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FUZZY APPROACH USING EXPERTS' PSYCHOLOGICAL CONDITIONS TO ESTIMATE THE CRITERIA IMPORTANCE FOR THE ASSESSMENT OF INNOVATIVE PROJECTS RISK

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Abstract
The difficulty of innovation risk assessment makes it necessary to use a multi-criteria analysis. Innovative projects are related to unstructured problems and the uncertainty, therefore, the use of fuzzy logic in the innovation risk assessment is analyzed. This paper proposes a method of determining the weights of criteria in order to innovation risk assessment. The weights are determined by 5 general criteria and 14 detailed criteria of innovation risk assessment. The proposed method is an extension of the fuzzy AHP method. The extension consists in taking into consideration the group decision-making approach with experts' psychological conditions. The groups of experts have been chosen based on an elaborated form. The form makes it possible to characterize the persons within the scope of different psychological conditions. The proposed method provides objective and rational decision-making. The paper presents also a comparison of results with the fuzzy AHP method without the group decision making. The weights obtained by the proposed method are more diversified and bring out the most important criteria.

Keywords
Fuzzy Multiple Criteria Decision Making (FMCDM), fuzzy Analytic Hierarchy Process (fuzzy AHP), group decision making, innovative project, assessment of risk, psychological aspects in process of making a decision.

Introduction

The issue of innovation is very popular in the business world and science [1–4]. For researchers, interesting are topics associated with both economic and technical aspects of innovation. The realization of innovative projects is associated with the necessity of analyzing potential dangers. This action requires assessment of risk which should focus mainly on the minimization of innovation costs as well as on the specifying detailed time of the investment realization [5]. The issue complexity makes it necessary to use a multi-criteria analysis. The literature on the subject-matter contains many methods supporting the decision-making process, among others [6–12]: ELECTRE, PROMETHEE, DEMATEL, AHP and ANP, Data Envelopment Analysis (DEA), fuzzy-logic methods.

The practice in the scope of applying specific methods of supporting the decision-making process indicates a multiple uses of the AHP (Analytic Hierarchy Process) method in the context of innovative solutions. The application of this method is usually connected with the issue of choosing an innovative project which should be realized. Such a situation took place e.g. in Hewlett-Packard company. This method has also been applied in another company in the selection of new products [13, 14].

The assessment of criterion importance constitutes a significant stage of a decision-making process.

The choice of a certain method of stating the importance of criteria usually depends on the degree of the method complexity, availability of data and the goal which we want to reach. The aim of this paper is to obtain universal weights of the criteria, which can be used in the assessment of technological innovation risk. The paper proposes the fuzzy AHP based method in order to determine weights for the earlier defined evaluation criteria. The method takes into consideration the choice of experts' groups and its evaluations of the psychological conditions. One of the first examples of weights has been presented in [15]. However, the previous studies do not take into account a fuzzy group decision-making approach and the choice of experts' psychological conditions. A set of used criteria has been suggested in [16]. The criteria are divided into general ones (characterizing the company) and detailed ones (characterizing the innovation).

The paper is organized as follows. In the introduction, the problem of assessment risk innovation is presented. The psychological aspect in the evaluation of innovative projects is given in the next section. Further, the method of estimating the importance of criteria with taking into consideration psychological conditions of decision-makers is proposed. The case study of estimating the importance of criteria for the innovative projects evaluation is given in the next section. The results and discussion for realized studies are described in another part of the paper. The conclusions of the research are in the final part of this paper.

The psychological aspect in the evaluation of innovative projects

Three attitudes towards the risk are known in the theory of risk which are generally called aversion, neutrality or willingness [17–19]. It is also possible to find a different division in psychology, a division into inner-directed and other-directed individuals. The fact of making a decision concerning the implementation of innovations depends on the attitude of the person responsible for the decision. Knowing certain behaviors of decision-makers [20–23] makes it possible to create a proper group of decision-makers who are able to assess innovation risk in a rational way.

