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EVALUATION AND RANKING OF INSURANCE COMPANIES BY COMBINING TOPSIS AND THE INTERVAL FUZZY ROUGH SETS

Predrag Mimović[a], Danijela Tadić[b], Ankica Borota-Tišma[c], Snežana Nestić[b]* and Jaime Gil Lafuente[d]

[a]University of Kragujevac, Faculty of Economics, Liceja Kneževine Srbije 3, 34000 Kragujevac, Serbia
[b]University of Kragujevac, Faculty of Engineering, Sestre Janjić 6, 34000 Kragujevac, Serbia
[c]Belgrade Business Academy for Applied Studies, Bulevar Zorana Đinđića 152a, 11070 Beograd, Serbia
[d]University of Barcelona, Diagonal, 690-696, 08034 Barcelona, Spain

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Abstract

Corporate and organizational performance assessment is an important activity for both the managers and other stakeholders, as it provides them with an asset to evaluate their own strengths and weaknesses in relation to the competition, as well as guidelines for selecting appropriate measures to address the existing problems. The issue of criteria selection has been overcome through the literature review and the issue of criteria weights is handled by applying group decision making procedure. The procedure itself consists of using predefined linguistic expressions that are modelled by triangular fuzzy numbers and the aggregation of decision makers' opinion based on the rules of rough sets algebra. The values of the decision matrix are determined by prognosis method and they are described by crisp values. The proposed algorithm is tested on the insurance companies that operate in the Republic of Serbia.

Keywords: group decision making, interval –valued fuzzy-rough numbers, TOPSIS, insurance

1. INTRODUCTION

Corporate and organizational performance assessment is an important activity for both the managers and other stakeholders, as it supplies them with a tool to evaluate their own strengths and weaknesses in relation to the competition, as well as guidelines for selecting appropriate measures to address existing problems. The diverse nature of factors affecting the financial decision-making process, as well as the complexity of the financial, business and economic environment, and the subjective

* *Corresponding author: s.nestic@kg.ac.rs*

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nature of many financial decisions are just some of the financial decisions' characteristics in the companies and financial institutions that can be tackled by applying multi-criteria analysis. The need to observe multiple criteria at the same time is an important component of the management function. This usually incorporates the personal preferences of the investors, especially in the institutions that perform money management professionally, such as the banks, the pension funds, the investment funds, the insurance companies, etc.

There are significant advantages of an multicriteria decision making approach in the scope of financial decision making (Zopounidis, 1999, 2002): 1) the ability to structure complex problems, 2) the possibility of considering quantitative and qualitative criteria simultaneously, 3) the transparency in the evaluation process, which allows for good argumentation in financial decision making, and 4) the application of sophisticated, flexible and pragmatic scientific methods in financial decision making. The application of multi-criteria decision-making allows the decision-maker (manager) to actively participate in the financial decision-making process and helps him/her to understand and to deal with complexity and uncertainty as characteristics of the business environment. This means that his/her role is not reduced to the passive implementation of the optimal solution (if there is such solution) obtained by applying the multicriteria model, but he/she actively participates in the process of structuring and modelling the problem, as well as in analysing, interpreting and implementing the obtained solution. A detailed survey of MCDM methods that have been developed to analyse the variety of management problems in the economic domain are given by Steuer and Na (2003), Wang et al. (2009), Toloie-Eshlaghy and Homayonfar (2011), Zavadskas and Turskis (2011), Aruldoss et al. (2013), Ghadikolaei and Esbouei (2014), etc. As the insurance companies operate in an unstable political, economic and social environment, where the customer demands change rapidly and it is imperative that the requirements expressed are fully met, it can be said that the rating and ranking of the insurance companies can be defined as a management problem under uncertainty. The uncertainties related to the values of the evaluation criteria as well as their relative importance can be described in a sufficiently good way by using linguistic variables.

The motivation for this research comes from the fact that the insurance company managers, by using the obtained results, are able to easily identify strengths and weaknesses, so that the appropriate improvement strategies can be defined in a short period of time with a goal to improve business activities. Taking into account the uncertainties during the process of decision making, a tool that can handle it should be employed.

The development of fuzzy sets theory (Dubois & Prade, 1980; Zimmerman, 2011) and the theory of rough sets (Pawlak, 2012), and, in particular, the combination of these two fields of mathematics (Pamučar et al., 2017), allows the quantitative representation of uncertainty to be satisfactorily accurate. The basic characteristic of the fuzzy number is a membership function which may take different shapes. In decision making problems embracing different areas, uncertain decision variables are the most often described by triangular fuzzy numbers (TFNs). The domains of fuzzy numbers are defined on closed interval containing upper and lower bound as well as modal value.

Fuzzy number considers the perception of individual DM. By using the rough set theory, assessment of uncertainties into each DM are described as a boundary region which is determined by respecting perceptions of all DMs. Hence, a rough number can better reflect real perceptions of DMs and thus heighten the objectivity of original data.

The aim of the paper is to propose a model the application of which can accurately determine the rank of the insurance companies that exist in a changing environment.

The paper is organized in the following manner: in Section 2 there is a comprehensive literature review related to the applied MCDM in the insurance sector and the rough set theory in modelling of the uncertainties. The proposed methodology is presented in Section 3. In Section 4, the proposed model is illustrated by real life data which comes from domestic insurance companies which exist in the Republic of Serbia. The discussion of the obtained results and Conclusion is given in Section 5.

2. LITERATURE REVIEW

The wide literature review indicates that the assessment and ranking of the financial institutions that operate at the level of one country is performed by respecting personal preferences of the investors and the preferences of their clients (Akhisar & Tunay, 2015; Lu & Zhu 2018). It should be emphasized that investor and client preferences differ. For example, the investors want to maximize profits while at the same time clients have aversion to risk, the investment horizon, etc. Many authors have suggested that the rating and ranking of the insurance companies should be considered as a multi-criteria analysis task (Akhisar & Tunay, 2015). According to the literature sources, it can be concluded that the Analytic hierarchy process (AHP), The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), "Visekriterijumska optimizacija i kompromisno resenje" (VICOR) have been mostly employed in the multi-criteria decision analysis methods (MCDA) for the ranking of the insurance companies (Ercan & Orden, 2016). There are a few papers related to the insurance companies' ranking that deal with the uncertainties. In the scope of presented research, the proposed methods, which can be found in the relevant literature, are presented and analysed in detail. The comparative analysis of the proposed model and other related research in the scope of the insurance companies ranking, by respecting many criteria, evaluation criteria and its weights, respectively, is presented in section 2.1.

2.1. Applied MCDM in the insurance domain

The insurance may be treated as the basis of each country's economic development. The economic development is causally related to the development of the insurance. The higher the level of economic development and the available resources for the insurance purposes, the greater the awareness of people about the insurance needs. The insurance, in interaction with other segments of the financial system, enables long-term economic development. The insurance companies in the developed financial markets belong to a group of highly active non-deposit financial institutions. For appropriate regular payments of the policyholders, the insurance companies make contractual payments in the event of an adverse event. The insurance may be seen as a community of individuals who are exposed to risk and who pass the risk on to the insurance company. In doing so, insurance companies agree to indemnify policyholders in the event of an accident, provide other cash benefits in the event of a loss, or provide them with risk-related services (Rejda, 2011). The most important features of the insurance are the transfer of risk from the individual to the risk community and the distribution of loss to all members of the risk community. Insurance provides financial stability, social security, enhancement of risk management, encourages economic activity and thus preserves the living standard of the population and enables financial development and economic growth.

It may be concluded that the assessment of the insurance companies is very important for companies themselves but also for the clients. Authors define different criteria for the process of insurance companies' assessment. It should be emphasized that there is no unified list of criteria.

