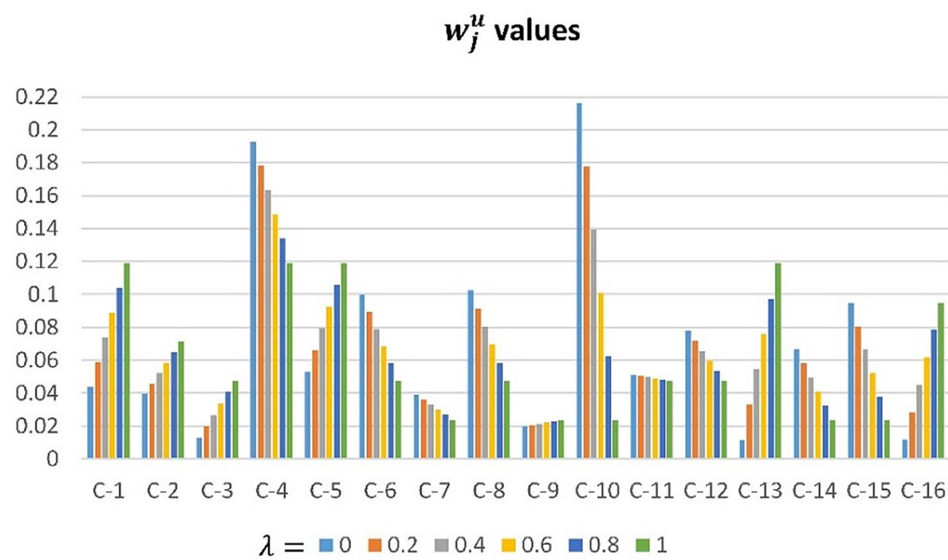

Fig. 4 The upper values of the importance weights for different λ values

Table 8 The weight values obtained for the criteria using different λ values

Criterion code	$\lambda = 0$		$\lambda = 0.2$		$\lambda = 0.4$		$\lambda = 0.6$		$\lambda = 0.8$		$\lambda = 1$	
	w_j^l	w_j^u	w_j^l	w_j^u	w_j^l	w_j^u	w_j^l	w_j^u	w_j^l	w_j^u	w_j^l	w_j^u
C-1	0.0313	0.0439	0.0489	0.0589	0.0664	0.0739	0.0840	0.0890	0.1015	0.1040	0.1190	0.1190
C-2	0.0293	0.0394	0.0377	0.0458	0.0462	0.0522	0.0546	0.0586	0.0630	0.0650	0.0714	0.0714
C-3	0.0059	0.0130	0.0142	0.0199	0.0226	0.0268	0.0309	0.0338	0.0393	0.0407	0.0476	0.0476
C-4	0.1558	0.1929	0.1484	0.1781	0.1411	0.1633	0.1337	0.1486	0.1264	0.1338	0.1190	0.1190
C-5	0.0354	0.0532	0.0522	0.0664	0.0689	0.0796	0.0856	0.0927	0.1023	0.1059	0.1190	0.1190
C-6	0.0881	0.0999	0.0800	0.0895	0.0719	0.0790	0.0638	0.0685	0.0557	0.0581	0.0476	0.0476
C-7	0.0346	0.0392	0.0324	0.0361	0.0303	0.0330	0.0281	0.0300	0.0260	0.0269	0.0238	0.0238
C-8	0.0903	0.1025	0.0818	0.0915	0.0732	0.0805	0.0647	0.0696	0.0562	0.0586	0.0476	0.0476
C-9	0.0174	0.0198	0.0187	0.0206	0.0200	0.0214	0.0213	0.0222	0.0225	0.0230	0.0238	0.0238
C-10	0.1905	0.2161	0.1572	0.1776	0.1238	0.1392	0.0905	0.1007	0.0572	0.0623	0.0238	0.0238
C-11	0.0452	0.0513	0.0457	0.0505	0.0462	0.0498	0.0466	0.0491	0.0471	0.0483	0.0476	0.0476
C-12	0.0687	0.0780	0.0645	0.0719	0.0603	0.0658	0.0561	0.0598	0.0518	0.0537	0.0476	0.0476
C-13	0.0102	0.0116	0.0320	0.0331	0.0538	0.0546	0.0755	0.0761	0.0973	0.0976	0.1190	0.1190
C-14	0.0070	0.0668	0.0103	0.0582	0.0137	0.0496	0.0171	0.0410	0.0204	0.0324	0.0238	0.0238
C-15	0.0639	0.0949	0.0559	0.0807	0.0479	0.0665	0.0399	0.0523	0.0318	0.0380	0.0238	0.0238
C-16	0.0079	0.0119	0.0254	0.0286	0.0428	0.0453	0.0603	0.0619	0.0778	0.0786	0.0952	0.0952

