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METHODOLOGIES AND APPLICATION

A novel multi-criteria analysis model for the performance evaluation of bank regions: an application to Turkish agricultural banking

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Abstract
The banks serve in a highly dynamic and competitive environment and need to systematically evaluate their performance to improve their competitiveness. Performance evaluation is an important and complex process that requires flexible and analytic methods while handling the multidimensionality of the problem. This study presents a hybrid multi-criteria performance evaluation model for banking sector which combines two multi-criteria decision making methods that are simulation-integrated hesitant fuzzy linguistic term sets-based analytic hierarchy process method to determine the importance level of each criterion according to the decision makers' subjective judgements and grey relational analysis method to rank bank regions according to their performance values. The presented model is based on both probability theory and fuzzy sets theory and thus better represents all the dimensions of the uncertainty inherent in decision making process. A real-life application of the proposed performance evaluation model for a private bank operating in agricultural banking sector in Turkey is also given to illustrate the effectiveness and the applicability of the model.

Keywords Banking · Performance evaluation · Simulation · Hesitant fuzzy sets · AHP · GRA

1 Introduction

Banks are financial institutions, which receive deposits and make loans, provide many other services to its customers and play an important role on the performance of the economy. Banking sector is an important sector, and any development in it affects the other sectors (Seçme et al. 2009). This sector is a highly competitive sector and is affected by the developments such as globalization, technological changes, legal regulations and disintermediation (Grifell-Tatjé and Marques-Gou 2008). Banks have to adapt to these changes very quickly and provide the necessary and flexible services to its customers to be successful in competition (Shafiee et al. 2016). One of the important means of achieving sustainable competitive advantage is the systematic performance measurement and evaluation. A good performance measurement and analysis system enables organizations to better understand and evaluate their operations and can form the basis for many tactical and strategic decisions (Fu et al. 2015). It also contributes to the effective monitoring of business progress by increasing the overall efficiency and profitability (Rushton et al. 2014; Tüysüz and Şimşek 2017).

Since banks operate in a highly competitive business environment and have complex structure (Shafiee et al. 2016), performance measurement and evaluation can be performed in different ways. Although one of the earliest methods used for the performance evaluation of banks is ratio analysis, there have been developed different methods and techniques in the literature which can be generally classified as parametric and nonparametric methods (Saleh and Malkhalifeh 2013; Shafiee et al. 2013, 2016). Parametric methods are stochastic frontier approach (Aigner et al. 1977; Berger and Humphrey 1992; Lensink and Meesters 2014; Sokic 2015; Gil-Alana et al. 2017), thick frontier approach (Berger and Humphrey 1997; Lang and Welzel 1998), distribution-free approach (Berger et al. 1993; Berger 1993; Berger and Di Patti 2006; Bolt and Humphrey 2010), financial ratio analysis (Tözüm 2002;

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Delen et al. 2013; Kumar 2016; Daly and Frikha 2017) and regression analysis approach (Rangan et al. 1988; Chantapong 2005; Waemustafa and Sukri 2015; Aiello and Bonanno 2016). The most widely used nonparametric method is data envelopment analysis (DEA) developed by Charnes et al. (1978) and is an operations research-based method. It can be easily said that DEA and its other improved versions are the ones of the most frequently encountered techniques used for performance and efficiency evaluation in banking sector. The related studies in the literature can be found in Thanassoulis et al. (1996), Parkan and Wu (1999), Seiford and Zhu (1999), Mercan et al. (2003), Demir and Astarcıoğlu (2007), Ho and Wu (2009), Wu and Dash Wu (2010), Yang and Liu (2012), Shahroudi and Assimi (2012), Lin and Chiu (2013), Shafiee et al. (2013), Matthews (2013), Saleh and Malkhalifeh (2013), Chiu et al. (2013), Yılmaz (2013), Ahn and Le (2014), Wang et al. (2014), Wanke and Barros (2014), Titko et al. (2014), Fukuyama and Weber (2015), An et al. (2015), Avkiran (2015), Shafiee et al. (2016), Nguyen et al. (2016), Wanke et al. (2016), Fukuyama and Matousek (2017), Fukuyama and Weber (2017), Silva et al. (2017), Li et al. (2018) and Cook et al. (2019).

These developed methods and techniques distinguish from each other in terms of fundamental assumptions, complexity and computational performance, and thus each may have its own advantages and disadvantages. Ratio analysis takes into account only single inputs and outputs and ignores the fact that banks produce multiple outputs from multiple inputs (Yang and Liu 2012; Yılmaz 2013). The parametric and nonparametric methods can be used for overcoming the mentioned disadvantage of ratio analysis. Parametric and nonparametric methods have some important differences in terms of the assumptions about the shape of the efficient frontier and the way they consider random error (Yılmaz 2013). The parametric techniques define a function for the cost, profit, etc., between the inputs and outputs and consider the random error, whereas nonparametric ones do not require to define a function. Besides, DEA technique has also some limitations indicated by some researchers. Jain et al. (2011) indicate that DEA cannot consider the short-term and long-term measures together, and Shafiee et al. (2016) indicate that DEA does not provide sufficient details for managerial decisions. In order to overcome these limitations, network DEA (NDEA) model (Färe and Grosskopf 2000) was proposed which can also estimate the sub-process efficiency and provide process-specific guidance to decision making unit (DMU) managers. Since the traditional DEA and NDEA models use certain input and output data for the main system, their results are sensitive to the imprecision of data. In order to represent this uncertainty, fuzzy sets (Zadeh 1965) extensions have also been developed. Beginning with Sengupta (1992), there have been developed some different fuzzy DEA models. Detailed review about different fuzzy DEA approaches and their classification can be found in Emrouznejad et al. (2014).

Due to the changes in financial sector, performance evaluation of banks became more difficult and it requires flexible analytical approaches that can consider the multi-dimensionality of the problem. Multi-criteria decision making (MCDM) methods can be very helpful in performance evaluation and policy and decision making process by providing flexibility. Since performance evaluation of banks requires more than one criterion to be considered and also appropriate data related to these criteria should be used, this study proposes a hybrid multi-criteria performance evaluation model for banking sector. The proposed model combines two MCDM methods that are simulation-integrated hesitant fuzzy linguistic term sets-based analytic hierarchy process (HFLTS-AHP) and grey relational analysis (GRA) methods. Simulation-integrated HFLTS-AHP is used to calculate the weights of the criteria based on the decision makers' judgements, and then GRA is used to rank the alternatives according to their performances based on the collected data. A real case application of the proposed model for a private bank operating in Turkey is also presented. We think that this study makes contribution to the literature in several ways. Firstly, the proposed model takes into consideration the subjectivity of decision makers by enabling them to express their opinions in the most flexible and natural way while determining the importance of performance evaluation criteria and also provide the flexibility of adding or deleting criteria depending on the problem on hand. Additionally, the presented model enables to represent both dimensions of uncertainty which are vagueness and ambiguity by using simulation technique which is based on probability theory and HFLTS-AHP method which is based on fuzzy sets, which is the main difference of the presented approach from the other approaches.

The rest of the study is organized as follows. In Sect. 2, the methodology used in the study is explained in detail and also the literature review is presented. Section 3 presents the proposed performance evaluation model. In Sect. 4, a real-life application of the presented performance evaluation model for agricultural banking sector is given. Finally, results and discussion and concluding remarks are presented, respectively.

2 Methodology and literature review

This section presents the detailed information about the methodology proposed in the study. The application of multi-criteria methods in performance evaluation is quite reasonable as mentioned previously, and there are some studies in the literature for different applications of MCDM methods in the area. Table 1 gives a summary of the applications of MCDM methods for performance evaluation studies.

As it can be seen from the summarized literature review given in Table 1, MCDM methods and their fuzzy extensions have been widely used in performance evaluation recently. Another important result that can be drawn from Table 1 is that the MCDM methods are usually applied in an integrated manner to benefit from the strength of each method.

At this point, it will be better to indicate that there have been developed new extensions of fuzzy sets (Zadeh 1965) since the introduction of the theory. These new types of fuzzy sets are type-2 fuzzy sets (Zadeh 1975), intuitionistic fuzzy sets (Atanassov 1986), fuzzy multisets (Yager 1986), non-stationary fuzzy sets (Garibaldi and Ozen 2007), hesitant fuzzy sets (Torra 2010) and hesitant fuzzy linguistic term sets (HFLTS) (Rodríguez et al. 2012). These extensions mainly differ from each other in terms of defining the membership functions. The reason for the development of these new extensions or types of fuzzy sets is to be able to better model and control uncertainty (Kahraman et al. 2016). In ordinary fuzzy sets, it is required to define a membership degree for each element of the set. Type-2 fuzzy sets allow the membership of an element to be defined as a fuzzy set. Intuitionistic fuzzy sets model uncertainty on the membership function by including some hesitation on the membership degree which is named as degree of uncertainty. Fuzzy multisets allow repeated elements in the sets, and the membership can be defined as partial. Non-stationary fuzzy sets allow to express some variation in the membership function. Hesitant fuzzy sets allow a set of possible membership degrees to be defined for an element to better express the uncertainty related to doubt. A detailed literature review for the applications of fuzzy sets and their extensions in MCDM can be found in Kahraman et al. (2015). Among these extensions, intuitionistic fuzzy sets and hesitant fuzzy sets are the most used ones of the ordinary fuzzy sets history (Kahraman 2018). Due to this reason, hesitant fuzzy sets' extension of ordinary fuzzy sets is considered in this study.

The hybrid MCDM approach proposed in this study uses simulation-integrated hesitant fuzzy linguistic term sets-based analytic hierarchy process (HFLTS-AHP) method which was proposed by Tuysuz (2018) in combination with grey relational analysis method (GRA). The significant contribution of the proposed performance evaluation model is that it can determine the importance level of each performance evaluation factor/criterion (simulation-integrated HFLTS-AHP) based on the subjective assessments of decision makers and also can rank the alternatives or bank regions (GRA) according to these criteria by using the objective data, which are the two important issues in performance evaluation studies. Before presenting the proposed hybrid model, each method used in the model will be explained in detail.

2.1 Simulation-integrated HFLTS-AHP method

Hesitant fuzzy sets (HFSs) which were developed by Torra (2010) are the extensions of regular fuzzy sets (Zadeh 1965) and allow the membership degree of an element to a set to have possible values between 0 and 1 (Torra and Narukawa 2009). HFSs are especially effective in representing the hesitancy of preferences and can be used in different levels of decision making process. A HFS can be mathematically defined as follows:

$$E = \{\langle x, h_E(x)\rangle | x \in X\} \tag{1}$$

where $h_E(x)$ is a set of some values in [0, 1], denoting the possible membership degrees of the element $x \in X$ to the set E, and $h = h_E(x)$ is a hesitant fuzzy element (Xu and Xia 2011). Basic concepts and operations about HFSs can be found in Torra and Narukawa (2009) and Torra (2010).

Hesitant fuzzy linguistic term set (HFLTS) proposed by Rodríguez et al. (2012) enables to use rich linguistic expressions and context-free grammars by using comparative terms and thus provides a linguistic and computational basis. In this study, simulation-integrated HFLTS-AHP method which was proposed by Tuysuz (2018) is used. The importance of this method is that it brings together the strengths of probability theory and fuzzy sets theory to better represent the uncertainty in pairwise comparisons of AHP method. The algorithmic procedure of the Monte Carlo simulation-integrated AHP method with HFLTS which is taken from Tuysuz (2018) is given below.