Pardalos et al. (1997) have defined 16 financial criteria which should be used for the assessment of 27 insurance companies that operate in Greece. By applied Principal Components Analysis, nine of the most important financial criteria have been selected: (1) net profit margin, (2) return on equity, (3) general liquidity, (4) leverage ratio, (5) debt capacity, (6) viability ratio, (7) investment ratio, (8) stockholder's ratio, and (9) capital sufficiency ratio.

In Taiwan, the other research has been conducted (Tsai et al., 2008) that included 14 Taiwanese insurance companies which had been ranked according to the three evaluation criteria and 11 sub-criteria identified by applying modified DELPHI method. These evaluation criteria and its sub-criteria were: (1) business index (ration of changes for direct premium, ration of changes for direct paid loss and ration of changes for retain premium), (2) whole company operating index (retain premium/shareholders, gross premium/shareholders, net reinsurance comm./shareholders, total reserve/shareholders, ratio of shareholder changes and special claim reserve/shareholders), and (3) profit ability index (return on shareholders and loss ratio of retains earn premium).

Akhisar and Tunay (2015) have analysed the sector of life insurance in Turkey for the period from 2009 to 2013, by respecting the following criteria and sub criteria: (1) capital adequacy (premiums received, Shareholders' equity, Shareholders' equity / technical provisions, Shareholders' equity / total assets), (2) profitability (financial profit-loses / premiums received, loss ratios, technical profit-loses/ financial profit-loses, technical profit-loses / premiums received, total income / premiums received), and (3) asset quality (cash and cash equivalents / total assets, retention rate). The assumption that performances of the insurance companies have not changed during the analysed period has been introduced. Ercan and Orden (2016), have assessed five insurance companies listed on the Istanbul Stock Exchange in 2010-2015, based on four financial criteria: (1) current ratio, (2) asset growth, (3) return of asset and (4) return on equity. Ertugrul and Ozcil (2016) have used the financial charts of seven insurance companies which trade on Turkey- Istanbul Stock Exchange, according to the evaluation criteria related to the stability and profitability, for the period 2008-2014. These criteria are: (1) current ratio, (2) liquidity ratio, (3) cash ratio, (4) leverage ratio, (5) financial ratio, (6) asset turnover, (7) equity capital rate, (8) net profit margin, and (9) return on equity.

The analysis of the insurance sector, as it is very important component of each national economy, was performed by Valahzaghard and Ferdousnejhad (2013). They have considered 15 insurance companies which have been assessed in compliance with 30 financial criteria. According to the results of factor analysis, the first important factor, capital adequacy, represents 21.557% of the total variance, the second factor, quality of income, represents 20.958% of the total variance. In addition, the third factor, quality of cash flow, represents 19.417% of the total variance and the last factor, quality of assets, represents 18.641% of the total variance.

Chen and Lu (2014) have chosen the following criteria for the assessment of four major insurance companies in Taiwan: (1) market size, (2) market growth, (3) logistic support, (4) distribution, (5) market share, (6) synergy of cost reduction, and (7) synergy of revenue increase.

Saeedpoor et al. (2015) have considered the problem of ranking 13 life insurance companies which exist in Iran. This study aims at prioritizing insurance companies which hold the major proportion of Iran's total life insurance market. The life insurers have been assessed and ranked with regards to 5 criteria of customer service quality in the SERVQUAL model as well as opinions of 43 qualified insurance brokers in Tehran, Iran. These evaluation criteria were: (1) tangibility, (2) reliability, (3) assurance, (4) responsiveness and (5) empathy.

Lu and Zhu (2018) have analysed the problem of ranking Chinese insurance companies according to six evaluation criteria: (1) profitability (enterprise capital appreciation profitability, including net assets yield rate, total return on assets, income margins, profit margins), (2) operating growth (mainly includes the state-owned capital preservation and appreciation rate, profit growth rate, economic profit margins), (3) asset quality situation (recognized asset rate, accounts receivable ratio), (4) solvency (solvency adequacy ratio), (5) business development capacity (product market share, customer satisfaction, open up of new market success rate), and Learning (6) creativity (employee satisfaction, employee training time growth rate, employee reasonable proposal growth rate, the number of new products developed).

Mandić et al. (2017) have analysed the insurance sector of the Republic of Serbia in the period 2007-2014. Five key criteria have been identified for the assessment and rating of insurance companies: (1) equity and reserves, (2) business assets, (3) provision and liabilities, (4) financial incomes, and (5) cost of insurance.

In this research, the criteria are defined according to literature sources (Nissim, 2010; IAIS, 2010; Grigaliunas & Li, 2017; Kwon & Wolfrom, 2016; Mandić et al., 2017) and the evidence data of the considered insurance companies.

The rank of the insurance companies, in the short and medium run during the period, is based on applying different MCDM as it is shown in Table 1.

In the proposed model, the existing uncertainties in the relative importance of criteria are modelled by the Interval-Valued Fuzzy Rough Numbers (IVFRNs). It may be one of the main advantages of the proposed model compared to the models in the literature sources. The rank of the insurance companies derives from the procedure based on on the conventional TOPSIS with IVFRNs.

Table 1. Comparative analysis of literature sources and the proposed model

	The relative importance of criteria	The criteria weights	The criteria values	Rank
Pardalos et al. (1997)	-	-	Crisp	DEA/PROMETHEE, separately
Tsai, et al. (2008)	Crisp	ANP	Crisp/evidence data	TOPSIS
Valahzaghard and Ferdousnejhad (2013)	Crisp/factor analysis	AHP	Crisp/assessment of DMs	AHP
Akhisar and Tunay (2015)	Crisp	AHP	Crisp/evidence data	Modified TOPSIS by crisp number
Chen and Lu (2015)	TFNs	FAHP	TFNs	Modified fuzzy TOPSIS
Saeedpoor et al (2015)	TFNs/fuzzy averaging method	FAHP	TFNs/fuzzy averaging method	FTOPSIS
Ercan and Orden (2016)	Crisp	ANP	Crisp/literature source	VIKOR
Ertugrul and Ozcil (2016)	TFNs	FDEMATEL	TFNs	FTOPSIS
Mandić et al. (2017)	TFNs	FAHP	Crisp/evidence data	Modified TOPSIS with crisp numbers
Lu and Zhu (2018)	Crisp/assessment of DMs	AHP	Crisp/assessment of DMs	AHP
The proposed model	IVFRNs	Direct way	Crisp/evidence data/forecasting	TOPSIS with IVFRNs

2.2. MCDA, fuzzy sets and rough set theory

There are many mathematical theories which can be used for modelling of linguistic terms. According to the papers which can be found in the relevant literature, it can be said that the fuzzy sets theory and the rough sets theory are mostly used for quantitative description of linguistic variables.

It is known that, almost all management problems can be set as MCDM problems. As many authors suggest, solving of the management problem can be based on MCDM with fuzzy sets theory. At the same time, there are almost no papers in which MCDM is combined with fuzzy sets theory and rough sets theory.

In respect to the above-mentioned facts, authors of this paper consider that evaluation and ranking of insurance companies can be formally stated as MCDM with fuzzy sets theory and rough sets theory.

In this Section, there is an overview of the papers in which the uncertainties in criteria weights and criteria values are described by using the fuzzy sets and rough sets theory.

2.2.1. Criteria weights

Khan et al. (2016) suggest that the relative importance of criteria in many cases is suitable to be assessed in a direct manner. The criteria weights are modelled by RNs (Pawlak, 2012). Also, the redundant criteria from the decision table are eliminated by using the proposed procedure. In this way, the set of criteria that cannot be eliminated without disturbing the ability to approximate the classification, and the generation of logical rules from the reduced decision table. The proposed technique requires extensive study which may be rated as its major shortcoming. The relative importance of criteria at the level of each DM are stated by pair-wise comparison matrix (Song et al., 2014; Sharma et al., 2018). The elements of these matrices belong to common measurement scale (Saaty, 1990). The determination of the criteria weights is based on rules (Hu et al., 2006) which represent the information measure of fuzzy equivalence relations. A certain number of authors (Song et al., 2014; Sharma et al., 2018) suggest that criteria weights may be determined according to the following procedure: (1) consistency check of each DM's assessment may be performed by using eigen vector value (Saaty, 1990); (2) By using the rough set theory, pair-wise comparison matrix is constructed; (3) determining of the weights vector is based on procedure developed by Buckley, (1985) and rough algebra rules (Pawlak, 2012). The elements of the normalized weights vector are modelled by rough numbers, too. The fuzzy rating of the relative importance of criteria are performed by DMs according to Best-Worst Method framework (Pamučar et al, 2017). Respecting to all DMs, the relative importance of each criterion can be modelled by the IVFRNs. The criteria weights are given by using the modified Best-Worst Method with IVFRNs.