Table 9 Rankings obtained for the branches by the proposed interval EDAS approach for different λ values

Branch	Ranking when λ is equal to						Branch	Ranking when λ is equal to					
	0	0.2	0.4	0.6	0.8	1		0	0.2	0.4	0.6	0.8	1
B-1	38	41	45	46	47	47	B-27	29	29	27	25	26	24
B-2	42	46	48	49	49	49	B-28	40	37	35	34	32	32
B-3	6	5	5	4	4	4	B-29	45	42	38	36	37	35
B-4	35	32	33	31	31	29	B-30	23	22	22	24	23	25
B-5	1	1	1	1	1	1	B-31	28	26	23	20	20	13
B-6	7	7	6	7	8	11	B-32	51	51	50	47	45	43
B-7	46	43	42	39	39	39	B-33	19	17	17	15	13	8
B-8	3	4	4	6	7	12	B-34	27	25	24	22	22	20
B-9	34	38	39	43	44	45	B-35	4	2	2	2	2	2
B-10	2	3	3	3	3	3	B-36	11	10	7	5	5	5
B-11	49	45	43	40	38	38	B-37	36	31	28	26	25	22
B-12	14	13	13	12	10	7	B-38	37	39	44	45	46	46
B-13	15	15	15	17	17	18	B-39	44	44	47	48	48	48
B-14	16	16	16	16	14	10	B-40	48	50	51	51	51	51
B-15	39	33	32	30	28	28	B-41	25	28	31	33	33	36
B-16	12	12	11	10	6	6	B-42	33	34	34	35	35	34
B-17	32	30	30	29	27	27	B-43	47	49	46	44	43	42
B-18	13	14	14	14	15	19	B-44	26	24	20	21	21	21
B-19	8	8	9	8	9	9	B-45	5	6	8	9	11	15
B-20	21	21	21	23	24	26	B-46	22	23	26	28	29	30
B-21	50	48	40	37	36	33	B-47	30	35	36	38	40	40
B-22	9	9	10	11	12	17	B-48	31	36	37	42	42	44
B-23	10	11	12	13	18	23	B-49	18	20	25	27	30	31
B-24	17	19	19	19	19	16	B-50	41	40	41	41	41	41
B-25	43	47	49	50	50	50	B-51	24	27	29	32	34	37
B-26	20	18	18	18	16	14							

Table 10 The Jaccard similarity indexes for comparing the rankings of Table 9

	$\lambda = 0$	$\lambda = 0.2$	$\lambda = 0.4$	$\lambda = 0.6$	$\lambda = 0.8$	$\lambda = 1$
$\lambda = 0$	1	0.9301	0.8808	0.8352	0.8065	0.7597
$\lambda = 0.2$	–	1	0.9414	0.8929	0.8623	0.8102
$\lambda = 0.4$	–	–	1	0.9428	0.9120	0.8571
$\lambda = 0.6$	–	–	–	1	0.9615	0.9065
$\lambda = 0.8$	–	–	–	–	1	0.9385
$\lambda = 1$	–	–	–	–	–	1

Table 11 Rankings obtained for the branches by the interval EDAS approach of Ren and Toniolo (2018) for different λ values.