Step 1 Defining the semantics and syntax of the linguistic term set S and the context-free grammar G_H, where $G_H = \{V_N, V_T, I, P\}$

$$V_N = \{\langle \text{primary term}\rangle, \langle \text{composite term}\rangle, \langle \text{unary relation}\rangle, \langle \text{binary relation}\rangle, \langle \text{conjunction}\rangle\}$$

$$V_T = \{\text{lower than, greater than, at least, at most, between, and}, s_0, s_1, \ldots, s_g\} I \in V_N.$$

The production rules are obtained by applying Eq. (2):

$$P = \begin{cases} I ::= \langle \text{primary term}\rangle | \langle \text{composite term}\rangle, \langle \text{composite term}\rangle \\ ::= \langle \text{unary relation}\rangle \langle \text{primary term}\rangle | \langle \text{binary relation}\rangle \\ \langle \text{primary term}\rangle \langle \text{conjunction}\rangle \langle \text{primary term}\rangle, \\ \text{primary term} ::= s_0 | s_1 | \ldots | s_g, \langle \text{unary relation}\rangle :: \\ = \text{lower than} | \text{greater than} | \text{at least} | \text{at most}, \\ \langle \text{binary relation}\rangle ::= \text{between}, \langle \text{conjunction}\rangle ::= \text{and} \end{cases} \tag{2}$$

Table 1 A summary of the applications of MCDM methods in performance evaluation

Study	Method(s)	Application area
Yurdakul and Ic (2005)	AHP, TOPSIS	Manufacturing companies
Kalogeras et al. (2005)	Promethee II	Agri-food firms
Jyoti et al. (2008)	AHP, DEA	R&D organizations
Lee et al. (2008)	FAHP, BSC	IT Department
Wu et al. (2009)	BSC, FAHP, TOPSIS, VIKOR	Banks
Ertuğrul and Karakaşoğlu (2009)	FAHP, TOPSIS	Cement firms
Seçme et al. (2009)	FAHP, TOPSIS	Banks
Yang et al. (2009)	AHP, ANP	Manufacturing
Tseng (2010)	ANP, BSC, DEMATEL	Private universities
Sun (2010)	FAHP, Fuzzy TOPSIS	Notebook computer companies
Vincent and Hu (2010)	Fuzzy TOPSIS	Multiple manufacturing plants
Hsieh and Lin (2010)	Relational network DEA	International tourist hotels
Yang et al. (2010)	DEA	Banks
Tsai et al. (2010)	FAHP	Hospital
Saranga and Moser (2010)	DEA	Purchasing and supply management
Wu et al. (2010)	AHP, GRA, BSC	Banks
Wang et al. (2010)	GRA, DEA	Production and marketing
Aydogan (2011)	AHP, fuzzy TOPSIS	Aviation firms
Zeydan et al. (2011)	FAHP, fuzzy TOPSIS, DEA	Car manufacturing factory's supplier
Öztayşi et al. (2011)	ANP	E-commerce firms
Lee and Pai (2011)	DEA	TFT LCD manufacturer
Chen et al. (2011)	ANP, DEMATEL, BSC	Hot spring hotels
Wu et al. (2011)	ANP, BSC, DEMATEL, VIKOR	Education centres
Kuo and Liang (2012)	Fuzzy VIKOR	Intercity bus companies
Yalcin et al. (2012)	FAHP, TOPSIS, VIKOR	Manufacturing firms
Das et al. (2012)	FAHP, COPRAS	Technical institutions
Çelen and Yalçın (2012)	FAHP, TOPSIS, DEA	Electricity distribution utilities
Bentes et al. (2012)	AHP, BSC	Telecom company
Wu et al. (2012a, b)	AHP, VIKOR	Universities
Wu et al. (2012a, b)	FAHP, VIKOR	Aircraft maintenance staff
Önder et al. (2013)	AHP, TOPSIS	Banks
Goyal and Grover (2013)	ANP	Manufacturing
Dey and Cheffi (2013)	AHP	Manufacturing green supplier
Rabbani et al. (2014)	COPRAS, ANP, BSC	Oil producing companies
Shaverdi et al. (2014)	FAHP	Petrochemical companies
Shaik and Abdul-Kader (2014)	BSC, DEMATEL	Reverse logistics enterprise
Gürbüz and Albayrak (2014)	ANP, Choquet integral	Employees
Moghimi and Anvari (2014)	FAHP, TOPSIS	Cement firms
Rezaie et al. (2014)	FAHP, VIKOR	Cement firms
Bai et al. (2014)	Fuzzy C-Means, TOPSIS	E-commerce-based organizations
Chithambaranathan et al. (2015)	VIKOR, ELECTRE	Service supply chain
Tavana et al. (2015)	Fuzzy ANP, DEMATEL, Fuzzy DEA, BSC	Pharmaceutical companies
Omrani et al. (2015)	DEA	Electricity distribution companies
Yaghoobi and Haddadi (2016)	AHP, BSC	Telecom company
Ozcan and Tuysuz (2016)	GRA, DEMATEL	Retail stores
Varmazyar et al. (2016)	ANP, DEMATEL, ARAS, COPRAS, MOORA, TOPSIS, BSC	Research and technology organizations
Özceylan et al. (2016)	AHP, ANP, TOPSIS	Logistic
Uygun and Dede (2016)	Fuzzy DEMATEL, fuzzy ANP, fuzzy TOPSIS	Green supply chain management

Table 1 (continued)

Study	Method(s)	Application area
Li and Zhao (2016)	FAHP, fuzzy VIKOR, GRA	Eco-industrial thermal power plants
Haghighi et al. (2016)	Network DEA, BSC	Supply chains
Piltan and Sowlati (2016)	ANP	Partnerships
Görener et al. (2017)	FAHP, fuzzy TOPSIS	Airline companies' supplier
Büyüközkan and Karabulut (2017)	AHP, VIKOR	Energy project
Modak et al. (2017)	FAHP, BSC	Coal mining
Duman et al. (2017)	FAHP	Food industry
Zhou et al.(2017)	FAHP	Teaching performance
Tüysüz and Şimşek (2017)	Fuzzy hesitant AHP	Cargo sector
Salimi and Rezaei (2018)	Best–worst method (BWM)	R&D performance
Han and Trimi (2018)	Fuzzy TOPSIS	Reverse logistics
Srinivasan et al. (2019)	DEA-entropy-TOPSIS	Higher education institutions
Dos Santos et al. (2019)	Fuzzy TOPSIS	Green suppliers performance

Step 2 Collecting the pairwise comparisons of the decision makers and constructing the preference relations matrix. In the domain of group decision making, m decision makers ($E = \{e_1, e_2, \ldots, e_m\}$) select the best alternative among n alternatives ($X = \{x_1, x_2, \ldots, x_n\}$) where $m > 1$ and $n > 1$. A matrix which is composed of preference relations (p^ks) is formed as given in Eq. (3):

$$p^k = \begin{pmatrix} p_{11}^k & \cdots & p_{1m}^k \\ \vdots & \ddots & \vdots \\ p_{n1}^k & \cdots & p_{nm}^k \end{pmatrix} \quad (3)$$

where p_{ij}^k shows the degree of preference of the alternative x_i over x_j according to expert e_k.

Step 3 Converting the preference relations into HFLTS by using E_{G_H}, which is a function that converts linguistic expressions into an HFLTS. An envelope $\left[p_{ij}^{k-}, p_{ij}^{k+}\right]$ is obtained for each HFLTS.

Step 4 Calculating the numerical intervals by assigning the scale given in Table 2 to the linguistic terms.

Step 5 Simulating each pairwise comparison matrix. Each pairwise comparison matrix whose elements are expressed as intervals is simulated. Each interval-valued element in the matrix representing the uncertain preferences is defined as a uniform random variable with parameters (*a, b*) whose probability density function is defined as in Eq. (4).

$$f(x) = \begin{cases} \frac{1}{b-a}, & a \le x \le b \\ 0, & \text{otherwise} \end{cases} \quad (4)$$

where a is the minimum value and b is the maximum value.

Step 6 Calculating the priorities and checking for consistency. The averages of the simulated matrices are taken after simulating each pairwise comparison matrix. For each averaged simulated pairwise matrix A, the vector of weights w is calculated by solving Eq. (5):

$$Aw = \lambda_{\max} w \quad (5)$$

where $\lambda_{\max}$ is the largest eigenvalue of matrix A.

The consistency of each simulated pairwise comparison matrix is measured by the consistency ratio CR which is calculated by Eq. (6):

$$\mathrm{CR} = \mathrm{CI}/\mathrm{RI} \quad (6)$$

where CI is the consistency index and RI is a random index which is given in Table 3.

CI is calculated by using Eq. (7):

$$\mathrm{CI} = (\lambda_{\max} - n)/(n - 1) \quad (7)$$

A pairwise comparison matrix is accepted as inconsistent if the *CR* value is greater than 0.1.

2.2 Grey relational analysis

Grey relational analysis (GRA) is one of the important parts of grey system theory which was developed by Deng (1982). GRA presents a computationally simple and robust approach for MCDM problems and can work well with objective and discrete data (Wei 2011). It can assess quantitative and qualitative relationships between the

Table 2 Scale for linguistic terms

Equal (n)	V. low (vl)	Low (l)	Medium (m)	High (h)	V. high (vh)	A. high (ah)
1	2	3	4	5	6	7

Table 3 Random consistency index

Matrix size (n)	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

factors by using relatively small amount of data (Deng 1982). There are different applications of GRA method which can be found in Ozcan and Tuysuz (2016) and Yıldız and Tüysüz (2018). The computational steps of the GRA are as follows:

Step 1 Creating comparability sequences. Comparability sequence $X_i = \{x_i(1), x_i(2), \ldots, x_i(n)\}$ is established for each alternative. Decision matrix is formed by using comparability sequences as follows:

$$X = \begin{bmatrix} x_1(1) & x_1(2) & \ldots & x_1(n) \\ x_2(1) & x_2(2) & \ldots & x_2(n) \\ \vdots & \vdots & \ldots & \vdots \\ x_m(1) & x_m(2) & \ldots & x_m(n) \end{bmatrix} \quad (8)$$

where m is the number of alternatives ($i = 1, 2, \ldots, m$), n is the number of criteria ($j = 1, 2, \ldots, n$) and $x_i(j)$ is the value of the jth criterion of the ith alternative.

Step 2 Generating the reference sequence. A reference sequence $X_0 = \{x_0(1), x_0(2), \ldots, x_0(n)\}$ is generated according to comparability sequences. This sequence consists of the best or target values of criteria.

Step 3 Normalizing data series. Equations (9)–(11) are used for calculating the normalized values of the comparability sequences.

For the case,

the expectancy is larger-the-better,

$$x_i(j) = \frac{x_i(j) - \min_i x_i(j)}{\max_i x_i(j) - \min_i x_i(j)} \quad (9)$$

the expectancy is smaller-the-better,

$$x_i(j) = \frac{\max_i x_i(j) - x_i(j)}{\max_i x_i(j) - \min_i x_i(j)} \quad (10)$$

the expectancy is nominal-the-better,

$$x_i(j) = 1 - \frac{|x_i(j) - u_j|}{\max\{\max x_i(j) - u_j, u_j - \min x_i(j)\}} \quad (11)$$

where u_j is the nominal performance value for criterion j.