In the scope of this research, the evaluation of the relative criteria importance is stated as fuzzy group decision making problem and they are modelled by TFNs. It is assumed that DMs may assess the relative importance of criteria in the direct manner. In the literature, the fuzzy rating aggregation of DMs into unique assessment is based on aggregation operators in many cases (Nestic et al., 2019). In this way, the treated criteria are considered independently. Many authors have suggested that more accurate quantitative values of criteria weights can be calculated if all treated criteria are considered simultaneously, as discussed in this research.

2.2.2. TOPSIS with rough numbers

Song et al., (2014) have constructed rough decision matrix. The Positive Ideal Solution (PIS) and the Negative Ideal Solution (NIS) for each treated benefit type criterion is determined as the largest upper limit of all the rough numbers and the lowest lower limit of all the rough numbers, respectively. For the cost-type criterion, the reverse is true. The deviation coefficient can be defined as a measure to depict the distance between a rough number and its PIS and NIS values and it is calculated as a distance between a RN and its PIS and NIS, respecting the type of criteria. In this way, the deviation coefficient matrices can be established. By applying the linear normalized procedure, the normalized deviation coefficient matrices are given. The separation measures of each alternative and their representative scalars are calculated according to procedure which is applied in Song et al. (2014) and described by RNs. Determining the closeness coefficients and ranking of alternatives is based on rules of conventional TOPSIS. The assessment of failures (alternative) with respect to the risk factor (evaluation criterion) may be performed by DMs and modelled by RNs (Song et al., 2014). By applying simple normalization procedure, the normalized rough decision matrix is given. PIS and NIS are determined for each risk factor (Song et al., 2014). The separation measures from PIS and NIS are determined by using the n-dimensional Euclidean distance. By applying procedure of the conventional TOPSIS, the closeness coefficient and rank are determined. It is worth to mention that TOPSIS may be modified by rough sets (Yang et al., 2017). The construction of the decision matrix is determined by applying the following steps:

(1) the criteria values at the level of each alternative are assessed by DMs who employ the measurement scale; (2) the normalized criteria are given by using the proposed normalization procedure; (3) the weighted normalized decision matrix at the level of each DM is stated; (4) the decision matrix of RNs is constructed by using rough algebra rules (Yang et al., 2017). Distances from PIS and NIS, and closeness coefficient values are determined according to the procedure proposed in this paper. The rank of the alternative is determined in compliance with conventional TOPSIS.

In this research, forecasting criteria values are given according to evidence data from the period 2006-2016. It can be denoted as one of the advantages of the proposed model. The transformation of decision matrix into the normalized decision matrix is performed by using the vector normalization procedure. Determination of PIS and NIS are based on conventional TOPSIS. The separate measures, and closeness coefficient are based on the procedures of conventional TOPSIS, and rough set algebra rules. The rank of alternative is based on the rank of representative scalars of closeness coefficient. It may be stated that the introduced modifications of TOPSIS method by no means violate the rigor of the research.

3. METHODOLOGY

This section contains the developed methodology for the assessment and ranking of the insurance companies under uncertainties and imprecisions. In order to clarify the proposed methodology, the basics of rough set theory (Pawlak, 2012) are presented.

3.1. Basic consideration of the rough set theory

There is an assumption that decision makers' team participates in the decision-making process by interpreting their opinions using any measurement scale. Their assessments are presented by the set U, and Y is an arbitrary of U. The set of classes γ that cover all the objects in U is denoted as $\gamma=\{c_1,\dots, c_j,\dots, c_J\}$ so that the objects of set γ have a sequential relationship, $c_1<..c_j,..<c_J$. For arbitrary object c_j, $j=1,\dots,J$, lower and upper approximations are defined:

(1) The lower approximation

$$\underline{\text{Apr}}\ (c_j)=\cup\{Y\in U/\gamma(Y)\le c_j\} \tag{1}$$

(2) The upper approximation

$$\overline{\text{Apr}}\ (c_j)=\cup\{Y\in U/\gamma(Y)\ge c_j\} \tag{2}$$

(3) The boundary region can be defined as

$$\begin{aligned}\text{Bnd}(c_j)&=\cup\{Y\in U/\gamma(Y)\ne c_j\}=\\ &\{Y\in U/\gamma(Y)>c_j\}\cup\\ &\{Y\in U/\gamma(Y)<c_j\}\end{aligned} \tag{3}$$

Any ambiguous c_j, can be represented by a rough number (RN), c_j, such as:

$$\text{RN}\ (c_j)=(\underline{\text{Lim}}\ (c_j),\overline{\text{Lim}}\ (c_j)) \tag{4}$$

and:

$$\underline{\text{Lim}}\ (c_j)=\frac{1}{M_L}\cdot\sum\gamma(Y)|Y\in\underline{\text{Apr}}\ (c_j) \tag{5}$$

$$\overline{\mathrm{Lim}}\,(c_j)=\frac{1}{M_U}\cdot\sum \gamma(Y)\,|\,Y\in \overline{\mathrm{Apr}}\,(c_j) \quad (6)$$

Where M_L and M_U are the number of objects that are contained in $\underline{\mathrm{Apr}}\,(c_j)$, and $\overline{\mathrm{Apr}}\,(c_j)$, respectively.

Interval-valued fuzzy-rough numbers

Certain scholars call for combining two or more mathematical areas in order to determine quantitative values of the treated uncertainties in a more precise way (Pamučar et al, 2017; Bello et al, 2019). In this research, fuzzy sets (Dubois & Prade, 1980) and IVFRNs are introduced to handle vagueness and uncertainties within the DMs' assessment.

Fuzzy set $\tilde{C}$ is defined as a set of organized pairs:

$$\tilde{C}=\left\{x,\mu_{\tilde{C}}(x)\ \middle|\ x\in X,\ 0\le\mu_{\tilde{C}}(x)\le 1\right\} \quad (7)$$

where:

Fuzzy set $\tilde{C}$ is defined by the universe set $X\in R$. In general, set X can be either finite or infinite. $\mu_{\tilde{C}}(x)$ is a membership function of fuzzy set $\tilde{C}$. Each fuzzy set is completely and uniquely determined by its membership function.

Fuzzy number $\tilde{C}$ on R is a triangular fuzzy number if its membership function $\mu_{\tilde{C}}(x)$: $R\rightarrow[0,1]$ is equal to

$$\mu_{\tilde{C}}(x)=\begin{cases}\dfrac{x-a_1}{a_2-l} & x\in[a_1,a_2]\\ \dfrac{x-a_3}{a_2-a_3} & x\in[a_2,a_3]\\ 0 & otherwise\end{cases} \quad (8)$$

where $a_1\le a_2\le a_3$, a_1 and a_3 stand for the lower and upper value of the support of X respectively, and a_2 for the modal value. TFN can be denoted by (a_1, a_2, a_3).