Branch	Ranking when λ is equal to						Branch	Ranking when λ is equal to					
	0	0.2	0.4	0.6	0.8	1		0	0.2	0.4	0.6	0.8	1
B-1	38	42	46	47	48	49	B-27	30	29	28	29	27	29
B-2	40	44	47	48	47	47	B-28	43	38	36	33	33	32
B-3	12	12	11	8	9	11	B-29	45	41	37	37	35	33
B-4	34	32	30	27	26	25	B-30	22	22	22	22	23	22
B-5	3	4	5	5	5	10	B-31	28	26	24	24	24	21
B-6	1	1	3	4	4	13	B-32	51	51	50	46	45	43
B-7	47	45	42	40	39	37	B-33	20	19	17	17	14	14
B-8	8	9	9	11	13	19	B-34	24	23	21	21	18	9
B-9	36	37	40	43	44	44	B-35	6	3	2	2	1	2
B-10	11	11	10	9	11	17	B-36	2	2	1	1	3	3
B-11	50	48	43	39	36	34	B-37	35	28	25	23	21	4
B-12	14	13	13	10	7	7	B-38	37	39	44	45	46	46
B-13	15	15	15	13	10	8	B-39	44	49	49	50	50	50
B-14	19	17	18	18	15	12	B-40	48	50	51	51	51	51
B-15	39	35	32	30	28	28	B-41	23	25	29	31	34	36
B-16	10	7	4	3	2	1	B-42	33	33	33	32	31	31
B-17	32	30	27	25	25	24	B-43	46	47	45	44	42	39
B-18	13	14	14	15	20	23	B-44	21	20	20	19	17	6
B-19	4	5	6	6	6	15	B-45	7	8	8	12	16	20
B-20	25	24	26	26	29	30	B-46	26	27	31	34	37	42
B-21	49	43	38	35	32	27	B-47	29	34	35	38	40	41
B-22	5	6	7	7	8	16	B-48	31	36	39	42	43	45
B-23	9	10	12	14	22	26	B-49	18	21	23	28	30	35
B-24	16	18	19	20	19	18	B-50	41	40	41	41	41	38
B-25	42	46	48	49	49	48	B-51	27	31	34	36	38	40
B-26	17	16	16	16	12	5							

Table 12 The Jaccard similarity indexes for comparing the rankings of the proposed interval EDAS approach and the interval EDAS approach of Ren and Toniolo (2018)

	The proposed interval EDAS approach					
	$\lambda = 0$	$\lambda = 0.2$	$\lambda = 0.4$	$\lambda = 0.6$	$\lambda = 0.8$	$\lambda = 1$
Ren and Toniolo (2018)	0.9287	0.9203	0.9301	0.9189	0.9038	0.8480

Table 13 Rankings obtained for the multi-criteria problem of Niroomand et al. (2018) by the proposed interval EDAS approach

Alternative	Proposed interval EDAS approach	Interval TOPSIS Niroomand et al. (2018)	Jaccard similarity index value
Alternative 1	2	1	0.7837
Alternative 2	5	2	
Alternative 3	7	8	
Alternative 4	6	6	
Alternative 5	10	10	
Alternative 6	8	11	
Alternative 7	11	7	
Alternative 8	9	9	
Alternative 9	1	3	
Alternative 10	3	5	
Alternative 11	4	4	

tables, different λ values causes in different rankings. To interpret the obtained Jaccard indexes, the 0.9615 is the highest value which means that the rankings obtained by $\lambda = 0.6$ and $\lambda = 0.8$ are similar in 96.15 percent.

The proposed interval EDAS approach of this study is also compared to the interval EDAS approach of Ren and Toniolo (2018). For this aim the multi-criteria problem of this study is solved by the approach of Ren and Toniolo (2018). In order to apply a fair comparative study, the weight values obtained by Table 8 is used in the procedure of the approach of Ren and Toniolo (2018). The obtained rankings are represented in Table 11. In order to compare the ranking of the approach of Ren and Toniolo (2018) with the proposed interval EDAS approach of this study, the Jaccard similarity index values of Table 12 are calculated. The highest similarity of the rankings happens at $\lambda = 0.4$ and the lowest similarity happens when $\lambda = 1$. In conclusion, as the basics of the approaches are similar, the obtained rankings are somehow close to each other.