Step 4 Calculating the grey relational coefficient. Grey relational coefficient which shows the relationship between the reference sequence and comparability sequence is calculated using the normalized values as follows:

$$\gamma_i(j) = \frac{\Delta_{\min} + \xi\Delta_{\max}}{\Delta_i(j) + +\xi\Delta_{\max}} \quad (12)$$

where

$$\Delta_i(j) = |x_i(j) - x_0(j)| \quad (13)$$

$$\Delta_{\max} = \max_i \max_j |x_i(j) - x_0(j)| \quad (14)$$

$$\Delta_{\min} = \min_i \min_j |x_i(j) - x_0(j)| \quad (15)$$

and $\xi \in [0, 1]$ is the distinguishing coefficient and taken as 0.5 in most problems and is used to decrease the effect of $\Delta_{\max}$.

Step 5 Calculating the grey relational grade. Grey relational grade is calculated by using grey relational coefficients and criteria weights as follows:

$$r_i = \sum_{j=1}^{n} \gamma_i(j) * w_j. \quad (16)$$

The alternative with the highest grey relational grade (r_i) is evaluated as the best one.

In the next section, the proposed performance evaluation model for bank regions will be explained.

3 Proposed performance evaluation model

This study presents a hybrid multi-criteria performance evaluation model for banking sector which uses simulation-integrated HFLTS-AHP and GRA methods. The main contribution of this model is that it handles the performance evaluation of bank regions multidimensionally on a multi-criteria basis and can both rank the bank regions and determine the level of importance of each criterion used for evaluating bank regions according to the decision makers' subjective judgements. Simulation-integrated HFLTS-AHP method's main advantage over crisp or classical AHP method and its other extensions is that it represents both types uncertainty which are vagueness and ambiguity inherent in AHP procedure by using both probability theory and fuzzy sets theory. Steps of the proposed performance evaluation approach are explained below.

Step 1 Determining the criteria set used for performance evaluation and defining the semantics and syntax of the linguistic term set S and the context-free grammar: Criteria are determined based on the literature, sectoral applications and the experts. Semantics and syntax of the linguistic term set S and the context-free grammar G_H are also defined, and the production rules are derived as given in Eq. (2).

Step 2 Gathering evaluations of the experts by using questionnaires and constructing the preference relations matrix: The preselected group of experts make pairwise comparisons by using linguistic term sets to calculate the weights of the criteria. Then, the preference relations matrix is constructed as in Eq. (3).

Step 3 Transforming the preference relations into HFLTS by using the transformation function E_{G_H}: An envelope $\left[p_{ij}^{k-}, p_{ij}^{k+}\right]$ is obtained for each HFLTS.

Step 4 Calculating the numerical intervals: the scale given in Table 2 is assigned to the linguistic terms and the numerical intervals are obtained.

Step 5 Simulating pairwise comparison matrices. Each pairwise comparison matrix which consists of preferences expressed as intervals is simulated.

Step 6 Calculating the weights of the criteria and checking for consistency. The results of the simulation are averaged, and for each averaged simulated matrix, the vector of weights is calculated by using Eq. (5). The consistency of each pairwise comparison matrix is checked by applying Eqs. (6) and (7).

Step 7 Creating comparability sequences: For each alternative, comparability sequence is established and the decision matrix is formed by using these comparability sequences as in Eq. (8).

Step 8 Generating the reference sequence. A reference sequence which consists of the best or target values of criteria is generated according to comparability sequences.

Step 9 Normalizing data series: Both comparability and reference sequences are normalized by applying appropriate Eqs. (9)–(11) depending on the character of the criteria.

Step 10 Calculating the grey relational coefficient: Grey relational coefficient which shows the relationship between the reference sequence and comparability sequence is calculated using the normalized values by using Eqs. (12)–(15).

Step 11 Calculating the grey relational grade and ranking alternatives: Grey relational grade is calculated using grey relational coefficients and criteria weights as given in Eq. (16). Then, the alternatives are ranked according to the grey relational grade in descending order.

In the next section, a real-life application of the presented performance evaluation model for agricultural banking sector will be given.

4 An application of the proposed approach

The proposed hybrid MCDM model for agricultural banking sector that integrates simulation-integrated HFLTS-AHP and GRA methods aims at defining the weights of importance of the criteria that are used in performance evaluation of regions where bank branches are located and ranking the alternative regions according to determined criteria. Figure 1 shows the general framework for the proposed bank regional performance evaluation model.

The proposed model is applied for regional performance evaluation of agricultural banking in Turkey. As a real-life application, using the actual data of a private bank operating in Turkey, the performance of the regions in which bank operates is investigated. For this purpose, in step 1, the criteria to be used are obtained by considering the literature (Oral and Yolalan 1990; Zaim 1995; Ertuğrul and Karakaşoğlu 2009; Albayrak and Erkut 2005; Dinçer and Görener 2011) and interview with the experts from both academy and working in the banking sector. As a result, 10 criteria are determined which are given and explained in Table 4.

After determining the criteria to be used for performance evaluation, the semantics and syntax of linguistic term set S is identified as follows:

$$S = \left\{ \begin{array}{l} \text{absolutely low } (n), \text{ very low } (\text{vl}), \text{ low } (l), \text{ medium } (m), \\ \text{high } (h), \text{ very high } (\text{vh}), \text{ absolutely high } (\text{ah}) \end{array} \right\}.$$

The binding expression or context-free grammar shown with G_H is defined as presented in Table 5.

In step 2, the preference relations (p^ks) of each expert which are obtained through pairwise evaluations are gathered to form the matrix as given in Eq. (3). Linguistic pairwise evaluations of Expert 1 are shown in Table 6 as an example (see Appendix Table 17 for the linguistic pairwise evaluations of all experts).

In step 3, using the transformation function E_{G_H}, the preference relations are converted into HFLTS. Then, the HFLTS intervals or the envelopes are obtained. So as to keep the study short and make the methodology be understood more easily, the remaining calculations will be given for only the evaluations of Expert 1 (Table 6). The same calculations can easily be applied for the evaluations of other four experts who are the professionals from the banking sector and have at least 15-year experience. Obtained envelopes of Expert 1's evaluations (see Table 6) are presented in Table 7 (see Appendix Table 18 for all the obtained envelopes for the HFLTS).

The pairwise evaluations in Table 6 are first expressed as discrete sets; later, they are transformed into intervals. For example, Expert 1's preference of $C3$ with respect to $C6$ is "Between medium and very high" in linguistic terms and it can be expressed as discrete set {m, h, vh} and then as the interval [m, vh]. Similarly, Expert 1's preference of $C3$ with respect to $C7$ is "At least high" in linguistic terms and it can be expressed as discrete set {h, vh, ah} and then as the interval [h, ah] as it can be seen in Table 7.

In step 4, the scales consisting of numerical equivalents of linguistic terms in Table 8 are assigned to the HFLTS intervals. Thus, the HFLTS intervals are expressed

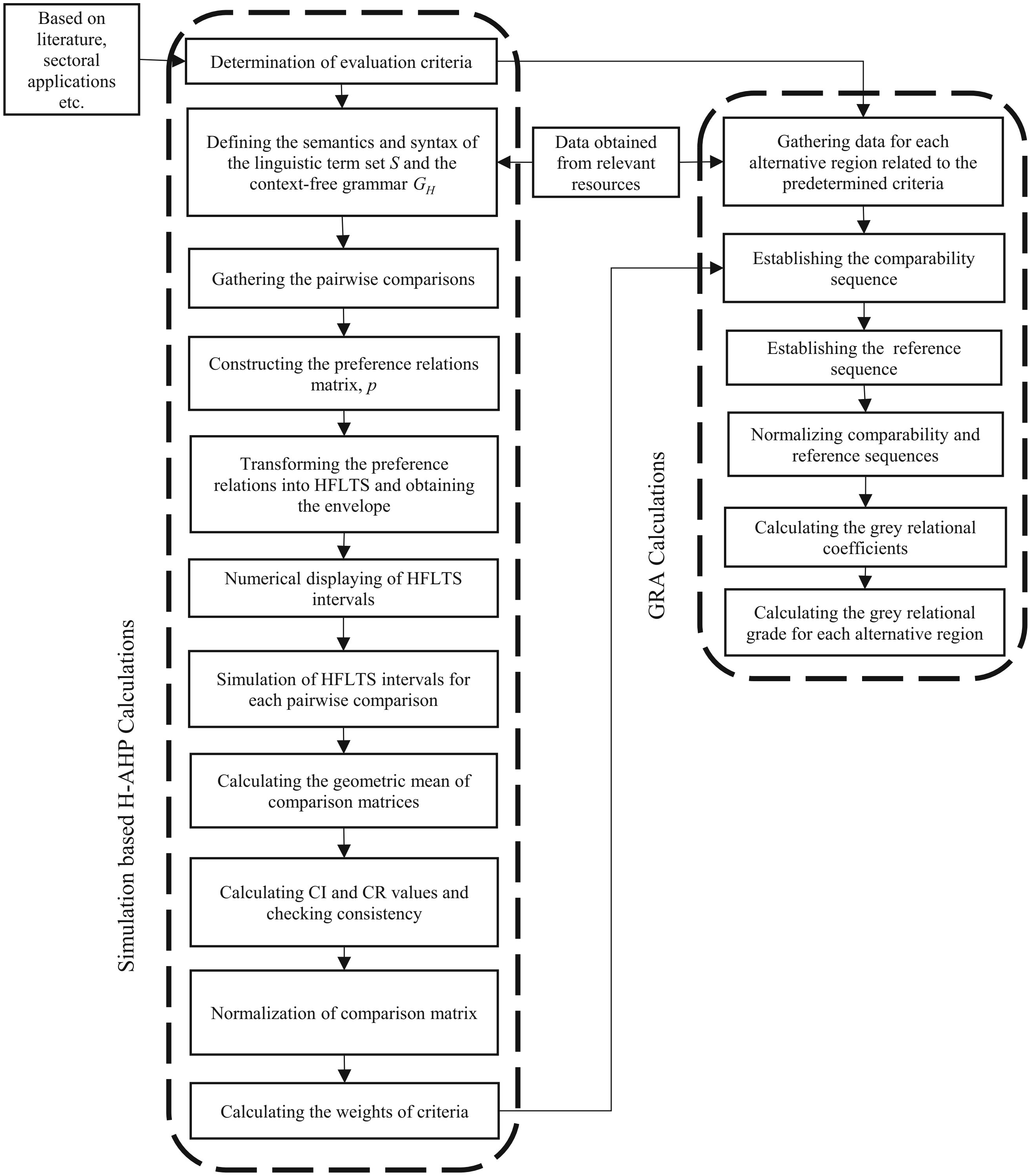

Fig. 1 Proposed bank regional performance evaluation model

numerically. After the scales are assigned to the HFLTS intervals, the comparison matrix is free of verbal expressions. Let's explain the example above. If the HFLTS interval is [*m*, vh] according to the *C*6 criterion of the *C*3 criterion, this interval is expressed as the numerical interval [3, 5]. Similarly, if the HFLTS interval is [*h*, ah] according to the *C*7 criterion of the *C*3 criterion, this interval is expressed as the numerical interval [4, 6]. Table 9 shows the numerical equivalents of the values in Table 7 (see Appendix Table 19 for all the obtained numerical envelopes for the HFLTS).