In the scope of research, the DMs express their assessment through the linguistic expressions which are modelled by TFNs (see Eq. 8). These TFNs belong to the universe set U. Under this assumption, the set of classes γ^* that cover all the objects in U is denoted as $\gamma^*=\left\{\tilde{C}_1,...,\tilde{C}_j,...,\tilde{C}_J\right\}=\left\{(a_{11},a_{21},a_{31}),...(a_{1j},a_{2j},a_{3j}),....,(a_{1J},a_{2J},a_{3J})\right\}$. The objects of set γ^* have a sequential relationship, $a_{q1}<..a_{qj}...<a_{qJ}$, $1\le q\le 3$. The lower and upper approximations for each a_{qj}, $1\le q\le 3$ are calculated by using Eq. (1) and Eq. (2). According to Eq. (5) and Eq. (6) the lower and upper values of boundary interval for each value $a_{qj}, q=1,2,3$ are determined. The values $a_{qj}, q=1,2,3$ are represented in the rough number by using the Eq. (4).

IVFRNs can be defined as:

$$\begin{aligned}\bar{\bar{C}}_j=(&[\underline{\mathrm{Lim}}\,(a_{1j}),\overline{\mathrm{Lim}}\,(a_{1j})],\\ &[\underline{\mathrm{Lim}}\,(a_{2j}),\overline{\mathrm{Lim}}\,(a_{2j})],\\ &[\underline{\mathrm{Lim}}\,(a_{3j}),\overline{\mathrm{Lim}}\,(a_{3j})])\end{aligned} \quad (9)$$

Or concisely:

$$\begin{aligned}\bar{\bar{C}}_j=&([a_{1j}^L,a_{1j}^U],[a_{2j}^L,a_{2j}^U],[a_{3j}^L,a_{3j}^U])=\\ &[C_j^L,C_j^U]\end{aligned} \quad (10)$$

Consider two IVFRNs, $\bar{\bar{B}}=\left([b_1^L,b_1^U],[b_2^L,b_2^U],[b_3^L,b_3^U]\right)$ and $\bar{\bar{C}}=\left([c_1^L,c_1^U],[c_2^L,c_2^U],[c_3^L,c_3^U]\right)$.

Their operational laws are as follows (Pamučar et al 2017):

$$\bar{\bar{B}}+\bar{\bar{C}}=\left(\left[b_1^L+c_1^L, b_1^U+c_1^U\right],\left[b_2^L+c_2^L, b_2^U+c_2^U\right],\left[b_3^L+c_3^L, b_3^U+c_3^U\right]\right)$$

$$\bar{\bar{B}}-\bar{\bar{C}}=\left(\left[b_1^L-c_3^L, b_1^U-c_3^U\right],\left[b_2^L-c_2^L, b_2^U-c_2^U\right],\left[b_3^L-c_1^L, b_3^U-c_1^U\right]\right)$$

$$\bar{\bar{B}}\cdot\bar{\bar{C}}=\left(\left[b_1^L\cdot c_1^L, b_1^U\cdot c_1^U\right],\left[b_2^L\cdot c_2^L, b_2^U\cdot c_2^U\right],\left[b_3^L\cdot c_3^L, b_3^U\cdot c_3^U\right]\right)$$

$$\bar{\bar{B}}:\bar{\bar{C}}=\left(\left[b_1^L: c_3^U, b_1^U: c_3^L\right],\left[b_2^L: c_2^U, b_2^U: c_2^L\right],\left[b_3^L: c_1^U, b_3^U: c_1^L\right]\right)$$

$$k\cdot\bar{\bar{B}}=\left(\left[k\cdot b_1^L, k\cdot b_1^U\right],\left[k\cdot b_2^L, k\cdot b_2^U\right],\left[k\cdot b_3^L, k\cdot b_3^U\right]\right)$$

3.2. The problem statement

The insurance companies may be formally presented as a set of indices ε={1,...,e,...,E}. The index for an insurance company is denoted as e, e=1,..,E and E is the total number of the insurance companies. The decision makers represent top managers of the treated companies. It may be assumed that index e, e=1,..,E may be adjoined to the insurance company as well as DM that is employed within the company. The assessment criteria that are used for the considered insurance companies' ranking are identified by DMs in respect to literature sources (Nissim, 2010; IAIS, 2010; Grigaliunas & Li, 2017; Kwon & Wolfrom, 2016; Mandić et al., 2017) and the best practice of the European insurance companies. These criteria can be presented by the set of indices k={1,...,k,...,K}. The index for a criterion is denoted as k, k=1,..,K and K is the total number of identified evaluation criteria. In the scope of the proposed research, the treated criteria are: (1) investment income, (2) value of the settled claims by insurance companies, (3) administration expenses, (4) deferred acquisition, and (5) number of insurances. Some of the criteria are benefit type while the other are cost type.

The proposed procedure for evaluation and ranking of the insurance companies can be realized in a way that is presented in fig. 1.

The relative importance of criteria is assessed by DMs who use one of five pre-defined linguistic expressions. These linguistic terms are modelled by using TFNs.

The proposed linguistic expressions and corresponding TFNs are as follows:

very low importance (VLW)-(1,1,5.5)
low importance (LW)-(1,3.5,6)
medium importance (MW)-(2.5,5,7.5)
high importance (HW)-(4,6.5,9)
very high importance (VHW)-(4.5,9,9)

The domains of these TFNs are defined into common measurement scale (Saaty, 1990). The value 1 and the value 9 denote that the relative importance of criteria is negligible, or dominant, respectively. The overlap in the domain of these TFNs shows a lack of knowledge of the decision makers and practice results about the problem under consideration.

Criteria values at the level of each insurance company i i=1,..,I for each period t, t=1,..,T are obtained according to the evidence data and they are crisp, v^e_{kt}, k=1,...,K; t=1,..., T; e=1,...,E. Using the variance analysis technique, it has been shown that the value of each criterion can be described by the regression law. Hence, the values of criteria at the level of each

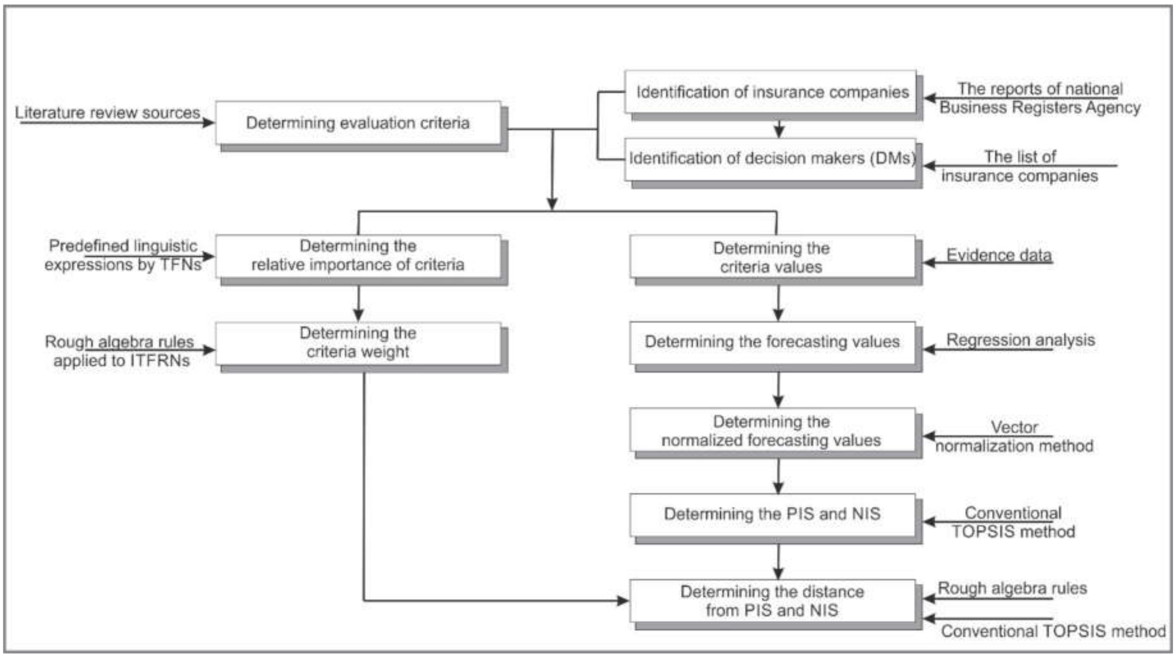

Figure 1. The evaluation procedure and ranking of the insurance companies

insurance company for the future period t›, v^e_{kt}, k=1,...,K; e=1,...,E. may be forecasted. By applying the vector normalization procedure, all v^e_{kt}, are mapped into the normalized values, r^e_{kt}, k=1,...,K; e=1,...,E.