The inner-directed individuals are convinced that everything depends on their knowledge, competence and acquired skills. On the other hand, the other-directed individuals are convinced that they have an influence on what is happening only by means of external factors. They see life as a roulette in which one has either fortune or misfortune. They act focusing on the behavior of other people and avoid failure. They are characterized by dogmatism, cognitive conservatism, fearfulness, they are prone to frustration, impulsive in making decisions, chaotic and they tend to think globally. They are prone to hesitate in making decisions and are afraid of everything that is new and unknown. However, the inner-directed individuals are focused more on themselves, open to new experience, goal-oriented, willing to reach their goal with big self-assurance and perseverance. They are also oriented to analytic thinking, reflexivity in the decision-making process and have a high level of organization. On the basis of research concerning the motivation of achievements and the approach to risk, it has been stated that success-oriented people choose undertakings of an average risk degree. This action is thus characteristic for inner-directed individuals, whereas decision-makers avoiding failure make decisions which are extremely careful or extremely risky. This kind of behavior is similar to the one of other-directed individuals because failure is not interpreted by them as a lack of skills or competence but only as a result of events [24–27].

In case of innovative undertakings, it is important to have success-oriented people in the group of experts. They see the decision-making process from the point of view of positive results and they then gradually aim for the results. They are thus sure that they have skills, sometimes they are proud and even boast, they are independent in their actions, ambitious and full of enthusiasm. Their contraries are people who are not sure of their skills, who focus on external opinions, think of each failure as of their own incompetence, set only short-term goals and withdraw. This is why success-oriented individuals are ideal candidates to perform actions in which independent thinking and creativity are required. People who tend to avoid failure are prone to make low-risk decisions and make all decisions under conditions of full certainty [24, 28].

The third aspect which should be taken into consideration is the temperament of decision-makers. According to psychological research, temperament has a huge influence on making or avoiding risk. People characterized by a strong need of stimulation are created to work in situations full of stress and risk, whereas people avoiding strong impressions are great in situations where conditions of work are stable, require precise planning and analyzing. An innovative undertaking requires making many analyses in order to achieve desired results. In this case, it is worth finding a place for both kinds of experts in the decision-makings' group. The need for strong stimulation can lead to making too risky undertakings where the result is often determined by specific cases. However, the expert who prefers low levels of stimulation is able to react to real dangers, that in turn increases the efficacy of the company's operation [24].

The risk assessment process depends on a decision-maker. This stage is marked by subjectivity which in reality occurs in almost all stages of the risk analysis. This is why the knowledge and experience of a lot of experts are used in the paper to estimate the weights for the criteria of evaluating innovative projects. The choice of 7 experts was purposeful. The following individuals were chosen for the group of experts:

- The inner-directed ones, because they aim at achieving the best possible results. They are sure of their competence and abilities, thus they represent a positive aspect of the risk assessment of a given project. These are people who motivate to achieve the best results and find the best solution.
- The success-oriented ones, those supporting inner-directed individuals. It happens frequently that inner-directed decision-makers also have the need to succeed but not always. This is why it is suggested to analyze these traits independently. Moreover, including an external, success-oriented expert to the group, makes it possible to balance the level of risk in decisions which are made. The willingness to succeed ensures persistence and consistency in actions of the group.
- Those focused on avoiding impressions. They introduce elements of rational decision making into the group, as their decisions depend on the results and are not left to chance. Individuals characterized by the need to have strong impressions in risky situations feel happiness and a thrill of emotion, thus prefer to choose more risky options. A contrary situation takes place in the case of people avoiding impressions.

The fuzzy method of estimating the importance of criteria with taking into consideration psychological conditions of decision-makers

Multiple Criteria Decision Making (MCDM) with the estimation of the importance of criteria are the methods which are very often used in many evaluation processes, decision-making processes, selection, forecasting, diagnostics, development planning, etc. In the case of an analysis of the conditions of uncertainty, for non-structural problems or distant drawing conclusions, the Fuzzy Multiple Criteria Decision Making (FMCDM) methods are most often used. These methods, contrary to the above-mentioned ones, use fuzzy numbers instead of the crisp weights for each criterion and the crisp evaluation of alternatives in relation to the analyzed criteria. There are several ways of finding the weights of criteria. One of the frequently used approaches is the Fuzzy Analytic Hierarchy Process (FAHP), as a development of the Saaty's concept [29]. This approach uses fuzzy numbers to create criteria of comparison matrices. Chang [30], described the extent analysis method on the fuzzy AHP, which calculates directly crisp values from the fuzzy comparison matrix. Due to its little

Table 1
Stages of the estimating weights process.