In order to further study the performance of the proposed interval EDAS approach, we compare it to the interval TOPSIS approach of Niroomand et al. (2018). For this aim the multi-criteria emergency center location problem presented at Niroomand et al. (2018) is solved by the proposed interval EDAS approach of this study by the weight values used in the study of Niroomand et al. (2018). The rankings obtained by both approaches are reported by Table 13. The similarity index value of 0.7837 is obtained for the obtained rankings. It can be seen that some alternatives obtained similar rank by both of the approaches while the difference of the ranks of the other alternatives in the applied approaches is at most 4 (for Alternative 7).

5 Conclusion

In this study an important real-world multi-criteria problem was focused. The ranking problem of bank branches in Iran subject to some economic criteria and interval type data was considered. A new solution procedure was proposed for this aim. In the proposed procedure first the criteria were weighted as interval values according to a method combining experts opinions and the Shannon's entropy. Then, the classical EDAS multi-criteria solution approach was newly modified for interval value data in order to overcome the shortcomings of the interval EDAS approaches of the literature. Finally, using the data obtained from the case study, an extensive computational study was performed for the proposed interval EDAS approach and its performance was compared to the approaches of the literature. The sensitivity of the proposed approach also was analyzed according to the changes of its parameters.

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Appendix

The decision matrix of the case study is represented in the following tables (Tables 14, 15).