According to the normalized decision matrix, PIS and NIS are determined, by analogy to conventional TOPSIS (Hwang & Yoon, 1982). Distances from PIS and NIS, and the closeness coefficient values are determined with respect to rough sets algebra rules, and procedure of conventional TOPSIS so that, their values are described by IVFRNs. The rank of the insurance companies is obtained by applying conventional TOPSIS (Hwang & Yoon, 1982).

3.3. Algorithm

The proposed Algorithm for determination of the insurance companies' rank is presented in the following steps.

Step 1. The assessment of the relative importance of criterion k,k=1,..,K is performed by all DMs. These fuzzy ratings are presented by the set U.

Step 2. The set of classes that cover all the objects in U is denoted as

$$\gamma_k^* = \left\{ \tilde{C}_{1k}, ..., \tilde{C}_{jk}, ..., \tilde{C}_{Jk} \right\} = \left\{ \begin{array}{l} (a_{11k}, a_{21k}, a_{31k}), ... \\ (a_{1jk}, a_{2jk}, a_{3jk}), ..., \\ (a_{1Jk}, a_{2Jk}, a_{3Jk}) \end{array} \right\} \quad (11)$$

Step 3. The values in the domain of the treated TFNs are presented by rough numbers by applying Eq. (9). Then, rating of DM, $\tilde{C}_{jk}$ is described by IVFRNs, $\overset{=}{C}_{jk}$ by using Eq. (10).

Step 4. The aggregated criterion weight, $\overset{=}{W}_k = ([a^L_{1k}, a^U_{1k}],[a^L_{2k}, a^U_{2k}],[a^L_{3k}, a^U_{3k}])$ is determined by using rough set algebra rules (Pawlak, 2012).

Step 5. The normalized aggregated criterion weight, $\overline{\overline{\omega}}_k$ is given by using normalization procedure, such as:

$$\overline{\overline{\omega}}_k = \frac{1}{a_3^{max}} \cdot \overline{\overline{W}}_k \tag{12}$$

Where $a_3^{max} = \max_{k=1,...,K} a_{3k}^U$

Step 6. Criteria values are given according to the evidence data. By using the regression analyses, the forecasting criteria values, v_{ek}, $e = 1,..,E; k = 1,..,K$ are obtained. In this way, the rank of the treated insurance companies for the next two years is obtained.

Step 7. Determination of the normalized decision matrix, $[r_{ek}]_{ExK}$ is performed by using the vector normalization procedure, such as:

for the benefit type criterion:

$$r_{ek} = \frac{v_{ek}}{\sqrt{\sum_{e=1}^{E} (v_{ek})^2}}, \quad e = 1,...,E; k = 1,...,K \tag{13}$$

for the cost type criterion:

$$r_{ek} = \frac{1 / v_{ek}}{\sqrt{\sum_{e=1}^{E} (1 / v_{ek})^2}}, \quad e = 1,...,E; k = 1,...,K \tag{14}$$

Step 8. Determination of PIS, d_k^+ and NIS, d_k^-, $k = 1,...,K$:

$$\Delta_k^+ = \max_{e=1,...,E} (r_{ek}) \quad \text{and} \quad \Delta_k^- = \min_{e=1,...,E} (r_{ek}) \tag{15}$$

Step 9. Determination of the distances from PIS and NIS according to conventional TOPSIS (Hwang & Yoon, 1981) and rough algebra rules (Pawlak, 2012):

$$\overline{\overline{d}}_k^+ = \sum_{k=1}^{K} \overline{\overline{\omega}}_k \cdot \left|\Delta_k^+ - r_{ek}\right| \quad \text{and} \quad \overline{\overline{d}}_k^- = \sum_{k=1}^{K} \overline{\overline{\omega}}_k \cdot \left|\Delta_k^- - r_{ek}\right| \tag{16}$$

According to the algebra rules of rough sets (Pawlak, 2012), the distances are described by rough numbers.

Step 10. The rough closeness coefficient values are given by the expression:

$$\overline{\overline{c}}_e = \frac{\overline{\overline{d}}_k^-}{\overline{\overline{d}}_k^- + \overline{\overline{d}}_k^+} \tag{17}$$

Step 11 The representative scalar of rough number, $\overline{\overline{c}}_e$, $c_e, e = 1,.., E$ is calculated.

Step 12. The values, c_e, e= 1,...,E are sorted into decreasing order. The rank of the insurance companies is based on the obtained results.

Step 13. The management of each treated insurance company may determine the management initiatives respecting the obtained rank and benchmarking methods, with a goal to increase the overall business effectiveness.

4. CASE STUDY

The data taken into account for the modelling include the entire insurance sector in Serbia during the period between the year 2006 and 2016. The study utilizes the financial data for the four insurance companies that operate in Serbia. In the form of interview with the top managers of the treated companies, who are in this case DMs, the input data is obtained. The model is constructed by combining two methods: of multi-criteria decision-making TOPSIS and rough sets. In the scientific and practitioners' literature, the different criteria for the analysis and assessment of the insurance companies have been applied. The evaluation criteria are defined in the section 3.1.

By applying the proposed Algorithm (Step 1), the fuzzy rating of the relative importance of evaluation criteria is performed by DMs and presented in Table 2.

By using the procedure (Step 2 to Step 4 of the proposed Algorithm), the aggregated values of considered evaluation criteria are calculated. The proposed procedure is illustrated in the assessed data for the evaluation criterion (k=2).

The set of classes γ^* that cover all the objects in U is denoted as γ^*_2={LW,MW,HW}.

Table 2. Fuzzy rating of the relative importance of evaluation criteria.

	DM (e=1)	DM (e=2)	DM (e=3)	DM (e=4)
k=1	*VHW*	*HW*	*VHW*	*HW*
k=2	*HW*	*LW*	*MW*	*MW*
k=3	*MW*	*VLW*	*LW*	*LW*
k=4	*LW*	*VLW*	*LW*	*VLW*
k=5	*HW*	*MW*	*VHW*	*HW*

For each arbitrary value a_{1j}, j=1,..,3 lower and upper approximations are defined:

$$\underline{\mathrm{Apr}}\,(1)=\cup\{Y\in U/\gamma(Y)\le 1\}=\{1\}\rightarrow \underline{\mathrm{Lim}}\,(1)=\frac{1}{1}\cdot 1=1$$

$$\underline{\mathrm{Apr}}\,(2.5)=\cup\{Y\in U/\gamma(Y)\le 2.5\}=\{1,2.5\}\rightarrow \underline{\mathrm{Lim}}\,(2.5)=\frac{1}{2}\cdot(1+2.5)=1.75$$

$$\underline{\mathrm{Apr}}\,(4)=\cup\{Y\in U/\gamma(Y)\le 4\}=\{1,2.5,4\}\rightarrow \underline{\mathrm{Lim}}\,(4)=\frac{1}{3}\cdot(1+2.5+4)=2.5$$

$$\overline{\mathrm{Apr}}\,(1)=\cup\{Y\in U/\gamma(Y)\ge 1\}=\{1,2.5,4\}\rightarrow \overline{\mathrm{Lim}}\,(1)=\frac{1}{3}\cdot(1+2.5+4)=2.5$$

$$\overline{\mathrm{Apr}}\,(2.5)=\cup\{Y\in U/\gamma(Y)\ge 2.5\}=\{2.5,4\}\rightarrow \overline{\mathrm{Lim}}\,(2.5)=\frac{1}{2}\cdot(2.5+4)=3.25$$

$$\overline{\mathrm{Apr}}\,(4)=\cup\{Y\in U/\gamma(Y)\ge 4\}=\{4\}\rightarrow \overline{\mathrm{Lim}}\,(4)=\frac{1}{1}\cdot(4)=4$$