Stage	Description
1	Creating a structure of the general and detailed criteria for the problem of evaluating the innovation of projects. The general criteria and the detailed ones do not form a hierarchical structure such as is normally created in AHP methods. The cause of such a fact is the willingness of creating a universal tool to evaluate innovative projects in which detailed criteria are chosen individually to the characteristics of an innovative project and the enterprise realizing it. Therefore analyses for general and detailed criteria are performed separately.
2	The choice of the group of experts and making psychological forms in the group. Dividing the group of experts into E groups, by psychological conditions of the examined individuals. Stating the importance of evaluation (the importance of knowledge) for particular groups of experts by means of indicating a vector of subjective values of weights w'^e $(e = 1, \ldots, E)$, where $\sum_{e=1}^{E} w'^e = 1$.
3	An individual linguistic evaluation of the importance of particular criteria for each expert.
4	Determination of an aggregated fuzzy matrix of comparisons for the general and detailed criteria. The stage is realized separately for each group of experts, divided by psychological conditions.
5	Using the modified extent analysis method in order to state the importance of the general and detailed criteria by means of assigning crisp values of weights to them. The stage is realized separately for each group of experts, divided by psychological conditions.
6	Stating the final values of the importance of the general and detailed criteria by means of the weighted aggregation of results received in particular groups of experts.

calculation complexity, the method is often used in the applications of multi-criteria evaluations. The extent analysis method has also some adversaries [31, 32], who indicate the wrongly evaluated weights. One of the conditions of the method correctness is the application of an appropriate normalization formula for a set of the triangular membership function of fuzzy weights [33]. In the following part of the section, the modified extent analysis method is proposed to estimate the importance of criteria for the assessment of innovative projects with taking into consideration psychological conditions of experts (decision-makers). The process of estimating weights of criteria is divided into the stages as in Table 1.

The realization of stages 3-6 requires a detailed discussion with taking into consideration the applied mathematical calculation.

Individual linguistic evaluation of the importance of criteria

Due to a simple way of transferring knowledge, experts are asked to express their opinion on the importance of particular n criteria with taking into account the linguistic description: very low, low, medium low, medium, medium high, high, very high. The linguistic description indirectly expresses the evaluation of the importance of criteria in the 7-point scale c_i^k $(i = 1, \ldots, n)$ for k-expert $(k = 1, \ldots, K)$, where $c_i^k = 1$ for very low, ..., $c_i^k = 7$ for very high. The task is realized separately for the general and detailed criteria.

Determining an aggregated, fuzzy comparison matrix

The comparison matrix of criteria A^k is calculated for the k-th expert on the basis of the point difference of the i, j criteria importance evaluation compared in pairs and the transformation of results into a scale similar to the Saaty's scale [29]:

$$\forall_{k=1,\ldots,K} \quad A^k = (a_{ij}^k)_{n\times n} = \begin{bmatrix} 1 & a_{12}^k & \cdots & a_{1n}^k \\ a_{21}^k & 1 & \cdots & a_{2n}^k \\ \vdots & \vdots & \vdots & \vdots \\ a_{n1}^k & a_{n2}^k & \cdots & 1 \end{bmatrix}, \quad (1)$$

where k stands for the expert's number in the group of K experts and $a_{ij}^k = 1/a_{ji}^k$ for $i, j = 1, \ldots, n$ and $i \neq j$. The values of the matrix A^k elements result from the following dependencies:

$$\forall_{i<j} \quad a_{ij}^k = \begin{cases} b_{ij}^k + 1, & \text{for } b_{ij}^k \geq 0, \\ (-b_{ij}^k + 1)^{-1}, & \text{for } b_{ij}^k < 0, \end{cases} \quad (2)$$