Table 14 The decision matrix of the case study

Branch	C-1	C-2	C-3	C-4	C-5	C-6	C-7	C-8
B-1	[82934,96443]	[51164,67347]	[40.6,48]	[27299,31087]	[0.042,0.079]	[14496,14496]	[9946,9946]	[24442,24442]
B-2	[69875,110246]	[37288,65622]	[37.5,49.3]	[18116,24082]	[0.079,0.123]	[13230,13230]	[4561,4561]	[17791,17791]
B-3	[416321,656225]	[311897,527261]	[62.4,74.2]	[598490,703112]	[0.174,0.447]	[37416,37416]	[36359,36359]	[110285,110285]
B-4	[113908,182794]	[92971,161600]	[73.8,83.6]	[15733,17697]	[0.176,0.241]	[7734,7734]	[9389,9389]	[17124,17124]
B-5	[450690,701136]	[234218,358987]	[31.8,73.5]	[1892522,2070191]	[0.248,0.448]	[97833,97833]	[34689,34689]	[335241,335241]
B-6	[168252,240895]	[116393,196016]	[59.3,73.9]	[319799,471567]	[0.087,0.186]	[15213,15213]	[17921,17921]	[66925,66925]
B-7	[62658,110315]	[51847,89716]	[75.6,79.6]	[10799,20196]	[0.026,0.042]	[4404,4404]	[5656,5656]	[10060,10060]
B-8	[420884,583696]	[180585,286824]	[31.1,40.2]	[598527,937101]	[0.161,0.295]	[80471,80471]	[31223,31223]	[139384,139384]
B-9	[101318,150922]	[54420,72925]	[36.1,40.9]	[16873,18679]	[0.009,0.024]	[20946,20946]	[6635,6635]	[27582,27582]
B-10	[534865,635900]	[374782,462596]	[55.5,62.7]	[780564,958111]	[0.14,0.355]	[56762,56762]	[29685,29685]	[129206,129206]
B-11	[61145,94067]	[54442,86786]	[77,90.5]	[27458,43651]	[0.032,0.097]	[2668,2668]	[5944,5944]	[8611,8611]
B-12	[222063,364741]	[193946,335533]	[83.7,90.3]	[123862,150325]	[0.095,0.384]	[7712,7712]	[19960,19960]	[27673,27673]
B-13	[134096,220775]	[120672,205351]	[88.5,92.4]	[129449,162254]	[0.093,0.308]	[3321,3321]	[12754,12754]	[16075,16075]
B-14	[174434,289283]	[146423,260202]	[80,88]	[66394,123285]	[0.126,0.259]	[7961,7961]	[10597,10597]	[18558,18558]
B-15	[80495,149486]	[77746,144690]	[94,96]	[15709,49867]	[0.117,0.223]	[2043,2043]	[6289,6289]	[8332,8332]
B-16	[197542,316778]	[164983,273407]	[81.8,85.3]	[199094,263938]	[0.228,0.394]	[10295,10295]	[12582,12582]	[23475,23475]
B-17	[97111,162913]	[85937,145479]	[82.5,86.8]	[38450,56393]	[0.053,0.132]	[4450,4450]	[5833,5833]	[10283,10283]
B-18	[116722,225357]	[88166,182421]	[73.2,79.6]	[156122,209242]	[0.253,0.462]	[9619,9619]	[5738,5738]	[21995,21995]
B-19	[284831,414090]	[159338,269533]	[47.5,60.4]	[329717,473451]	[0.211,0.278]	[35703,35703]	[14533,14533]	[54468,54468]
B-20	[99556,201767]	[80024,176813]	[71.9,86.8]	[74765,153585]	[0.161,0.33]	[6066,6066]	[8966,8966]	[15032,15032]
B-21	[85149,129885]	[73178,116772]	[85.8,91.2]	[6072,6682]	[0.01,0.051]	[3596,3596]	[5613,5613]	[9210,9210]
B-22	[255417,375945]	[173609,250718]	[46.8,55.1]	[432969,593073]	[0.373,0.492]	[38660,38660]	[17952,17952]	[79942,79942]
B-23	[151127,259218]	[75935,154298]	[28.6,43.2]	[267455,358150]	[0.184,0.467]	[37561,37561]	[10187,10187]	[57158,57158]
B-24	[489187,649645]	[386281,546617]	[67.8,75.6]	[69714,79332]	[0.012,0.018]	[65039,65039]	[11553,11553]	[76592,76592]
B-25	[68283,115117]	[44932,81341]	[50.3,61.4]	[34805,45379]	[0.163,0.281]	[9960,9960]	[7985,7985]	[17944,17944]