For each arbitrary value a_{2j}, j=1,..,3 lower and upper approximations are defined:

$$\underline{\mathrm{Apr}}\,(3.5)=\cup\{Y\in U/\gamma(Y)\le 3.5\}=\{3.5\}\rightarrow \underline{\mathrm{Lim}}\,(3.5)=\frac{1}{1}\cdot 3.5=3.5$$

$$\underline{\mathrm{Apr}}\,(5)=\cup\{Y\in U/\gamma(Y)\le 5\}=\{3.5,5\}\rightarrow \underline{\mathrm{Lim}}\,(5)=\frac{1}{2}\cdot(3.5+5)=4.25$$

$$\underline{\mathrm{Apr}}\,(6.5)=\cup\{Y\in U/\gamma(Y)\le 6.5\}=\{3.5,5,6.5\}\rightarrow \underline{\mathrm{Lim}}\,(6.5)=\frac{1}{3}\cdot(3.5+5+6.5)=5$$

$$\overline{\mathrm{Apr}}\,(3.5)=\cup\{Y\in U/\gamma(Y)\ge 3.5\}=\{3.5,5,6.5\}\rightarrow \overline{\mathrm{Lim}}\,(3.5)=\frac{1}{3}\cdot(3.5+5+6.5)=5$$

$$\overline{\mathrm{Apr}}\,(5)=\cup\{Y\in U/\gamma(Y)\ge 5\}=\{5,6.5\}\rightarrow \overline{\mathrm{Lim}}\,(5)=\frac{1}{2}\cdot(5+6.5)=5.75$$

$$\overline{\mathrm{Apr}}\,(6.5)=\cup\{Y\in U/\gamma(Y)\ge 6.5\}=\{6.5\}\rightarrow \overline{\mathrm{Lim}}\,(6.5)=\frac{1}{1}\cdot(6.5)=6.5$$

For each arbitrary value a_{3j}, j=1,..,3 lower and upper approximations are defined:

$$\underline{Apr}(6) = \cup\{Y \in U/\gamma(Y) \le 6\} = \{6\} \rightarrow \underline{Lim}(6) = \frac{1}{1}\cdot 6 = 6$$

$$\underline{Apr}(7.5) = \cup\{Y \in U/\gamma(Y) \le 7.5\} = \{6, 7.5\} \rightarrow \underline{Lim}(7.5) = \frac{1}{2}\cdot(6+7.5) = 6.75$$

$$\underline{Apr}(9) = \cup\{Y \in U/\gamma(Y) \le 9\} = \{6, 7.5, 9\} \rightarrow \underline{Lim}(9) = \frac{1}{3}\cdot(6+7.5+9) = 7.5$$

$$\overline{Apr}(6) = \cup\{Y \in U/\gamma(Y) \ge 6\} = \{6, 7.5, 9\} \rightarrow \overline{Lim}(6) = \frac{1}{3}\cdot(6+7.5+9) = 7.5$$

$$\overline{Apr}(7.5) = \cup\{Y \in U/\gamma(Y) \ge 7.5\} = \{7.5, 9\} \rightarrow \overline{Lim}(7.5) = \frac{1}{2}\cdot(7.5+9) = 8.25$$

$$\overline{Apr}(9) = \cup\{Y \in U/\gamma(Y) \ge 9\} = \{9\} \rightarrow \overline{Lim}(9) = \frac{1}{1}\cdot(9) = 9$$

The values in the domain of the treated TFNs are presented by RN so that:

$$\overset{=}{C}_{12} = ([1,2.5],[3.5,5],[6,7.5]),$$

$$\overset{=}{C}_{22} = ([1.75,3.25],[4.25,5.75],[6.75,8.25]),$$

$$\overset{=}{C}_{32} = ([2.5,4],[5,6.5],[7.5,9])$$

The aggregated criterion weight, $\overset{=}{W}_2$ is:

$$\overset{=}{W}_2 = \frac{1}{4}\cdot\left(\overset{=}{C}_{12} + 2\cdot\overset{=}{C}_{22} + \overset{=}{C}_{32}\right) =$$

$$([1.75,3.25],[4.25,5.75],[6.75,8.25])$$

In a similar way, the weight values of other selected evaluation criteria are calculated and presented in Table 3.

Table 3. The weights vector

The weights vector
$\overset{=}{W}_1 = ([4.125, 4.375],[7.125, 8.375],[9, 9])$
$\overset{=}{W}_2 = ([1.750, 3.250],[4.250, 5.750],[6.750, 8.250])$
$\overset{=}{W}_3 = ([1.125, 1.750],[2.475, 4.207],[5.542, 6.793])$
$\overset{=}{W}_4 = ([1,1],[1.625, 2.875],[5.625, 5.875])$
$\overset{=}{W}_5 = ([3.167, 4.167],[5.833, 7.833],[8.250, 8.875])$

By using the Eq. (12) (Step 5 of the proposed Algorithm) the normalized weights vector is given and presented in Table 4.

Table 4. The normalized weights vector

The normalized weights vector
$\overset{=}{\omega}_1 = ([0.458, 0.486],[0.792, 0.931],[1,1])$
$\overset{=}{\omega}_2 = ([0.194, 0.361],[0.472, 0.639],[0.750, 0.917])$
$\overset{=}{\omega}_3 = ([0.125, 0.194],[0.275, 0.467],[0.616, 0.755])$
$\overset{=}{\omega}_4 = ([0.111, 0.111],[0.181, 0.319],[0.625, 0.653])$
$\overset{=}{\omega}_5 = ([0.352, 0.463],[0.648, 0.871],[0.917, 0.986])$

The values of evaluation criteria at the level of each insurance company come from evidence data. According to these data, the linear regression line for each evaluation criterion is constructed. The utilized forecasting method is illustrated in the example of determining the number of issued insurance policies (k=5) at the level of the first insurance company (Table 5).

$$\hat{y}^{e}_{i5} = 364970.56 + 72265.87 \cdot v^{e}_{i5}$$

For i=2020 $\Rightarrow \hat{y}^{e}_{2020,5} = 1810287.96$

Table 5. The utilized forecasting method illustrated by the example of determining the number of issued insurance policies (k=5) at the level of the first insurance company

	Number of the insured cases
2008	1053584
2009	1181738
2010	1168513
2011	949667
2012	1107641
2013	1146969
2014	1365862
2015	1386421
2016	1445678
2017	1732221
2018	1810402

The forecasted criteria values for each treated insurance company are calculated in a similar way. The decision matrix is presented in Table 6.

Table 6. Decision matrix

	k=1	k=2	k=3	k=4	k=5
e=1	9308.9	62489.9	52912.5	16508.8	1810287.9
e=2	4188.7	23092.92	15095.3	1	292212.1
e=3	94032.1	7612.48	7252.7	5165.1	241172.6
e=4	818.1	731.34	227.8	359.9	964.9

The normalized decision matrix, PIS and NIS are determined by using procedure (Step 7 to Step 8 of the proposed Algorithm) and presented in Table 7.