$$b_{ij}^k = c_i^k - c_j^k, \quad (3)$$

where c_i^k (c_j^k) stands for the score of the i-th (j-th) criterion in an importance scale provided by the k-th expert. The triangular fuzzy comparison matrix $\widetilde{A}$ is calculated as an aggregation of comparison matrices A^k $(k = 1, \ldots, K)$, created on the basis of each expert's knowledge in the group of K experts, divided by psychological conditions:

$$\widetilde{A} = (\widetilde{a}_{ij})_{n\times n}$$
$$= \begin{bmatrix} (1,1,1) & (l_{12}, m_{12}, u_{12}) & \cdots & (l_{1n}, m_{1n}, u_{1n}) \\ (l_{21}, m_{21}, u_{21}) & (1,1,1) & \cdots & (l_{2n}, m_{2n}, u_{2n}) \\ \vdots & \vdots & \vdots & \vdots \\ (l_{n1}, m_{n1}, u_{n1}) & (l_{n2}, m_{n2}, u_{n2}) & \cdots & (1,1,1) \end{bmatrix}, \quad (4)$$

where:

$$\forall_{i<j} \quad l_{ij} = \min\{a_{ij}^k,\ k = 1, \ldots, K\}, \quad (5)$$

$$\forall_{i<j} \quad m_{ij} = (a_{ij}^1 \cdot a_{ij}^2 \cdot a_{ij}^3 \cdot \ldots \cdot a_{ij}^K)^{1/K}, \quad (6)$$

$$\forall_{i<j} \quad u_{ij} = \max\{a_{ij}^k,\ k = 1, \ldots, K\}, \quad (7)$$

$$\forall_{ij, i\neq j} \quad \widetilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij}) = \widetilde{a}_{ji}^{-1} = (1/u_{ji}, m_{ji}, 1/l_{ji}). \quad (8)$$

The geometric mean approach formulated as (6) was mentioned in [34] as an efficient method to synthesize the evaluations of K experts. What is more, the geometric mean is, in contrast to the arithmetic mean, less sensitive to extreme values. The values l_{ij}, m_{ij}, u_{ij} stand for parameters of the fuzzy number $\widetilde{a}_{ij}$ on R, which is defined as a set of pairs $\{x,\ \mu_{\widetilde{a}_{ij}}(x)\}$, where $\mu_{\widetilde{a}_{ij}}(x)$ stands for the membership function determining as follows:

$$\mu_{\widetilde{a}_{ij}}(x) = \begin{cases} \dfrac{x - l_{ij}}{m_{ij} - l_{ij}}, & \text{for } x \in \langle l_{ij}, m_{ij} \rangle, \\ \dfrac{x - u_{ij}}{m_{ij} - u_{ij}}, & \text{for } x \in (m_{ij}, u_{ij} \rangle, \\ 0, & \text{otherwise } x \in \mathsf{R}. \end{cases} \quad (9)$$

Because none of the methods for verifying the consistency of a fuzzy comparison matrix has been widely accepted [35], the problem of verifying the consistency of fuzzy comparison matrices is circumvented in this stage.

The above-mentioned tasks (Stages 3-4) is realized separately for the general and detailed criteria.

Determining the importance of the general and detailed criteria with the use of the modified extent analysis method

The modification of the extent analysis is based on the application of the correct normalization formula [31] for triangular fuzzy weights. Particular steps of this method have been presented below.

1. Summing-up of each row for the fuzzy comparison matrix $\widetilde{A}$ (Eq. (4)) with the use of arithmetic operations on triangular fuzzy numbers:

$$\forall_{i=1,\ldots,n} \quad SR_i = \sum_{j=1}^{n} \widetilde{a}_{ij} = \left(\sum_{j=1}^{n} l_{ij}, \sum_{j=1}^{n} m_{ij}, \sum_{j=1}^{n} u_{ij} \right). \tag{10}$$

2. Standardization of sums in rows by means of the formula [33]:

$$\forall_{i=1,\ldots,n} \quad \widetilde{Q}_i = \frac{SR_i}{\sum_{j=1}^{n} SR_j}$$
$$= \left(\frac{\sum_{j=1}^{n} l_{ij}}{\sum_{j=1}^{n} l_{ij} + \sum_{g=1,g\neq i}^{n} \sum_{j=1}^{n} u_{gj}}, \frac{\sum_{j=1}^{n} m_{ij}}{\sum_{g=1}^{n} \sum_{j=1}^{n} m_{gj}}, \frac{\sum_{j=1}^{n} u_{ij}}{\sum_{j=1}^{n} u_{ij} + \sum_{g=1,g\neq i}^{n} \sum_{j=1}^{n} l_{gj}} \right). \tag{11}$$