B-26	[166049,274391]	[143041,235651]	[82.6,88]	[72399,115196]	[0.102,0.196]	[8147,8147]	[11027,11027]	[19174,19174]
B-27	[98215,229930]	[84096,199532]	[76.2,85.5]	[20294,27016]	[0.035,0.23]	[4564,4564]	[4837,4837]	[9401,9401]
B-28	[78715,150316]	[70182,138664]	[86.1,92.1]	[3172,3866]	[0.04,0.158]	[2012,2012]	[7328,7328]	[9340,9340]
B-29	[78318,118202]	[63843,109417]	[68.4,89.5]	[9079,13412]	[0.066,0.151]	[5651,5651]	[4984,4984]	[10635,10635]
B-30	[104431,178270]	[93255,148209]	[77.6,83.3]	[70305,110278]	[0.082,0.292]	[5307,5307]	[6829,6829]	[12136,12136]
B-31	[140668,297284]	[123934,275729]	[85.7,93.1]	[9652,10378]	[0.005,0.012]	[4117,4117]	[7331,7331]	[11448,11448]
B-32	[61930,101363]	[51342,85756]	[79.6,83.9]	[3001,4755]	[0.005,0.013]	[2526,2526]	[7285,7285]	[9811,9811]
B-33	[164539,309540]	[144111,272715]	[85.2,89.1]	[70254,104269]	[0.133,0.162]	[8555,8555]	[7682,7682]	[16237,16237]
B-34	[210644,330291]	[186427,302473]	[76,83.8]	[19669,21191]	[0.107,0.308]	[11136,11136]	[12310,12310]	[23446,23446]
B-35	[226489,368434]	[190607,323532]	[71.3,82.6]	[486931,700354]	[0.067,0.369]	[18292,18292]	[14868,14868]	[83832,83832]
B-36	[214121,354798]	[154645,273614]	[65.8,75.5]	[256771,299304]	[0.282,0.443]	[18924,18924]	[13442,13442]	[35005,35005]
B-37	[126070,200256]	[119682,193712]	[93.9,97.3]	[15079,16930]	[0.041,0.15]	[1732,1732]	[6423,6423]	[8155,8155]
B-38	[94408,131915]	[46444,73466]	[36.5,49.4]	[30031,34299]	[0.048,0.17]	[15282,15282]	[6460,6460]	[21742,21742]
B-39	[77665,97398]	[43195,59076]	[45.8,56]	[25557,33529]	[0.07,0.188]	[11116,11116]	[5596,5596]	[16713,16713]
B-40	[67942,103050]	[32923,46055]	[38.9,42.8]	[18165,20783]	[0.15,0.194]	[11185,11185]	[4697,4697]	[15882,15882]
B-41	[117034,215672]	[68925,151704]	[41.2,55.3]	[50275,62042]	[0.164,0.252]	[21007,21007]	[10962,10962]	[31969,31969]
B-42	[86523,131566]	[76817,116700]	[68.1,79.3]	[23839,27985]	[0.097,0.158]	[7061,7061]	[11439,11439]	[18499,18499]
B-43	[67128,101755]	[42632,71217]	[59.8,69.5]	[12020,17446]	[0.018,0.043]	[5819,5819]	[5694,5694]	[11512,11512]
B-44	[188072,273029]	[155887,237328]	[74.1,80.5]	[15590,22319]	[0.084,0.158]	[11955,11955]	[10605,10605]	[22560,22560]
B-45	[490643,642681]	[168618,238022]	[26,31.9]	[422441,483260]	[0.07,0.276]	[89573,89573]	[40638,40638]	[122105,122105]
B-46	[113442,445815]	[61644,107065]	[13.7,74.7]	[17810,23933]	[0.058,0.074]	[74086,74086]	[15089,15089]	[89175,89175]
B-47	[88417,143361]	[49390,94848]	[31.7,48.4]	[26665,30937]	[0.186,0.237]	[20001,20001]	[6191,6191]	[26192,26192]
B-48	[85589,144651]	[47094,95747]	[34,54.1]	[27621,35130]	[0.036,0.089]	[16038,16038]	[8467,8467]	[24505,24505]
B-49	[185119,227018]	[65782,102745]	[24.9,36.2]	[48054,52274]	[0.076,0.106]	[37877,37877]	[7842,7842]	[45719,45719]
B-50	[60374,93714]	[52878,86018]	[63.5,79.4]	[36592,41111]	[0.087,0.136]	[4969,4969]	[8331,8331]	[13299,13299]
B-51	[79445,145448]	[47009,88250]	[43,54.3]	[37343,124804]	[0.031,0.066]	[13625,13625]	[6107,6107]	[19732,19732]