Table 4 Criteria set for the bank regional performance evaluation

Criterion code	Criterion	Criterion type	Explanation
*C*1	Volume of time deposit account (TL)	Max	Total time deposits of customers (%)
*C*2	Volume of demand deposit account (TL)	Max	Total demand deposits of customers (%)
*C*3	Credit risk	Min	Risk arising from non-repayment of debts
*C*4	Volume of producer card	Max	The credit card that provides special services to agricultural customers is called "producer card". "Volume of average producer card/targeted volume" (%)
*C*5	Volume of agriculture loans	Max	The loans that meet the needs of agricultural customers and offer special payment methods and interest to these customers are called "agricultural credits". "Volume of average agricultural credit/targeted volume" (%)
*C*6	Annual return	Max	Annual return of banks by region (TL)
*C*7	Waiting times	Min	It is the average of the time until the moment when the customers get service from the time they receive the order (minutes)
*C*8	The capacity utilization rate	Max	Ratio of capacity utilization (%)
*C*9	The transaction rate in banks office instead of ATM	Min	– (%)
*C*10	Number of active clients/number of owned clients	Max	Ratio of the number of customers who actively use products and products to the total number of active and inactive customers in the same period (%)

Table 5 Defined context-free grammar or the binding expression

Binding expression
Lower than
Greater than
At least
At most
Between
Is (exactly)

In step 5, only the upper parts of the diagonals of the evaluation matrix whose elements are expressed as uniformly distributed intervals are simulated. Random numbers are used to perform the Monte Carlo simulation analysis to better demonstrate the variability of the evaluation matrix and the uncertainty of the decision makers. In order to prevent the effects of random variations, 1000 simulation runs have been performed. The averages of the simulated elements are calculated, and a single aggregate matrix is obtained. The evaluation matrix with the average values is presented in Table 10.

After all decision makers' comparison matrices have been simulated, the bottom of the diagonals is complemented by the method of reversing the multiplication process. After the simulation, all the values in the matrices have crisp numbers. The geometric mean method is utilized for aggregating the evaluations of five experts. Table 11 shows simulated aggregate evaluation matrix of all the experts.

After the expert comparisons are aggregated into single comparison matrices, it is processed with AHP in step 6. Thus, weights of criteria are obtained and consistency is checked. The consistency check of this aggregated comparison matrix is done using the consistency index (CI) and the consistency ratio (CR). Due to the nature of human judgments, these ratios are not expected to be fully consistent. Besides, the judgements of the experts are hesitant and each pair is expressed as an interval. Accordingly, achieving a consistency ratio of 0.11, which is very close to 0.1, (makes us acceptably) shows that this matrix with fuzziness is consistent. For this reason, there is no inconvenience in the use of these criteria weights during the evaluation of bank region alternatives. The obtained importance weights of the criteria are shown in decreasing order in Table 12.

According to the results given in Table 12, the most important criterion among the determined criteria is "Volume of time deposit account (TL)" (*C*1) with the weight of 23.29% and the least important criterion is "Number of Active Clients/Number of Owned Clients" (*C*10) with the weight of 2.59%. According to the evaluations of the 5 experts, the total weight of the first three criteria (*C*1, *C*3 and *C*2) is about 55% which is more than the total weight of the remaining seven criteria.

In step 7, a comparability sequence is established for each region where branches of a private bank operating in the agricultural sector. The comparability sequence consists of performance values for each region according to the predetermined criteria. In step 8, the reference sequence is determined using the comparability sequences of 10 regions. Regions, performance values of them, weights of criteria and reference sequence are given in Table 13.

Table 6 Pairwise evaluations of the criteria with respect to goal for Expert 1

	*C*1	*C*2	*C*3	*C*4	*C*5	*C*6	*C*7	*C*8	*C*9	*C*10
Expert 1's linguistic evaluations										
*C*1	–	Between (*m* and *h*)	Is (*m*)	Between (*m* and *h*)	Between (*m* and *h*)	Is (*l*)	Between (*h* and vh)	At least (*h*)	At least (*h*)	Between (*m* and *h*)
*C*2	Between (*l* and *m*)	–	Between (*l* and *h*)	Is (*m*)	Is (*l*)	Between (vl and *m*)	Between (*m* and *h*)	Is (*h*)	At least (*h*)	Between (*h* and vh)
*C*3	Is (*m*)	Between (*l* and *h*)	–	Between (*h* and vh)	Is (vh)	Between (*m* and vh)	At least (*h*)	Is (*h*)	At least (vh)	Between (*h* and vh)
*C*4	Between (*l* and *m*)	Is (*m*)	Between (vl and *l*)	–	Is (*m*)	Between (vl and *l*)	Between (*l* and *h*)	Between (*l* and *h*)	Between (*m* and vh)	Is (vh)
*C*5	Between (*l* and *m*)	Is (*h*)	Is (vl)	Is (*m*)	–	Between (*m* and *h*)	Between (*h* and vh)	Between (*m* and vh)	Between (*m* and vh)	At least (*h*)
*C*6	Is (*h*)	Between (*m* and vh)	Between (vl and *m*)	Between (*h* and vh)	Between (*l* and *m*)	–	Between (*m* and vh)	Between (*m* and vh)	At least (*h*)	Between (*h* and vh)
*C*7	Between (vl and *l*)	Between (*l* and *m*)	At *most* (*l*)	Between (*l* and *h*)	Between (vl and *l*)	Between (vl and *m*)	–	Is (*m*)	Between (*l* and *h*)	Between (*l* and *h*)
*C*8	At most (*l*)	Is (*l*)	Is (*l*)	Between (*l* and *h*)	Between (vl and *m*)	Between (vl and *m*)	Is (*m*)	–	Between (*m* and *h*)	Between (*l* and *h*)
*C*9	At most (*l*)	At most (*l*)	At most (vl)	Between (vl and *m*)	Between (vl and *m*)	At most (*l*)	Between (*l* and *h*)	Between (*l* and *m*)	–	Is (*m*)
*C*10	Between (*l* and *m*)	Between (vl and *l*)	Between (vl and *l*)	Is (vl)	At most (*l*)	Between (vl and *l*)	Between (*l* and *h*)	Between (*l* and *h*)	Is (*m*)	–

Table 7 Obtained envelopes for the HFLTS given in Table 6

Goal	*C*1	*C*2	*C*3	*C*4	*C*5	*C*6	*C*7	*C*8	*C*9	*C*10
Expert 1's obtained envelopes										
*C*1	–	[*m*, *h*]	[*m*, *m*]	[*m*, *h*]	[*m*, *h*]	[*l*, *l*]	[*h*, vh]	[*h*, ah]	[*h*, ah]	[*m*, *h*]
*C*2	[*l*, *m*]	–	[*l*, *h*]	[*m*, *m*]	[*l*, *l*]	[vl, *m*]	[*m*, *h*]	[*h*, *h*]	[*h*, ah]	[*h*, vh]
*C*3	[*m*, *m*]	[*l*, *h*]	–	[*h*, vh]	[vh, vh]	[*m*, vh]	[*h*, ah]	[*h*, *h*]	[vh, ah]	[*h*, vh]
*C*4	[*l*, *m*]	[*m*, *m*]	[vl, *l*]	–	[*m*, *m*]	[vl, *l*]	[*l*, *h*]	[*l*, *h*]	[*m*, vh]	[vh, vh]
*C*5	[*l*, *m*]	[*h*, *h*]	[vl, vl]	[*m*, *m*]	–	[*m*, *h*]	[*h*, vh]	[*m*, vh]	[*m*, vh]	[*h*, ah]
*C*6	[*h*, *h*]	[*m*, vh]	[vl, *m*]	[*h*, vh]	[*l*, *m*]	–	[*m*, vh]	[*m*, vh]	[*h*, ah]	[*h*, vh]
*C*7	[vl, *l*]	[*l*, *m*]	[*n*, *l*]	[*l*, *h*]	[vl, *l*]	[vl, *m*]	–	[*m*, *m*]	[*l*, *h*]	[*l*, *h*]
*C*8	[*n*, *l*]	[*l*, *l*]	[*l*, *l*]	[*l*, *h*]	[vl, *m*]	[vl, *m*]	[*m*, *m*]	–	[*m*, *h*]	[*l*, *h*]
*C*9	[*n*, *l*]	[*n*, *l*]	[*n*, vl]	[vl, *m*]	[vl, *m*]	[*n*, *l*]	[*l*, *h*]	[*l*, *m*]	–	[*m*, *m*]
*C*10	[*l*, *m*]	[vl, *l*]	[vl, *l*]	[vl, vl]	[*n*, *l*]	[vl, *l*]	[*l*, *h*]	[*l*, *h*]	[*m*, *m*]	–

Table 8 Scale for linguistic terms

A. low (*n*)	V. low (vl)	Low (*l*)	Medium (*m*)	High (*h*)	V. high (vh)	A. high (ah)
0	1	2	3	4	5	6

Table 9 Obtained numerical envelopes for the HFLTS given in Table 6

Goal	*C*1	*C*2	*C*3	*C*4	*C*5	*C*6	*C*7	*C*8	*C*9	*C*10
Expert 1's obtained numerical envelopes										
*C*1	–	[3, 4]	[3, 3]	[3, 4]	[3, 4]	[2, 2]	[4, 5]	[4, 6]	[4, 6]	[3, 4]
*C*2	[2, 3]	–	[2, 4]	[3, 3]	[2, 2]	[1, 3]	[3, 4]	[4, 4]	[4, 6]	[4, 5]
*C*3	[3, 3]	[2, 4]	–	[4, 5]	[5, 5]	[3, 5]	[4, 6]	[4, 4]	[5, 6]	[4, 5]
*C*4	[2, 3]	[3, 3]	[1, 2]	–	[3, 3]	[1, 2]	[2, 4]	[2, 4]	[3, 5]	[5, 5]
*C*5	[2, 3]	[4, 4]	[1, 1]	[3, 3]	–	[3, 4]	[4, 5]	[3, 5]	[3, 5]	[4, 6]
*C*6	[4, 4]	[3, 5]	[1, 3]	[4, 5]	[2, 3]	–	[3, 5]	[3, 5]	[4, 6]	[4, 5]
*C*7	[1, 2]	[2, 3]	[0, 2]	[2, 4]	[1, 2]	[1, 3]	–	[3, 3]	[2, 4]	[2, 4]
*C*8	[0, 2]	[2, 2]	[2, 2]	[2, 4]	[1, 3]	[1, 3]	[3, 3]	–	[3, 4]	[2, 4]
*C*9	[0, 2]	[0, 2]	[0, 1]	[1, 3]	[1, 3]	[0, 2]	[2, 4]	[2, 3]	–	[3, 3]
*C*10	[2, 3]	[1, 2]	[1, 2]	[1, 1]	[0, 2]	[1, 2]	[2, 4]	[2, 4]	[3, 3]	–

In step 9, the comparability sequence is normalized. For this application, Eq. (9) is applied for the benefit criteria (*C*1, *C*2, *C*4, *C*5, *C*6, *C*8 and *C*10) and Eq. (10) for the cost criteria (*C*3, *C*7 and *C*9), respectively. The calculated normalized values for the bank regions are given in Table 14.