3. Determination of the degrees of possibility V, as the fuzzy number $\widetilde{Q}_i = (l_i, m_i, u_i)$ is bigger than or equal to fuzzy numbers $\widetilde{Q}_j = (l_j, m_j, u_j)$ $(j = 1,\ldots,n; j \neq i)$ by means of the following dependence [30]:

$$\forall_{j=1,\ldots,n,j\neq i} \quad V(\widetilde{Q}_i \geq \widetilde{Q}_j) = \begin{cases} 1, & \text{for } m_i \geq m_j, \\ \dfrac{l_j - u_i}{(m_i - u_i) - (m_j - l_j)}, & \text{for } l_j \geq u_i, \\ 0, & \text{otherwise.} \end{cases} \tag{12}$$

4. Calculating the least degree of possibility $V(\widetilde{Q}_i \geq \widetilde{Q}_j)$ for the set $\widetilde{Q}_i$:

$$\forall_{i=1,\ldots,n} \quad V(\widetilde{Q}_i \geq \widetilde{Q}_j | j = 1,\ldots,n, j \neq i) = \min_{j=1,\ldots,n,j\neq i} V\left(\widetilde{Q}_i \geq \widetilde{Q}_j\right). \tag{13}$$

5. Determining the vector of criteria weights crisp values $W^e = [w_1^e, \ldots, w_n^e]^T$ for e-th group of experts $(e = 1,\ldots,E)$ on the basis of the following dependency:

$$\forall_{i=1,\ldots,n} \quad w_i^e = \frac{V(\widetilde{Q}_i \geq \widetilde{Q}_j | j = 1,\ldots,n, j \neq i)}{\sum_{g=1}^{n} V(\widetilde{Q}_g \geq \widetilde{Q}_j | j = 1,\ldots,n, j \neq i)}. \tag{14}$$

The above-mentioned steps of the method are realized separately for the general and detailed criteria.

Determining the final value of importance of the general and detailed criteria

The final value of weights determining the importance of the general (detailed) criteria results from the weighted arithmetic mean of weights, obtained in stage 5, made for the$E$ group of experts. The resulting vector of weights $W = [w_1, \ldots, w_n]^T$ is thus calculated by means of the following dependency:

$$\forall_{i=1,\ldots,n} \quad w_i = \sum_{e=1}^{E} w_i^e \times w'^e, \tag{15}$$

where w_i stands for the final crisp weight of the i-th general (detailed) criterion, $i = 1,\ldots,n$, w_i^e – crisp weights of the i-th general (detailed) criterion, determined on the basis of the experts' knowledge from the e-th group of experts, divided by psychological conditions, w'^e – weight concerning the importance of knowledge for the e-th group of experts. A drawback of the extent analysis method is obtaining zero weights for less important criteria, what can lead to erroneous conclusions. The weighted arithmetic mean (contrary to the weighted geometric mean) makes it possible to obtain positive weights, even if one of the experts' groups calculations indicates a zero weight for a given criterion.

Case study: estimating the importance of criteria for the innovative projects evaluation

In this section, the modified extent analysis method is proposed to estimate the importance of criteria for the assessment of innovative projects with taking into consideration psychological conditions of experts (decision-makers).

Stage 1. Structure of the innovative projects evaluation criteria

The analysis of general criteria (Table 2) aims at determining a general degree of risk in the context of the whole company which undertook to make a specific kind of investment. This is why the first criterion concerns the size of the company. It specifies the possibility of coping with practical problems resulting from the need of an additional engagement of a larger number of employees in the process of innovations realization and the possibility of using additional forms of support (subsidies) which are connected with highly developed projects. The scale of innovations is to determine how developmental is a given undertaking, the period of the applied technology is an additional information and the time of the project realization places a given innovation in time both in the context of its scale and the applied technology. The last criterion concerns the project external financing that is to determine the ability of the company to cope with additional costs [16].