Table 7. The normalized decision matrix, PIS and NIS

	k=1	k=2	k=3	k=4	k=5
e=1	0.0984	0.9319	0.0043	0.0001	0.9788
e=2	0.0443	0.34444	0.0151	0.9999	0.1579
e=3	0.9941	0.1135	0.0314	0.0002	0.1304
e=4	0.0087	0.0109	0.9994	0.0028	0.0005
PIS	0.9941	0.9319	0.9994	0.9999	0.9788
NIS	0.0087	0.0109	0.0043	0.0001	0.0005

By applying the proposed Algorithm (Step 9 to Step 11) distances from PIS and NIS, as well as the rough closeness coefficient values, are calculated and presented in the following example.

$$\overset{=}{d}{}_1^{+} = ([0.458, 0.486],[0.792, 0.931],[1,1]) \cdot 0.8957 + ([0.125, 0.194],[0.275, 0.467],[0.616, 0.755]) \cdot 0.9951 + ([0.111, 0.111],[0.181, 0.319],[0.625, 0.653]) \cdot 0.9998 = ([0.642, 0.739],[1.164, 1.618],[2.134, 2.230])$$

$$\overset{=}{d}{}_1^{-} = ([0.458, 0.486],[0.792, 0.931],[1,1]) \cdot 0.089 + ([0.194, 0.361],[0.472, 0.639],[0.750, 0.917]) \cdot 0.9209 + ([0.352, 0.463],[0.648, 0.871],[0.917, 0.986]) \cdot 0.9783 = ([0.556, 0.814],[1.189, 1.499],[1.700, 1.889])$$

$$\overset{=}{c}_1 = \frac{([0.556, 0.829],[1.139, 1.523],[1.677, 1.889])}{([1.202, 1.568],[2.303, 3.141],[3.811, 4.128])} = ([0.135, 0.218],[0.363, 0.661],[1.069, 1.572])$$

The representative scalar of rough number, $\overset{=}{c}_1$, c_1 is:

$$c_1 = \frac{1}{6} \cdot (0.135 + 0.218 + 0.363, +0.661 + 1.069, +1.572) = 0.669$$

The rough closeness coefficient values and their representative scalars are calculated in a similar way. The obtained values are presented in Table 8. By using the proposed Algorithm (Step 12) the rank of the insurance companies is given and presented in Table 8.

Table 8. Rough closeness coefficients, their representative scalars and the rank of the insurance companies

	$\overset{=}{c}_e$	c_e	Rank
e=1	([0.133,0.210],[0.383,0.639],[1.102, 1.577])	0.674	1
e=2	([0.061,0.082],[0.157,0.299],[0.692, 0.935])	0.371	3
e=3	([0.125,0.150],[0.298,0.471],[0.778, 0.994])	0.469	2
e=4	([0.029,0.047],[0.086,0.192],[0.421, 0.598])	0.229	4

5. DISCUSSION AND CONCLUSION

The proposed approach combines the selected methods and provides a flexible, systematic and objective framework for the comprehensive assessment of the insurance companies with a goal to provide reliable information for clients regarding investment decisions and other stakeholder perspectives.

The first company in rank is the best regarding the treated criteria values and corresponding weights. This is important data for the stakeholders and the companies themselves. The company management may seek for comparative benchmarking and strive for overall improvement. On the other hand, clients who are choosing the best company at the moment, may choose the desired insurance company for contracting them. The research findings may also be of interest to the institutional investors in emerging financial markets. In addition, assumptions are also made for a critical analysis of the selected criteria for the rating and ranking of the insurance companies.

The results obtained can have practical implications, in terms of methodological support for managers in the insurance companies, in general, to better understand the company's environment and to make better strategic decisions and position their company on the basis of formal quantitative models.

The analysis of the obtained results generates the preconditions for identifying opportunities and defining a formal framework for improving strategic decision-making, not only in the specific case, but also at the level of financial institutions and the financial system as a whole.

The proposed framework may also serve to support the construction of an effective analytical framework for managerial decision-making and it can easily be further expanded or modified, to better adapt to a specific problem and context.

In the mathematical sense, the application of IVFRNs provide a solid base for modelling uncertainties and vagueness by using natural language.

It is worth to mention that literature review identifies no similar research that connects IVFRNs and insurance companies ranking. This represents one of the major contributions of the research.

It should be noticed that there is a certain limitation of the model regarding the chosen criteria. Other limitation is the definition of the linguistic expressions and the assessment scale.

The future research will be realized through testing with a larger database and applying the proposed model for solving management problems in different domains.

References

Akhisar, I., & Tunay, N. (2015, May). Performance Ranking of Turkish Life Insurance Companies Using AHP and TOPSIS. In Management International Conference, Portoroz, Slovenia, 241-250.

Aruldoss, M., Lakshmi, T.M., & Venkatesan, V.P. (2013). A survey on multi criteria decision making methods and its applications. American Journal of Information Systems, 1 (1), 31-43.

Bello, R., Falcón, R., & Verdegay, J. L. (Eds.). (2019). Uncertainty Management with Fuzzy and Rough Sets: Recent Advances and Applications: Springer, New York, NY, USA.

Buckley, J. J. (1985). Fuzzy hierarchical analysis. Fuzzy sets and systems, 17 (3), 233-247.

Chen, S. Y., & Lu, C. C. (2015). Assessing the competitiveness of insurance corporations using fuzzy correlation analysis and improved fuzzy modified TOPSIS.

ЕВАЛУАЦИЈА И РАНГИРАЊЕ ОСИГУРАВАЈУЋИХ ДРУШТАВА КОМБИНОВАЊЕМ “TOPSIS” И ИНТЕРВАЛНИХ ФАЗИ ГРУБИХ СКУПОВА

Предраг Мимовић, Данијела Тадић, Анкица Борота-Тишма, Снежана Нестић, Jaime Gil Lafuente

Извод

Процена корпоративног и организационог учинка је важна активност како за менаџере, тако и за друге заинтересоване стране, јер им даје предност да процене сопствене снаге и слабости у односу на конкуренцију, као и смернице за одабир одговарајућих мера за решавање постојећих проблема. Питање избора критеријума превазиђено је прегледом литературе, а питање тежине критеријума решава се применом групног поступка одлучивања. Сама процедура се састоји од коришћења унапред дефинисаних лингвистичких израза који су моделовани триангуларним фази бројевима и агрегације мишљења доносилаца одлука на основу правила грубе алгебре скупова. Вредности матрице одлуке су одређене методом прогнозе и описане су прецизним вредностима. Предложени алгоритам је тестиран на осигуравајућим друштвима која послују у Републици Србији.

Кључне речи: групно одлучивање, интервално-вредновани фази груби бројеви, TOPSIS, осигурање

Expert Systems, 32 (3), 392-404.

Dubois, D., & Prade, H. (1980). Theory and applications, fuzzy sets and systems. New York, USA: Academic.

Ercan, M., & Onder, E. (2016). Ranking Insurance Companies in Turkey Based on Their Financial Performance Indicators Using VIKOR Method. International Journal of Academic Research in Accounting, Finance and Management Sciences, 6 (2), 104-113.

Ertugrul, I., & Özçil, A. (2016). The Performance Analysis of Fuzzy Topsis and Fuzzy Dematel Methods into Insurance Companies. Cankırı Karatekin University journal of the Faculty of Economics et Administrative Sciences, 6 (1), 175 – 200. (In Turkish)

Ghadikolaei, A.S., & Esbouei, S.K. (2014). Integrating Fuzzy AHP and Fuzzy ARAS for evaluating financial performance. Boletim da Sociedade Paranaense de Matemática, 32 (2), 163-174.

Grigaliunas, L., & Li, J. (2017, July). Dagong Europe Criteria for Rating Insurance Companies, Dagong Europe - www.dagongeurope.com

Hu, Q., Yu, D., & Xie, Z. (2006). Information-preserving hybrid data reduction based on fuzzy-rough techniques. Pattern recognition letters, 27 (5), 414-423.

Hwang, C. L., & Yoon, K. (1981). Methods for multiple attribute decision making. In Multiple attribute decision making, Berlin, Heidelberg, DE: Springer.

International Association of Insurance Supervisors, IAIS, Application paper on information gathering and analysis, 2010.