In step 10, grey relational coefficient which shows the relationship between the reference sequence and

Table 10 Simulated decision matrix for Expert 1

Goal	*C*1	*C*2	*C*3	*C*4	*C*5	*C*6	*C*7	*C*8	*C*9	*C*10
Expert 1's simulated preferences										
*C*1	1	2.5419	2.9826	1.5001	1.9966	4.4928	4.4962	3.4964	4.4881	5.5107
*C*2	0.3934	1	1.9870	2.9735	0.9980	5.0290	3.0128	1.5059	0.9998	2.0031
*C*3	0.3353	0.5033	1	5.5037	4.5051	1.9864	4.9643	3.5106	4.4905	2.4958
*C*4	0.6666	0.3363	0.1817	1	1.5212	4.0000	3.4996	3.0032	2.9933	2.0068
*C*5	0.5009	1.0020	0.2220	0.6574	1	4.0154	4.4906	4.0000	3.5010	3.4955
*C*6	0.2226	0.1988	0.5034	0.2500	0.2490	1	0.5036	4.5027	5.0000	2.5090
*C*7	0.2224	0.3319	0.2014	0.2858	0.2227	1.9856	1	2.5088	1.0000	2.0247
*C*8	0.2860	0.6641	0.2849	0.3330	0.2500	0.2221	0.3986	1	2.9996	3.0238
*C*9	0.2228	1.0002	0.2227	0.3341	0.2856	0.2000	1.0000	0.3334	1	1.9855
*C*10	0.1815	0.4992	0.4007	0.4983	0.2861	0.3986	0.4939	0.3307	0.5037	1

Table 11 Simulated aggregate evaluation matrix

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
C1	1	3.0852	3.0573	3.1181	3.0389	2.7856	4.7823	4.3281	4.9953	4.2505
C2	0.3241	1	2.8333	2.6701	1.9006	2.2947	3.3841	3.0924	3.3168	3.3802
C3	0.3271	0.3529	1	4.5702	4.3822	3.2942	4.9747	3.6625	5.0583	4.0849
C4	0.3207	0.3745	0.2188	1	2.2521	1.9633	2.9668	3.4666	4.0411	3.9761
C5	0.3291	0.5262	0.2282	0.4440	1	3.4704	4.3912	4.0611	4.3179	4.0612
C6	0.3590	0.4358	0.3036	0.5093	0.2882	1	3.1381	4.5879	5.0866	4.0708
C7	0.2091	0.2955	0.2010	0.3371	0.2277	0.3187	1	2.7927	2.3980	2.5644
C8	0.2310	0.3234	0.2730	0.2885	0.2462	0.2180	0.3581	1	3.2749	2.9868
C9	0.2002	0.3015	0.1977	0.2475	0.2316	0.1966	0.4170	0.3054	1	2.4565
C10	0.2353	0.2958	0.2448	0.2515	0.2462	0.2457	0.3900	0.3348	0.4071	1

Table 12 Weights of the evaluation criteria

Criterion code	Criterion	Weights
C1	Volume of time deposit account (TL)	0.2329
C3	Credit risk	0.1725
C2	Volume of demand deposit account (TL)	0.1491
C5	Volume of agriculture loans	0.1089
C4	Volume of producer card	0.1012
C6	Annual return	0.0883
C7	Waiting times	0.0475
C8	Capacity utilization rate	0.0434
C9	Rate of the transaction in banks office instead of ATM	0.0302
C10	Number of active clients/number of owned clients	0.0259

comparability sequence is calculated using the normalized values by using Eqs. (12)–(15). Table 15 presents the calculated grey relational coefficients for 10 bank regions.

Finally, in the last step, the grey relational grade of each region is calculated using grey relational coefficients and the weights of the criteria which are determined by simulation-integrated HFLTS-AHP method in step 6. Then, the regions are ranked by using the grey relational grades. The higher the grey relational degree, the better the region performance. The grey relational grades and ranks of the regions are presented in Table 16.

According to the results presented in Table 16, the best 3 regions for performance evaluation of agricultural serving are İstanbul Anadolu, Marmara and Batı Anadolu with the

Table 13 Comparability sequences for the regions

Criterion type	Max	Max	Min	Max	Max	Max	Min	Max	Min	Max
Weights	0.2329	0.1491	0.1725	0.1012	0.1089	0.0883	0.0475	0.0434	0.0302	0.0259
Criterion code	C1 (%)	C2 (%)	C3 (%)	C4 (%)	C5 (%)	C6 (%)	C7 (%)	C8 (%)	C9 (%)	C10 (%)
Regions										
Akdeniz	104.16	106.86	0.7091	117.83	111.71	56.122.369	404	49	54	86
Başkent	87.41	88.00	0.6982	118.24	113.73	63.593.264	791	41	30	88
Batı Anadolu	129.42	98.90	0.718	114.57	119.55	130.237.928	654	76	37	80
Çukurova	97.45	82.62	0.7093	114.80	115.22	82.481.228	502	52	61	84
Güneydoğu Anadolu	110.19	108.26	0.7014	115.00	119.74	61.459.973	366	42	33	86
İstanbul Anadolu	120.10	105.84	0.6937	129.62	111.81	35.662.450	852	71	32	84
Karadeniz	111.18	106.54	0.7096	120.68	123.36	69.639.819	566	75	56	67
Marmara	133.92	107.59	0.7087	115.17	114.89	59.427.758	907	57	20	86
Orta Anadolu	109.40	89.92	0.7035	116.81	125.70	99.502.012	573	78	92	90
Trakya	102.79	103.58	0.7084	113.63	121.68	61.210.531	432	82	30	86
Reference sequence	133.92	108.26	0.6937	129.62	125.70	130.237.928	366	82	20	90

Table 14 Normalized values of the 10 bank regions

Criterion code	*C*1	*C*2	*C*3	*C*4	*C*5	*C*6	*C*7	*C*8	*C*9	*C*10
Regions										
Akdeniz	0.360	0.950	0.370	0.260	0.000	0.220	0.930	0.200	0.530	0.820
Başkent	0.000	0.210	0.810	0.290	0.140	0.300	0.210	0.000	0.860	0.920
Batı Anadolu	0.900	0.630	0.000	0.060	0.560	1.000	0.470	0.850	0.760	0.560
Çukurova	0.220	0.000	0.360	0.070	0.250	0.500	0.750	0.270	0.430	0.720
Güneydoğu Anadolu	0.490	1.000	0.680	0.090	0.570	0.270	1.000	0.020	0.820	0.810
İstanbul Anadolu	0.700	0.910	1.000	1.000	0.010	0.000	0.100	0.730	0.830	0.750
Karadeniz	0.510	0.930	0.350	0.440	0.830	0.360	0.630	0.830	0.500	0.000
Marmara	1.000	0.970	0.380	0.100	0.230	0.250	0.000	0.390	1.000	0.840
Orta Anadolu	0.470	0.280	0.600	0.200	1.000	0.680	0.620	0.900	0.000	1.000
Trakya	0.330	0.820	0.400	0.000	0.710	0.270	0.880	1.000	0.860	0.850
Reference sequence	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table 15 Grey relational coefficients of the 10 regions

Criterion	*C*1	*C*2	*C*3	*C*4	*C*5	*C*6	*C*7	*C*8	*C*9	*C*10
Regions										
Akdeniz	0.4386	0.9014	0.4407	0.4042	0.3333	0.3895	0.8768	0.3832	0.5143	0.7345
Başkent	0.3333	0.3876	0.7280	0.4127	0.3689	0.4151	0.3889	0.3333	0.7826	0.8555
Batı Anadolu	0.8378	0.5780	0.3333	0.3470	0.5321	1.0000	0.4843	0.7736	0.6792	0.5306
Çukurova	0.3893	0.3333	0.4378	0.3504	0.4004	0.4975	0.6654	0.4059	0.4675	0.6441
Güneydoğu Anadolu	0.4949	1.0000	0.6132	0.3535	0.5401	0.4074	1.0000	0.3388	0.7347	0.7298
İstanbul Anadolu	0.6272	0.8413	1.0000	1.0000	0.3350	0.3333	0.3576	0.6508	0.7500	0.6659
Karadeniz	0.5055	0.8817	0.4329	0.4720	0.7492	0.4383	0.5749	0.7455	0.5000	0.3333
Marmara	1.0000	0.9504	0.4468	0.3563	0.3929	0.4004	0.3333	0.4505	1.0000	0.7614
Orta Anadolu	0.4867	0.4115	0.5533	0.3844	1.0000	0.6061	0.5665	0.8367	0.3333	1.0000
Trakya	0.4276	0.7326	0.4529	0.3333	0.6352	0.4065	0.8039	1.0000	0.7826	0.7737

relational grades of 0.696, 0.651 and 0.611, respectively. Akdeniz, Başkent and Çukurova have the worst performance with the relational grades of 0.517, 0.458 and 0.419, respectively. The average of relational grades of 10 regions is 0.565. "İstanbul Anadolu", "Marmara", "Batı Anadolu", "Güneydoğu Anadolu", "Karadeniz", Orta Anadolu" have relational grades which are more than the average. The other 4 regions' relational grades are below the average.

Table 16 Grey relational grades and ranks of the 10 regions

Region	Grey relational grade (Γi)	Rank
Akdeniz	0.517	8
Başkent	0.458	9
Batı Anadolu	0.611	3
Çukurova	0.419	10
Güneydoğu Anadolu	0.604	4
İstanbul Anadolu	0.696	1
Karadeniz	0.575	5
Marmara	0.651	2
Orta Anadolu	0.571	6
Trakya	0.551	7

5 Results and discussion

The purpose of evaluating the performance is analysing the current situation for increasing the efficiency and checking whether the planned performance has been achieved. By looking at the performance results of the banks, they can gain information about their regions and can make decisions accordingly.

Growing population, changing climatic conditions, drought, changing consumer preferences, changing agriculture policies and the different fluctuations in economic conditions have important effect on agricultural sector. Particularly, economic conditions are at the forefront for agriculture even in fertile lands like Turkey. Farmers may need support from the banks to grow their products and to improve their productivity. In this context, agricultural banking has an important place for farmers. In this study, the regional performance of a private bank operating in the agricultural sector in Turkey is evaluated. For this purpose, this study presents a hybrid performance evaluation model which integrates simulation-integrated HFLTS-AHP and GRA methods to provide a better assessment of the performances of regions in the banking sector. The proposed model enables both to determine the importance level of each criterion by simulation-integrated HFLTS-AHP method and to rank 10 regions operating in the agricultural banking by using GRA method.

The results for the evaluation of criteria show (Table 12) that "Volume of time deposit account (TL)" (0.2329), "Credit risk" (0.1725) and "Volume of demand deposit account (TL)" (0.1491) have higher weight or level of importance, while "Number of Active Clients/Number of Owned Clients" (0.0259) has the lowest weight. According to the ranking results of the bank regions (Table 16), it is found that "Istanbul Anatolia" region has the best performance, while "Çukurova" region has the worst performance among the region alternatives under the criteria determined. The reason for the differences in performances of regions is due to the fact that agricultural products grown in each region are different and farmers need different financial services. Since "Istanbul Anatolia" and "Marmara" regions are where the population is the most intensive and the consumption is the greatest, it could have caused high sales. High sale means that agricultural customers have high amount of time deposits. In addition, agricultural customers in these regions may have advantages especially in terms of transportation costs and high volume sales since they are closer to region where there is high consumption. Besides, the cost of land, the cost of seeds, etc., which change from region to region, can increase costs for these regions and can cause more credits than other regions. By looking at the values of the regions, although it is expected that "Marmara" region will have better performance than "Istanbul Anatolia" region when evaluated according to 3 criteria with the highest weights ($C1$, $C3$ and $C2$), it is seen that "Istanbul Anatolia" is the first in the ranking which cannot be found out without a detailed analysis. It should also be stated that as the number of the criteria and the number of alternatives increase, it will not be possible to evaluate performance so easily and a comprehensive and quantitative analysis method as presented in this study will be required. As it can be seen from the proposed model, MCDM approaches allow decision makers/managers to compare alternatives (regions) based on a numerical basis by providing such a comprehensive analysis.

6 Conclusion

Evaluation of regional performance in the banking sector, which has a significant share in the economy, is an important issue. In the banking sector where intense competition is experienced, both commercial banking branches and other banks operating in the other specialized areas should evaluate their performance in order to improve productivity and increase their competitiveness. They also need systematic performance evaluation models to take the necessary tactical and strategic actions such as launching new products and services and planning incentive campaigns for their customers.