Table 15 The decision matrix of the case study (continue)

Branch	C-9	C-10	C-11	C-12	C-13	C-14	C-15	C-16
B-1	[0.407,0.407]	[2915,2915]	[606,606]	[17281,17281]	[0.707,0.707]	[333345,1512380]	[3.43,4.46]	[8.41,14.23]
B-2	[0.256,0.256]	[1917,1917]	[644,644]	[14820,14820]	[0.833,0.833]	[323668,1498003]	[5.07,5.63]	[6.64,13.47]
B-3	[0.33,0.33]	[80298,80298]	[4312,4312]	[87071,87071]	[0.79,0.79]	[478748,1527121]	[0.73,0.93]	[10.65,19.1]
B-4	[0.548,0.548]	[1014,1014]	[600,600]	[19900,19900]	[1.162,1.162]	[279845,1429988]	[5.87,9.09]	[10.92,19.53]
B-5	[0.103,0.103]	[258182,258182]	[1475,1475]	[270421,270421]	[0.807,0.807]	[823946,1650500]	[0.22,0.38]	[3.22,5.31]
B-6	[0.268,0.268]	[41175,41175]	[2729,2729]	[47565,47565]	[0.711,0.711]	[515181,1644114]	[0.5,0.62]	[9.34,18.33]
B-7	[0.562,0.562]	[887,887]	[923,923]	[10213,10213]	[1.015,1.015]	[316521,1486894]	[3.88,4.6]	[11.52,21.01]
B-8	[0.224,0.224]	[79225,79225]	[3893,3893]	[87281,87281]	[0.626,0.626]	[628812,1445772]	[0.7,0.92]	[7.06,13.65]
B-9	[0.241,0.241]	[1456,1456]	[555,555]	[21931,21931]	[0.795,0.795]	[327241,1502108]	[7.5,9.44]	[6.84,12.72]
B-10	[0.23,0.23]	[108255,108255]	[1971,1971]	[113328,113328]	[0.877,0.877]	[324443,1242131]	[0.68,0.78]	[9.87,18.49]
B-11	[0.69,0.69]	[3749,3749]	[575,575]	[10463,10463]	[1.215,1.215]	[316801,1497739]	[2,2.51]	[13.08,22.36]
B-12	[0.721,0.721]	[16021,16021]	[1650,1650]	[34100,34100]	[1.232,1.232]	[301597,1383067]	[1.58,2.32]	[13.24,22.81]
B-13	[0.793,0.793]	[13144,13144]	[1674,1674]	[18277,18277]	[1.137,1.137]	[336141,1473478]	[0.96,1.35]	[13.95,23.67]
B-14	[0.571,0.571]	[6231,6231]	[2590,2590]	[27261,27261]	[1.469,1.469]	[259737,1392863]	[1.99,2.63]	[12.4,21.56]
B-15	[0.755,0.755]	[1169,1169]	[1757,1757]	[13937,13937]	[1.673,1.673]	[295777,1461926]	[2.76,4.11]	[13.99,23.97]
B-16	[0.536,0.536]	[19568,19568]	[3005,3005]	[26175,26175]	[1.115,1.115]	[359890,1497373]	[0.93,1.11]	[12.76,22.55]
B-17	[0.567,0.567]	[2389,2389]	[1842,1842]	[14334,14334]	[1.394,1.394]	[299134,1455314]	[2.26,2.67]	[13.09,22.61]
B-18	[0.261,0.261]	[15623,15623]	[3235,3235]	[21081,21081]	[0.958,0.958]	[375664,1516344]	[0.69,0.99]	[10.53,19.96]
B-19	[0.267,0.267]	[42985,42985]	[2020,2020]	[48666,48666]	[0.893,0.893]	[347199,1499868]	[0.89,1.02]	[6.9,16]
B-20	[0.596,0.596]	[5235,5235]	[2564,2564]	[13908,13908]	[0.925,0.925]	[338306,1474614]	[1.28,1.73]	[11.93,20.82]
B-21	[0.609,0.609]	[453,453]	[283,283]	[13343,13343]	[1.449,1.449]	[295897,1455968]	[9.37,14.42]	[12.44,21.98]
B-22	[0.225,0.225]	[48413,48413]	[2406,2406]	[55180,55180]	[0.69,0.69]	[405334,1502067]	[0.68,0.87]	[9.94,16.34]
B-23	[0.178,0.178]	[37631,37631]	[1182,1182]	[41315,41315]	[0.723,0.723]	[478932,1649373]	[0.81,0.91]	[8.38,13.28]
B-24	[0.151,0.151]	[9026,9026]	[935,935]	[91250,91250]	[1.191,1.191]	[0,862623]	[7.53,9.18]	[9.14,16.42]
B-25	[0.445,0.445]	[5038,5038]	[557,557]	[12920,12920]	[0.72,0.72]	[335447,1491768]	[1.81,3.22]	[8.75,16.74]