Khan, C., Anwar, S., Bashir, S., Rauf, A., & Amin, A. (2015). Site selection for food distribution using rough set approach and TOPSIS method. Journal of Intelligent & Fuzzy Systems, 29 (6), 2413-2419.

Kwon, W.J., & Wolfrom, L. (2017). Analytical tools for the insurance market and macro-prudential surveillance. OECD Journal: Financial Market Trends, 2016 (1), 1-47.

Lu, M., & Zhu, K. (2018). Performance evaluation of the insurance companies based on AHP. In AIP Conference Proceedings (Vol. 1955, No. 1, p. 040002). AIP Publishing.

Mandić, K., Delibašić, B., Knežević, S., & Benković, S. (2017). Analysis of the efficiency of insurance companies in Serbia using the fuzzy AHP and TOPSIS methods. Economic research-Ekonomska istraživanja, 30 (1), 550-565.

Nestic, S., Lampón, J.F., Aleksic, A., Cabanelas, P., & Tadic, D. (2019). Ranking manufacturing processes from the quality management perspective in the automotive industry. Expert Systems, e12451.

Nissim, D. (2010). Analysis and valuation of insurance companies. CE| ASA (Center for Excellence in Accounting and Security Analysis) Industry Study, (2).

Pamučar, D., Petrović, I., & Ćirović, G. (2018). Modification of the Best–Worst and MABAC methods: A novel approach based on interval-valued fuzzy-rough numbers. Expert systems with applications, 91, 89-106.

Pardalos, P.M., Michalopoulos, M., & Zopounidis, C. (1997). On the use of multicriteria methods for the evaluation of insurance companies in Greece. In New operational approaches for financial modelling (pp. 271-283). Physica, Heidelberg

Pawlak, Z. (2012). Rough sets: Theoretical aspects of reasoning about data (Vol. 9). Springer Science & Business Media.

Rejda, G. E. (2011). Principles of risk management and insurance. Pearson Education India, Noida, India.

Saaty, T. L. (1980). The analytic hierarchy process. New York, US: McGraw-Hill.

Saeedpoor, M., Vafadarnikjoo, A., Mobin, M., & Rastegari, A. (2015, October). A servqual model approach integrated with fuzzy AHP and fuzzy topsis methodologies to rank life insurance firms. In Proceedings of the international annual conference of the American society for engineering management (p. 1).

Sharma, H. K., Roy, J., Kar, S., & Prentkovskis, O. (2018). Multi criteria evaluation framework for prioritizing Indian railway stations using modified rough AHP-MABAC method. Transport and telecommunication journal, 19 (2), 113-127.

Song, W., Ming, X., Wu, Z., & Zhu, B. (2014). A rough TOPSIS approach for failure mode and effects analysis in uncertain environments. Quality and Reliability Engineering International, 30 (4), 473-486.

Steuer, R.E., & Na, P. (2003). Multiple criteria decision making combined with finance: A categorized bibliographic study. European Journal of operational research, 150 (3), 496-515.

Toloie-Eshlaghy, A., & Homayonfar, M. (2011). MCDM methodologies and applications: a literature review from 1999 to 2009. Research Journal of International Studies, 21, 86-137.

Tsai, H.Y., Huang, B.H., & Wang, A.S. (2008). Combining ANP and TOPSIS concepts for evaluation the performance of property-liability insurance companies. Journal of Social Sciences, 4, 56–61.

Valahzaghard, M., & Ferdousnejhad, M. (2013). Ranking insurance firms using AHP and Factor Analysis. Management Science Letters, 3 (3), 937-942.

Wang, J.J., Jing, Y.Y., Zhang, C.F., & Zhao, J.H. (2009). Review on multi-criteria decision analysis aid in sustainable energy decision-making. Renewable and sustainable energy reviews, 13 (9), 2263-2278.

Yang, Q., Du, P.A., Wang, Y., & Liang, B. (2017). A rough set approach for determining weights of decision makers in group decision making. PloS one, 12 (2), e0172679.

Zavadskas, E.K., & Turskis, Z. (2011). Multiple criteria decision making (MCDM) methods in economics: an overview. Technological and economic development of economy, 17 (2), 397-427.

Zimmermann, H.J. (2011). Fuzzy set theory—and its applications. Springer Science & Business Media.

Zopounidis, C. (1999). Multicriteria decision aid in financial management. European Journal of Operational Research, 119 (2), 404-415.

Zopounidis, C., & Doumpos, M. (2002). Multi-criteria decision aid in financial decision making: methodologies and literature review. Journal of Multi-Criteria Decision Analysis, 11 (4-5), 167-186.

APPENDIX

Table A1. The criteria values for "Dunav" insurance company

	Investment income	Solved claims	Acquisition costs	Running costs	Number of insured cases
2006	5307,96	75477,54	23380,14	24990,70	1053584
2007	6690,45	85809,92	34922,12	20616,13	1181738
2008	16287,06	84745,16	37039,46	17608,44	1168513
2009	13764,00	68459,66	40089,13	17203,76	949667
2010	12911,99	63941,80	41804,11	18368,89	1107641
2011	9002,07	69502,48	49435,13	21837,33	1146969
2012	9823,48	65998,26	49359,97	23354,74	1365862
2013	5390,20	67718,60	47288,95	22067,40	1386421
2014	5795,61	70307,81	42247,55	19953,93	1445678
2015	11067,06	66035,24	44114,30	15610,43	1732221
2016	10800,12	70855,67	44876,90	14721,00	1810402

Table A2. The criteria values for "DDOR" insurance company

	Investment income	Solved claims	Acquisition costs	Running costs	Number of insured cases
2006	2679,34	67997,56	25062,22	28623,66	773858
2007	2989,24	80586,74	26628,67	30043,77	811581
2008	5855,77	71465,37	25438,43	27000,99	805343
2009	5061,51	62375,58	24920,08	16589,83	690319
2010	4868,63	55146,34	24420,61	12109,73	744422
2011	5640,80	51657,33	26744,08	10805,25	642980
2012	5958,29	46731,98	23271,50	9830,81	510185
2013	4279,12	42993,62	22802,99	8641,52	581606
2014	6018,93	39519,91	22105,88	7646,46	642932
2015	4666,93	41039,08	22017,76	7537,87	688219
2016	606,14	41990,15	22147,66	7307,41	680316

Table A3. The criteria values for "AMS" insurance company

	Investment income	Solved claims	Acquisition costs	Running costs	Number of insured cases
2006	218,51	5288,51	3534,09	644,57	152725
2007	760,94	5360,02	4229,76	771,12	173090
2008	1764,37	5095,29	4601,56	765,77	168297
2009	1715,31	6376,84	4084,64	896,16	188131
2010	1843,89	7471,25	4656,75	798,33	191593
2011	2040,67	7502,69	4831,99	1033,52	165448
2012	2344,08	6430,55	5423,16	1624,44	172174
2013	1433,03	6717,18	5574,05	2001,92	225589
2014	1553,97	6206,53	5288,56	3049,25	215185
2015	1724,45	6498,40	6229,40	2287,76	227641
2016	1522,33	7562,49	7049,10	2854,76	226113

Table A4. The criteria values for "Energoprojekt" insurance company

	Investment income	**Solved claims**	**Acquisition costs**	**Running costs**	**Number of insured cases**
2006	236,468354	150,493671	0	245,898734	634
2007	337,62346	19,460802	206,673212	333,143185	430
2008	760,318732	16,8846853	324,048261	370,977754	434
2009	463,965586	25,0078876	484,321784	396,880132	460
2010	348,972779	69,9158848	310,962651	363,636536	589
2011	166,044061	180,636826	258,866275	384,171008	775
2012	170,570612	128,237935	167,10591	349,284152	685
2013	90,6822188	91,9470247	162,357459	358,480872	634
2014	618,742162	93,6273079	160,377585	349,823038	757
2015	464,96599	209,782275	215,225186	327,199507	895
2016	1501,46227	179,295275	241,754628	325,603394	944