This performance evaluation process has to rely on flexible and analytic methods that can handle the multidimensionality of the problem. This study presents a hybrid multi-criteria performance evaluation model for banking sector. The proposed model takes into consideration more than one criterion and use appropriate data while considering the opinions of the decision makers. The proposed model combines two MCDM methods that are simulation-integrated HFLTS-AHP method to determine the importance level of each criterion according to the decision makers' judgements and GRA method to rank regions of bank branches according to their performance values.

One of the important issues in performance evaluation problems is the discrimination of the evaluation criteria or in other words finding the relative importance of each criterion. This mainly depends on the experts' or decision makers' subjective judgements. While making the pairwise comparisons to determine the relative importance, the decision makers are expected to express their opinions depending on their professional knowledge and experience by using fuzzy linguistic expressions that include hesitancy due to human nature. The simulation-integrated HFLTS-AHP method can handle this in the most natural and appropriate way. The importance of presented methodology is that it uses both probability theory and fuzzy sets theory together in representing the uncertainty. Besides, although the presented approach is applied for agricultural banking performance evaluation, the model gives the flexibility of adding or deleting criteria and thus can be applied in different sectors and also can be used for many real-life MCDM problems other than performance evaluation.

For further research, interested researchers may consider the application of the presented simulation-integrated HFLTS-AHP method and its integrated use with other crisp or fuzzy MCDM methods.

Compliance with ethical standards

Conflict of interest Fatih Tüysüz declares that he has no conflict of interest. Nurdan Yıldız declares that she has no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

Appendix A

See Tables 17, 18 and 19.

Table 17 Pairwise evaluations of the criteria with respect to goal

	*C*1	*C*2	*C*3	*C*4	*C*5	*C*6	*C*7	*C*8	*C*9	*C*10
Expert 1's linguistic evaluations										
*C*1	–	Between (*m* and *h*)	Is (*m*)	Between (*m* and *h*)	Between (*m* and *h*)	Is (*l*)	Between (*h* and vh)	At least (*h*)	At least (*h*)	Between (*m* and *h*)
*C*2	Between (*l* and *m*)	–	Between (*l* and *h*)	Is (*m*)	Is (*l*)	Between (vl and *m*)	Between (*m* and *h*)	Is (*h*)	At least (*h*)	Between (*h* and vh)
*C*3	Is (*m*)	Between (*l* and *h*)	–	Between (*h* and vh)	Is (vh)	Between (*m* and vh)	At least (*h*)	Is (*h*)	At least (vh)	Between (*h* and vh)
*C*4	Between (*l* and *m*)	Is (*m*)	Between (vl and *l*)	–	Is (*m*)	Between (vl and *l*)	Between (*l* and *h*)	Between (*l* and *h*)	Between (*m* and vh)	Is (vh)
*C*5	Between (*l* and *m*)	Is (*h*)	Is (vl)	Is (*m*)	–	Between (*m* and *h*)	Between (*h* and vh)	Between (*m* and vh)	Between (*m* and vh)	At least (*h*)
*C*6	Is (*h*)	Between (*m* and vh)	Between (vl and *m*)	Between (*h* and vh)	Between (*l* and *m*)	–	Between (*m* and vh)	Between (*m* and vh)	At least (*h*)	Between (*h* and vh)
*C*7	Between (vl and *l*)	Between (*l* and *m*)	At most (*l*)	Between (*l* and *h*)	Between (vl and *l*)	Between (vl and *m*)	–	Is (*m*)	Between (*l* and *h*)	Between (*l* and *h*)
*C*8	At most (*l*)	Is (*l*)	Is (*l*)	Between (*l* and *h*)	Between (vl and *m*)	Between (vl and *m*)	Is (*m*)	–	Between (*m* and *h*)	Between (*l* and *h*)
*C*9	At most (*l*)	At most (*l*)	At most (vl)	Between (vl and *m*)	Between (vl and *m*)	At most (*l*)	Between (*l* and *h*)	Between (*l* and *m*)	–	Is (*m*)
*C*10	Between (*l* and *m*)	Between (vl and *l*)	Between (vl and *l*)	Is (vl)	At most (*l*)	Between (vl and *l*)	Between (*l* and *h*)	Between (*l* and *h*)	Is (*m*)	–
Expert 2's linguistic evaluations										
*C*1	–	Is (*m*)	Between (*l* and *h*)	Between (*m* and vh)	Between (*l* and *h*)	Between (*l* and *h*)	At least (vh)	At least (vh)	At least (*h*)	Is (*h*)
*C*2	Is (*m*)	–	Between (*m* and *h*)	Between (*l* and *h*)	Between (*l* and *m*)	Between (*l* and *m*)	Is (*m*)	Between (*m* and *h*)	Between (*m* and vh)	Between (*m* and vh)
*C*3	Between (*l* and *h*)	Between (*l* and *m*)	–	At least (*h*)	Between (*h* and vh)	Between (*m* and *h*)	At least (*h*)	Between (*l* and *h*)	At least (*h*)	At least (*h*)
*C*4	Between (vl and *m*)	Between (*l* and *h*)	At most (*l*)	–	Between (*l* and *m*)	Between (*l* and *m*)	Between (*l* and *m*)	Between (*m* and *h*)	At least (*h*)	At least (*h*)
*C*5	Between (*l* and *h*)	Between (*m* and *h*)	Between (vl and *l*)	Between (*m* and *h*)	–	Is (*h*)	At least (*h*)	At least (*h*)	Is (ah)	Between (*h* and vh)
*C*6	Between (*l* and *h*)	Between (*m* and *h*)	Between (*l* and *m*)	Between (*m* and *h*)	Is (*l*)	–	At least (vh)	At least (*h*)	At least (*h*)	At least (*h*)
*C*7	At most (vl)	Is (*m*)	At most (*l*)	Between (*m* and *h*)	At most (*l*)	At most (vl)	–	Between (*l* and *m*)	Between (*l* and *m*)	Between (*m* and *h*)
*C*8	At most (vl)	Between (*l* and *m*)	Between (*l* and *h*)	Between (*l* and *m*)	At most (*l*)	At most (*l*)	Between (*m* and *h*)	–	Between (*l* and *h*)	Between (*l* and *m*)
*C*9	At most (*l*)	Between (vl and *m*)	At most (*l*)	At most (*l*)	Is (*n*)	At most (*l*)	Between (*m* and *h*)	Between (*l* and *h*)	–	Between (*l* and *h*)

Table 17 (continued)

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
C10	Is (*l*)	Between (vl and *m*)	At most (*l*)	At most (*l*)	Between (vl and *l*)	At most (*l*)	Between (*l* and *m*)	Between (*m* and *h*)	Between (*l* and *h*)	–
Expert 3's linguistic evaluations										
C1	–	Between (v*l* and *h*)	Between (*l* and *h*)	Between (vl and *l*)	Between (vl and *m*)	Between (*h* and vh)	Between (*h* and vh)	Between (*m* and *h*)	Between (*h* and vh)	At least (vh)
C2	Between (l and vh)	–	Between (vl and *m*)	Between (*l* and *h*)	At least (*l*)	At least (*h*)	Between (*l* and *h*)	Between (vl and *l*)	At most (*l*)	Between (vl and *m*)
C3	Between (*l* and *h*)	Between (*m* and vh)	–	At least (vh)	Between (*h* and vh)	Between (vl and *m*)	At least (*h*)	Between (*m* and *h*)	Between (*h* and vh)	Between (*l* and *m*)
C4	Between (*h* and vh)	Between (*l* and *h*)	At most (vl)	–	Between (vl and *l*)	Is (*h*)	Between (*m* and *h*)	Between (*l* and *h*)	Between (*l* and *h*)	Between (vl and *m*)
C5	Between (*m* and vh)	At most (*h*)	Between (vl and *l*)	Between (*h* and vh)	–	Between (vl and *m*)	Between (*h* and vh)	Is (*h*)	Between (*m* and *h*)	Between (l and vh)
C6	Between (vl and *l*)	At most (*l*)	Between (*m* and vh)	Is (*l*)	Between (*m* and vh)	–	At least (vh)	Between (*h* and vh)	Is (vh)	Between (*l* and *m*)
C7	Between (vl and *l*)	Between (*l* and *h*)	At most (*l*)	Between (*l* and *m*)	Between (vl and *l*)	At most (vl)	–	Between (*l* and *m*)	Is (vl)	Between (vl and *m*)
C8	Between (*l* and *m*)	Between (*h* and vh)	Between (*l* and *m*)	Between (*l* and *h*)	Is (*l*)	Between (vl and *l*)	Between (*m* and *h*)	–	Between (*l* and *h*)	Between (*l* and *h*)
C9	Between (vl and *l*)	At least (*h*)	Between (vl and *l*)	Between (*l* and *h*)	Between (*l* and *m*)	Is (vl)	Is (vh)	Between (*l* and *h*)	–	Between (vl and *m*)
C10	At most (vl)	Between (*m* and vh)	Between (*m* and *h*)	Between (*m* and vh)	Between (v*l* and *h*)	Between (*m* and *h*)	Between (*m* and vh)	Between (*l* and *h*)	Between (*m* and vh)	–
Expert 4's linguistic evaluations										
C1	–	Between (*m* and *h*)	Between (*l* and *m*)	Between (*m* and vh)	Between (*m* and *h*)	Between (*l* and *h*)	At least (*h*)	Between (*h* and vh)	At least (*h*)	Between (*m* and vh)
C2	Between (*l* and *m*)	–	Between (*m* and *h*)	Between (*l* and *m*)	Is (*l*)	Between (*l* and *m*)	Between (*m* and *h*)	Between (*h* and vh)	At least (*h*)	Between (*m* and *h*)
C3	Between (*m* and *h*)	Between (*l* and *m*)	–	Is (*h*)	Is (*h*)	Between (*m* and *h*)	Between (*h* and vh)	Between (*m* and *h*)	Between (*h* and vh)	Between (*h* and vh)
C4	Between (vl and *m*)	Between (*m* and *h*)	Is (*l*)	–	Between (vl and *m*)	Is (*l*)	Between (*l* and *m*)	Between (*h* and vh)	Between (*m* and vh)	Between (*m* and vh)
C5	Between (*l* and *m*)	Is (*h*)	Is (*l*)	Between (*m* and vh)	–	Is (*m*)	Between (*m* and vh)	Is (*h*)	Between (*m* and vh)	Between (*m* and vh)
C6	Between (*l* and *h*)	Between (*m* and *h*)	Between (*l* and *m*)	Is (*h*)	Is (*m*)	–	At least (*h*)	Between (*h* and vh)	Between (*h* and vh)	Between (*m* and vh)
C7	At most (*l*)	Between (*l* and *m*)	Between (vl and *l*)	Between (*m* and *h*)	Between (vl and *m*)	At most (*l*)	–	Between (*l* and *h*)	Between (*l* and *h*)	Between (*m* and *h*)
C8	Between (vl and *l*)	Between (vl and *l*)	Between (*l* and *m*)	Between (vl and *l*)	Is (*l*)	Between (vl and *l*)	Between (*l* and *h*)	–	Is (*h*)	Between (*l* and *h*)

Table 17 (continued)