B-26	[0.575,0.575]	[5795,5795]	[2654,2654]	[25067,25067]	[1.307,1.307]	[295553,1439858]	[2.16,2.66]	[12.3,21.84]
B-27	[0.515,0.515]	[1948,1948]	[762,762]	[15331,15331]	[1.631,1.631]	[279648,1359295]	[4.17,7.87]	[13.07,21.99]
B-28	[0.785,0.785]	[346,346]	[187,187]	[13223,13223]	[1.416,1.416]	[293214,1429427]	[16.15,33.99]	[14.12,23.16]
B-29	[0.469,0.469]	[954,954]	[349,349]	[14078,14078]	[1.324,1.324]	[304711,1479984]	[6.68,9.07]	[10.45,18.63]
B-30	[0.563,0.563]	[7384,7384]	[1453,1453]	[16988,16988]	[1.4,1.4]	[315150,1469156]	[1.39,1.68]	[12.51,22.13]
B-31	[0.64,0.64]	[59,59]	[523,523]	[27096,27096]	[2.367,2.367]	[242614,1292765]	[12.24,25.79]	[13.89,23.29]
B-32	[0.743,0.743]	[51,51]	[256,256]	[9554,9554]	[0.974,0.974]	[311720,1480867]	[10.09,13.91]	[12.7,22]
B-33	[0.473,0.473]	[6301,6301]	[3475,3475]	[26889,26889]	[1.656,1.656]	[293187,1387664]	[1.8,2.4]	[12.22,21.88]
B-34	[0.525,0.525]	[1585,1585]	[620,620]	[38700,38700]	[1.651,1.651]	[227911,1322402]	[10.12,15.62]	[12.65,21.36]
B-35	[0.177,0.177]	[89151,89151]	[1717,1717]	[98903,98903]	[1.18,1.18]	[462194,1544864]	[0.41,0.53]	[11.02,19.9]
B-36	[0.384,0.384]	[31875,31875]	[2848,2848]	[37368,37368]	[1.068,1.068]	[373968,1453323]	[0.79,1.16]	[9.87,19.22]
B-37	[0.788,0.788]	[517,517]	[456,456]	[21323,21323]	[2.615,2.615]	[248762,1374853]	[8.99,15.92]	[14.75,24.72]
B-38	[0.297,0.297]	[4322,4322]	[361,361]	[17784,17784]	[0.818,0.818]	[350491,1521800]	[3.06,4.42]	[5.11,13.21]
B-39	[0.335,0.335]	[3413,3413]	[642,642]	[13306,13306]	[0.796,0.796]	[336496,1527751]	[2.92,3.21]	[6.23,14.1]
B-40	[0.296,0.296]	[2140,2140]	[309,309]	[12734,12734]	[0.802,0.802]	[335382,1514829]	[3.77,4.92]	[5.72,14.2]
B-41	[0.343,0.343]	[6691,6691]	[627,627]	[23153,23153]	[0.724,0.724]	[323348,1449221]	[2.72,4.08]	[8.21,14.91]
B-42	[0.618,0.618]	[2364,2364]	[842,842]	[17928,17928]	[0.969,0.969]	[334368,1494156]	[3.81,5.08]	[13.25,20.7]
B-43	[0.495,0.495]	[1517,1517]	[341,341]	[11290,11290]	[0.981,0.981]	[301415,1478031]	[5.11,6.45]	[10.39,19.8]
B-44	[0.47,0.47]	[1405,1405]	[1027,1027]	[32416,32416]	[1.437,1.437]	[253497,1390885]	[9.5,11.26]	[11.01,20.3]
B-45	[0.333,0.333]	[58020,58020]	[2605,2605]	[82388,82388]	[0.675,0.675]	[0,379310]	[1.23,1.35]	[12.51,20.17]
B-46	[0.169,0.169]	[1959,1959]	[684,684]	[81256,81256]	[0.911,0.911]	[4007577,4791512]	[4.63,19.74]	[0,0]
B-47	[0.236,0.236]	[2380,2380]	[707,707]	[22844,22844]	[0.872,0.872]	[337164,1498259]	[4.53,6.17]	[9.88,14.14]
B-48	[0.346,0.346]	[3328,3328]	[714,714]	[18618,18618]	[0.76,0.76]	[349259,1501049]	[3.79,4.86]	[8.35,13.01]
B-49	[0.172,0.172]	[4883,4883]	[1152,1152]	[36651,36651]	[0.802,0.802]	[306300,1488888]	[4.85,5.4]	[3.54,11.58]
B-50	[0.626,0.626]	[4273,4273]	[817,817]	[12259,12259]	[0.922,0.922]	[330998,1496825]	[1.88,2.64]	[12.64,20.23]

Table 15 (continued)

Branch	C-9	C-10	C-11	C-12	C-13	C-14	C-15	C-16
B-51	[0.31,0.31]	[7318,7318]	[870,870]	[17289,17289]	[0.876,0.876]	[356611,1518848]	[1.28,2.77]	[6.89,14.54]

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