	*C*1	*C*2	*C*3	*C*4	*C*5	*C*6	*C*7	*C*8	*C*9	*C*10
*C*9	At most (*l*)	At most (*l*)	Between (vl and *l*)	Between (vl and *m*)	Between (vl and *m*)	Between (vl and *l*)	Between (*l* and *h*)	Is (*l*)	–	Between (*l* and *m*)
*C*10	Between (vl and *m*)	Between (*l* and *m*)	Between (vl and *l*)	Between (vl and *m*)	Between (vl and *m*)	Between (vl and *m*)	Between (*l* and *m*)	Between (*l* and *h*)	Between (*m* and *h*)	–
Expert 5's linguistic evaluations										
*C*1	–	Between (*l* and *h*)	Is (*h*)	Between (*m* and *h*)	Between (*m* and *h*)	Between (*l* and *m*)	Between (*h* and vh)	Between (*m* and *h*)	At least (vh)	Between (*h* and vh)
*C*2	Between (*l* and *h*)	–	Between (*l* and *m*)	Is (*l*)	Between (*l* and *m*)	At most (*l*)	Is (*h*)	Is (*m*)	Between (*m* and vh)	Between (*m* and *h*)
*C*3	Is (*l*)	Between (*m* and *h*)	–	Between (*m* and vh)	Between (*m* and vh)	Is (*h*)	At least (vh)	Between (*h* and vh)	Is (ah)	Between (*h* and vh)
*C*4	Between (*l* and *m*)	Is (*h*)	Between (vl and *m*)	–	Between (*l* and *m*)	At most (*l*)	Between (*m* and *h*)	Between (*m* and *h*)	Between (*h* and vh)	Is (vh)
*C*5	Between (*l* and *m*)	Between (*m* and *h*)	Between (vl and *m*)	Between (*m* and *h*)	–	Between (*l* and *h*)	Between (*l* and *h*)	Between (*m* and *h*)	Between (*h* and vh)	Between (*m* and *h*)
*C*6	Between (*m* and *h*)	At least (*h*)	Is (*l*)	At least (*h*)	Between (*l* and *h*)	–	At least (vh)	At least (*h*)	Is (ah)	At least (*h*)
*C*7	Between (vl and *l*)	Is (*l*)	At most (vl)	Between (*l* and *m*)	Between (*l* and *h*)	At most (vl)	–	Is (*m*)	Between (*m* and *h*)	Between (vl and *l*)
*C*8	Between (*l* and *m*)	Is (*m*)	Between (vl and *l*)	Between (*l* and *m*)	Between (*l* and *m*)	At most (*l*)	Is (*m*)	–	Is (*m*)	Between (*m* and *h*)
*C*9	At most (vl)	Between (vl and *m*)	Is (*n*)	Between (vl and *l*)	Between (vl and *l*)	Is (*n*)	Between (*l* and *m*)	Is (*m*)	–	Is (*l*)
*C*10	Between (vl and *l*)	Between (*l* and *m*)	Between (vl and *l*)	Is (vl)	Between (*l* and *m*)	At most (*l*)	Between (*h* and vh)	Between (*l* and *m*)	Is (*h*)	–

Table 18 Obtained envelopes for the HFLTS given in Table 17

	*C*1	*C*2	*C*3	*C*4	*C*5	*C*6	*C*7	*C*8	*C*9	*C*10
Expert 1's obtained envelopes										
*C*1	–	[*m*, *h*]	[*m*, *m*]	[*m*, *h*]	[*m*, *h*]	[*l*, *l*]	[*h*, vh]	[*h*, ah]	[*h*, ah]	[*m*, *h*]
*C*2	[*l*, *m*]	–	[*l*, *h*]	[*m*, *m*]	[*l*, *l*]	[vl, *m*]	[*m*, *h*]	[*h*, *h*]	[*h*, ah]	[*h*, vh]
*C*3	[*m*, *m*]	[*l*, *h*]	–	[*h*, vh]	[vh, vh]	[*m*, vh]	[*h*, ah]	[*h*, *h*]	[vh, ah]	[*h*, vh]
*C*4	[*l*, *m*]	[*m*, *m*]	[vl, *l*]	–	[*m*, *m*]	[vl, *l*]	[*l*, *h*]	[*l*, *h*]	[*m*, vh]	[vh, vh]
*C*5	[*l*, *m*]	[*h*, *h*]	[vl, vl]	[*m*, *m*]	–	[*m*, *h*]	[*h*, vh]	[*m*, vh]	[*m*, vh]	[*h*, ah]
*C*6	[*h*, *h*]	[*m*, vh]	[vl, *m*]	[*h*, vh]	[*l*, *m*]	–	[*m*, vh]	[*m*, vh]	[*h*, ah]	[*h*, vh]
*C*7	[vl, *l*]	[*l*, *m*]	[*n*, *l*]	[*l*, *h*]	[vl, *l*]	[vl, *m*]	–	[*m*, *m*]	[*l*, *h*]	[*l*, *h*]
*C*8	[*n*, *l*]	[*l*, *l*]	[*l*, *l*]	[*l*, *h*]	[vl, *m*]	[vl, *m*]	[*m*, *m*]	–	[*m*, *h*]	[*l*, *h*]
*C*9	[*n*, *l*]	[*n*, *l*]	[*n*, vl]	[vl, *m*]	[vl, *m*]	[*n*, *l*]	[*l*, *h*]	[*l*, *m*]	–	[*m*, *m*]
*C*10	[*l*, *m*]	[vl, *l*]	[vl, *l*]	[vl, vl]	[*n*, *l*]	[vl, *l*]	[*l*, *h*]	[*l*, *h*]	[*m*, *m*]	–
Expert 2's obtained envelopes										
*C*1	–	[*m*, *m*]	[*l*, *h*]	[*m*, vh]	[*l*, *h*]	[*l*, *h*]	[vh, ah]	[vh, ah]	[*h*, ah]	[*h*, *h*]
*C*2	[*m*, *m*]	–	[*m*, *h*]	[*l*, *h*]	[*l*, *m*]	[*l*, *m*]	[*m*, *m*]	[*m*, *h*]	[*m*, vh]	[*m*, vh]
*C*3	[*l*, *h*]	[*l*, *m*]	–	[*h*, ah]	[*h*, vh]	[*m*, *h*]	[*h*, ah]	[*l*, *h*]	[*h*, ah]	[*h*, ah]
*C*4	[vl, *m*]	[*l*, *h*]	[*n*, *l*]	–	[*l*, *m*]	[*l*, *m*]	[*l*, *m*]	[*m*, *h*]	[*h*, ah]	[*h*, ah]
*C*5	[*l*, *h*]	[*m*, *h*]	[vl, *l*]	[*m*, *h*]	–	[*h*, *h*]	[*h*, ah]	[*h*, ah]	[ah, ah]	[*h*, vh]
*C*6	[*l*, *h*]	[*m*, *h*]	[*l*, *m*]	[*m*, *h*]	[*l*, *l*]	–	[vh, ah]	[*h*, ah]	[*h*, ah]	[*h*, ah]
*C*7	[*n*, vl]	[*m*, *m*]	[*n*, *l*]	[*m*, *h*]	[*n*, *l*]	[*n*, vl]	–	[*l*, *m*]	[*l*, *m*]	[*m*, *h*]
*C*8	[*n*, vl]	[*l*, *m*]	[*l*, *h*]	[*l*, *m*]	[*n*, *l*]	[*n*, *l*]	[*m*, *h*]	–	[*l*, *h*]	[*l*, *m*]
*C*9	[*n*, *l*]	[vl, *m*]	[*n*, *l*]	[*n*, *l*]	[*n*, *n*]	[*n*, *l*]	[*m*, *h*]	[*l*, *h*]	–	[*l*, *h*]
*C*10	[*l*, *l*]	[vl, *m*]	[*n*, *l*]	[*n*, *l*]	[vl, *l*]	[*n*, *l*]	[*l*, *m*]	[*m*, *h*]	[*l*, *h*]	–
Expert 3's obtained envelopes										
*C*1	–	[vl, *h*]	[*l*, *h*]	[vl, *l*]	[vl, *m*]	[*h*, vh]	[*h*, vh]	[*m*, *h*]	[*h*, vh]	[vh, ah]
*C*2	[l, vh]	–	[vl, *m*]	[*l*, *h*]	[*n*, *l*]	[*h*, ah]	[*l*, *h*]	[vl, *l*]	[*n*, *l*]	[vl, *m*]
*C*3	[*l*, *h*]	[*m*, vh]	–	[vh, ah]	[*h*, vh]	[vl, *m*]	[*h*, ah]	[*m*, *h*]	[*h*, vh]	[*l*, *m*]
*C*4	[*h*, vh]	[*l*, *h*]	[*n*, vl]	–	[vl, *l*]	[*h*, *h*]	[*m*, *h*]	[*l*, *h*]	[*l*, *h*]	[vl, *m*]
*C*5	[*m*, vh]	[*h*, ah]	[vl, *l*]	[*h*, vh]	–	[*m*, vh]	[*h*, vh]	[*h*, *h*]	[*m*, *h*]	[l, vh]
*C*6	[vl, *l*]	[*n*, *l*]	[*m*, vh]	[*l*, *l*]	[vl, *m*]	–	[vh, ah]	[*h*, vh]	[vh, vh]	[*l*, *m*]
*C*7	[vl, *l*]	[*l*, *h*]	[*n*, *l*]	[*l*, *m*]	[vl, *l*]	[*n*, vl]	–	[*l*, *m*]	[vl, vl]	[vl, *m*]
*C*8	[*l*, *m*]	[*h*, vh]	[*l*, *m*]	[*l*, *h*]	[*l*, *l*]	[vl, *l*]	[*m*, *h*]	–	[*l*, *h*]	[*l*, *h*]
*C*9	[vl, *l*]	[*h*, ah]	[vl, *l*]	[*l*, *h*]	[*l*, *m*]	[vl, vl]	[vh, vh]	[*l*, *h*]	–	[vl, *m*]
*C*10	[*n*, vl]	[*m*, vh]	[*m*, *h*]	[*m*, vh]	[vl, *h*]	[*m*, *h*]	[*m*, vh]	[*l*, *h*]	[*m*, vh]	–
Expert 4's obtained envelopes										
*C*1	–	[*m*, *h*]	[*l*, *m*]	[*m*, vh]	[*m*, *h*]	[*l*, *h*]	[*h*, ah]	[*h*, vh]	[*h*, ah]	[*m*, vh]
*C*2	[*l*, *m*]	–	[*m*, *h*]	[*l*, *m*]	[*l*, *l*]	[*l*, *m*]	[*m*, *h*]	[*h*, vh]	[*h*, ah]	[*m*, *h*]
*C*3	[*m*, *h*]	[*l*, *m*]	–	[*h*, *h*]	[*h*, *h*]	[*m*, *h*]	[*h*, vh]	[*m*, *h*]	[*h*, vh]	[*h*, vh]
*C*4	[vl, *m*]	[*m*, *h*]	[*l*, *l*]	–	[vl, *m*]	[*l*, *l*]	[*l*, *m*]	[*h*, vh]	[*m*, vh]	[*m*, vh]
*C*5	[*l*, *m*]	[*h*, *h*]	[*l*, *l*]	[*m*, vh]	–	[*m*, *m*]	[*m*, vh]	[*h*, *h*]	[*m*, vh]	[*m*, vh]
*C*6	[*l*, *h*]	[*m*, *h*]	[*l*, *m*]	[*h*, *h*]	[*m*, *m*]	–	[*h*, ah]	[*h*, vh]	[*h*, vh]	[*m*, vh]
*C*7	[*n*, *l*]	[*l*, *m*]	[vl, *l*]	[*m*, *h*]	[vl, *m*]	[*n*, *l*]	–	[*l*, *h*]	[*l*, *h*]	[*m*, *h*]
*C*8	[vl, *l*]	[vl, *l*]	[*l*, *m*]	[vl, *l*]	[*l*, *l*]	[vl, *l*]	[*l*, *h*]	–	[*h*, *h*]	[*l*, *h*]
*C*9	[*n*, *l*]	[*n*, *l*]	[vl, *l*]	[vl, *m*]	[vl, *m*]	[vl, *l*]	[*l*, *h*]	[*l*, *l*]	–	[*l*, *m*]
*C*10	[vl, *m*]	[*l*, *m*]	[vl, *l*]	[vl, *m*]	[vl, *m*]	[vl, *m*]	[*l*, *m*]	[*l*, *h*]	[*m*, *h*]	–
Expert 5's obtained envelopes										
*C*1	–	[*l*, *h*]	[*h*, *h*]	[*m*, *h*]	[*m*, *h*]	[*l*, *m*]	[*h*, vh]	[*m*, *h*]	[vh, ah]	[*h*, vh]
*C*2	[*l*, *h*]	–	[*l*, *m*]	[*l*, *l*]	[*l*, *m*]	[*n*, *l*]	[*h*, *h*]	[*m*, *m*]	[*m*, vh]	[*m*, *h*]
*C*3	[*l*, *l*]	[*m*, *h*]	–	[*m*, vh]	[*m*, vh]	[*h*, *h*]	[vh, ah]	[*h*, vh]	[ah, ah]	[*h*, vh]

Table 18 (continued)

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
C4	[l, m]	[h, h]	[vl, m]	–	[l, m]	[n, l]	[m, h]	[m, h]	[h, vh]	[vh, vh]
C5	[l, m]	[m, h]	[vl, m]	[m, h]	–	[l, h]	[m, vh]	[m, h]	[h, vh]	[m, h]
C6	[m, h]	[h, ah]	[l, l]	[h, ah]	[l, h]	–	[vh, ah]	[h, ah]	[ah, ah]	[h, ah]
C7	[vl, l]	[l, l]	[n, vl]	[l, m]	[vl, m]	[n, vl]	–	[m, m]	[m, h]	[vl, l]
C8	[l, m]	[m, m]	[vl, l]	[l, m]	[l, m]	[n, l]	[m, m]	–	[m, m]	[m, h]
C9	[n, vl]	[vl, m]	[n, n]	[vl, l]	[vl, l]	[n, n]	[l, m]	[m, m]	–	[l, l]
C10	[vl, l]	[l, m]	[vl, l]	[vl, vl]	[l, m]	[n, l]	[h, vh]	[l, m]	[h, h]	–

Table 19 Obtained numerical intervals for the HFLTS given in Table 17

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
Expert 1's obtained numerical envelopes										
C1	–	[3, 4]	[3, 3]	[3, 4]	[3, 4]	[2, 2]	[4, 5]	[4, 6]	[4, 6]	[3, 4]
C2	[2, 3]	–	[2, 4]	[3, 3]	[2, 2]	[1, 3]	[3, 4]	[4, 4]	[4, 6]	[4, 5]
C3	[3, 3]	[2, 4]	–	[4, 5]	[5, 5]	[3, 5]	[4, 6]	[4, 4]	[5, 6]	[4, 5]
C4	[2, 3]	[3, 3]	[1, 2]	–	[3, 3]	[1, 2]	[2, 4]	[2, 4]	[3, 5]	[5, 5]
C5	[2, 3]	[4, 4]	[1, 1]	[3, 3]	–	[3, 4]	[4, 5]	[3, 5]	[3, 5]	[4, 6]
C6	[4, 4]	[3, 5]	[1, 3]	[4, 5]	[2, 3]	–	[3, 5]	[3, 5]	[4, 6]	[4, 5]
C7	[1, 2]	[2, 3]	[0, 2]	[2, 4]	[1, 2]	[1, 3]	–	[3, 3]	[2, 4]	[2, 4]
C8	[0, 2]	[2, 2]	[2, 2]	[2, 4]	[1, 3]	[1, 3]	[3, 3]	–	[3, 4]	[2, 4]
C9	[0, 2]	[0, 2]	[0, 1]	[1, 3]	[1, 3]	[0, 2]	[2, 4]	[2, 3]	–	[3, 3]
C10	[2, 3]	[1, 2]	[1, 2]	[1, 1]	[0, 2]	[1, 2]	[2, 4]	[2, 4]	[3, 3]	–
Expert 2's obtained numerical envelopes										
C1	–	[3, 3]	[2, 4]	[3, 5]	[2, 4]	[2, 4]	[5, 6]	[5, 6]	[4, 6]	[4, 4]
C2	[3, 3]	–	[3, 4]	[2, 4]	[2, 3]	[2, 3]	[3, 3]	[3, 4]	[3, 5]	[3, 5]
C3	[2, 4]	[2, 3]	–	[4, 6]	[4, 5]	[3, 4]	[4, 6]	[2, 4]	[4, 6]	[4, 6]
C4	[1, 3]	[2, 4]	[0, 2]	–	[2, 3]	[2, 3]	[2, 3]	[3, 4]	[4, 6]	[4, 6]
C5	[2, 4]	[3, 4]	[1, 2]	[3, 4]	–	[4, 4]	[4, 6]	[4, 6]	[6, 6]	[4, 5]
C6	[2, 4]	[3, 4]	[2, 3]	[3, 4]	[2, 2]	–	[5, 6]	[4, 6]	[4, 6]	[4, 6]
C7	[0, 1]	[3, 3]	[0, 2]	[3, 4]	[0, 2]	[0, 1]	–	[2, 3]	[2, 3]	[3, 4]
C8	[0, 1]	[2, 3]	[2, 4]	[2, 3]	[0, 2]	[0, 2]	[3, 4]	–	[2, 4]	[2, 3]
C9	[0, 2]	[1, 3]	[0, 2]	[0, 2]	[0, 0]	[0, 2]	[3, 4]	[2, 4]	–	[2, 4]
C10	[2, 2]	[1, 3]	[0, 2]	[0, 2]	[1, 2]	[0, 2]	[2, 3]	[3, 4]	[2, 4]	–
Expert 3's obtained numerical envelopes										
C1	–	[1, 4]	[2, 4]	[1, 2]	[1, 3]	[4, 5]	[4, 5]	[3, 4]	[4, 5]	[5, 6]
C2	[2, 5]	–	[1, 3]	[2, 4]	[0, 2]	[4, 6]	[2, 4]	[1, 2]	[0, 2]	[1, 3]
C3	[2, 4]	[3, 5]	–	[5, 6]	[4, 5]	[1, 3]	[4, 6]	[3, 4]	[4, 5]	[2, 3]
C4	[4, 5]	[2, 4]	[0, 1]	–	[1, 2]	[4, 4]	[3, 4]	[2, 4]	[2, 4]	[1, 3]
C5	[3, 5]	[4, 6]	[1, 2]	[4, 5]	–	[3, 5]	[4, 5]	[4, 4]	[3, 4]	[2, 5]
C6	[1, 2]	[0, 2]	[3, 5]	[2, 2]	[1, 3]	–	[5, 6]	[4, 5]	[5, 5]	[2, 3]
C7	[1, 2]	[2, 4]	[0, 2]	[2, 3]	[1, 2]	[0, 1]	–	[2, 3]	[1, 1]	[1, 3]
C8	[2, 3]	[4, 5]	[2, 3]	[2, 4]	[2, 2]	[1, 2]	[3, 4]	–	[2, 4]	[2, 4]
C9	[1, 2]	[4, 6]	[1, 2]	[2, 4]	[2, 3]	[1, 1]	[5, 5]	[2, 4]	–	[1, 3]
C10	[0, 1]	[3, 5]	[3, 4]	[3, 5]	[1, 4]	[3, 4]	[3, 5]	[2, 4]	[3, 5]	–
Expert 4's obtained numerical envelopes										
C1	–	[3, 4]	[2, 3]	[3, 5]	[3, 4]	[2, 4]	[4, 6]	[4, 5]	[4, 6]	[3, 5]
C2	[2, 3]	–	[3, 4]	[2, 3]	[2, 2]	[2, 3]	[3, 4]	[4, 5]	[4, 6]	[3, 4]
C3	[3, 4]	[2, 3]	–	[4, 4]	[4, 4]	[3, 4]	[4, 5]	[3, 4]	[4, 5]	[4, 5]

Table 19 (continued)

	*C*1	*C*2	*C*3	*C*4	*C*5	*C*6	*C*7	*C*8	*C*9	*C*10
*C*4	[1, 3]	[3, 4]	[2, 2]	–	[1, 3]	[2, 2]	[2, 3]	[4, 5]	[3, 5]	[3, 5]
*C*5	[2, 3]	[4, 4]	[2, 2]	[3, 5]	–	[3, 3]	[3, 5]	[4, 4]	[3, 5]	[3, 5]
*C*6	[2, 4]	[3, 4]	[2, 3]	[4, 4]	[3, 3]	–	[4, 6]	[4, 5]	[4, 5]	[3, 5]
*C*7	[0, 2]	[2, 3]	[1, 2]	[3, 4]	[1, 3]	[0, 2]	–	[2, 4]	[2, 4]	[3, 4]
*C*8	[1, 2]	[1, 2]	[2, 3]	[1, 2]	[2, 2]	[1, 2]	[2, 4]	–	[4, 4]	[2, 4]
*C*9	[0, 2]	[0, 2]	[1, 2]	[1, 3]	[1, 3]	[1, 2]	[2, 4]	[2, 2]	–	[2, 3]
*C*10	[1, 3]	[2, 3]	[1, 2]	[1, 3]	[1, 3]	[1, 3]	[2, 3]	[2, 4]	[3, 4]	–
Expert 5's obtained numerical envelopes										
*C*1	–	[2, 4]	[4, 4]	[3, 4]	[3, 4]	[2, 3]	[4, 5]	[3, 4]	[5, 6]	[4, 5]
*C*2	[2, 4]	–	[2, 3]	[2, 2]	[2, 3]	[0, 2]	[4, 4]	[3, 3]	[3, 5]	[3, 4]
*C*3	[2, 2]	[3, 4]	–	[3, 5]	[3, 5]	[4, 4]	[5, 6]	[4, 5]	[6, 6]	[4, 5]
*C*4	[2, 3]	[4, 4]	[1, 3]	–	[2, 3]	[0, 2]	[3, 4]	[3, 4]	[4, 5]	[5, 5]
*C*5	[2, 3]	[3, 4]	[1, 3]	[3, 4]	–	[2, 4]	[3, 5]	[3, 4]	[4, 5]	[3, 4]
*C*6	[3, 4]	[4, 6]	[2, 2]	[4, 6]	[2, 4]	–	[5, 6]	[4, 6]	[6, 6]	[4, 6]
*C*7	[1, 2]	[2, 2]	[0, 1]	[2, 3]	[1, 3]	[0, 1]	–	[3, 3]	[3, 4]	[1, 2]
*C*8	[2, 3]	[3, 3]	[1, 2]	[2, 3]	[2, 3]	[0, 2]	[3, 3]	–	[3, 3]	[3, 4]
*C*9	[0, 1]	[1, 3]	[0, 0]	[1, 2]	[1, 2]	[0, 0]	[2, 3]	[3, 3]	–	[2, 2]
*C*10	[1, 2]	[2, 3]	[1, 2]	[1, 1]	[2, 3]	[0, 2]	[4, 5]	[2, 3]	[4, 4]	–

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