The second set of evaluation criteria (Table 3) is characterized by the so-called specific innovation features. It is not connected with the first stage in any way, thus weights determined in this area are elaborated and discussed in a separate stages. Each criterion (we have 14 detailed criteria in the evaluation) has a suggested set of risk factors inside, which is not limited by anything. In further assumptions of using weights to evaluate the risk, a company has a possibility of choosing some dangers from a given area which will have the same weight.

Table 2
The general criteria and individual experts' evaluation of criteria importance [16].

		Gr 1			Gr 2		Gr 3	
	Expert	1	2	3	4	5	6	7
General criteria		Evaluation of criteria importance in a 7-point scale						
CG1	The company size	3	7	5	3	3	4	3
CG2	The scale of innovations	7	6	2	5	5	6	5
CG3	The period of applying the technology in the world	6	4	3	5	5	5	5
CG4	The period of the project realization	2	4	6	3	3	3	3
CG5	The relations of external sources of financing to the size of the whole project	3	4	6	3	4	3	4

Table 3
The detailed criteria and individual experts' evaluation of criteria importance [16].

		Gr 1			Gr 2		Gr 3	
	Expert	1	2	3	4	5	6	7
Detailed criteria		Evaluation of criteria importance in a 7-point scale						
CD1	Minimization of the negative impact on the environment	1	6	6	7	6	6	6
CD2	Minimization of procedural errors which can result in the lack of permission to start production	6	7	7	6	6	6	7
CD3	The innovative solution's competitiveness	5	6	6	5	5	5	5
CD4	The state of readiness for the realization of innovations	4	5	6	5	6	6	6
CD5	Minimization of solutions on the short market life of the product	3	5	3	5	5	5	5
CD6	Minimization of disturbances connected with the use of the product	4	4	6	5	4	5	5
CD7	Minimization of disturbances connected with the effective transfer of materials/subcomponents, etc.	3	4	6	5	5	5	5
CD8	Minimization of disturbances in the process of the product acceptance and complaint management	2	4	6	5	5	5	5
CD9	Minimization of disturbances connected with the use of the product of technologically non-developmental solutions	7	4	5	5	5	5	5
CD10	Minimization of disturbances connected with the use of the product of mistakes connected with submitting erroneous construction documents of the product	5	4	7	5	5	5	6
CD11	Minimization of disturbances connected with the use of the product of dangers in the scope of creating technological data sheets, as well as processing, mounting, control and cost calculation instruction manuals	5	4	5	4	4	5	5
CD12	Minimalization of disturbances in the process of changing shapes, dimensions, the surface quality or physical-chemical conversions of the product	4	4	6	5	5	5	5
CD13	Minimization of disturbances connected with the use of the product of dangers in the scope of mistakes formed as a result of joining parts and components forming the whole product	4	4	7	5	5	5	5
CD14	Minimization of projects which do not meet the customer's technical and economical requirements	7	6	7	5	5	5	5

Stage 2. The choice of experts' groups by their psychological conditions

Choice of the experts is based on psychological conditions. A form was prepared in order to determine expert's individual traits. The form makes it possible to characterize the decision-makers in the scope of the group with different psychological conditions (expert inner-directed or other-directed, success-oriented or avoid failure and strong need of stimulation or low levels stimulation). Exemplary questions, included in the form, are presented in the Table 4. Each expert had one option of two (statement A or B), which he/she marked with X. The form was composed of 15 questions.

Table 4
Personality form of an expert for chosen traits [36].

Statement A		Statement B	
The company financial results depend only on market mechanisms and behaviors of competitors. Weak company results are due to bad luck.		The company's profit depends on external factors but adequate people (specialists) are able to have an influence on the results obtained by the company.	X
I prefer to solve difficult and complicated problems, most often requiring a long period of time.	X	I feel better-accomplishing tasks in which it is well known in advance that the solution will certainly be found and the time of their accomplishment is relatively short.	
I like often changes and novelties as they make my work effective.	X	I think that the existing methods and techniques of work used in the company are good and sufficient as their efficacy has already been checked.	

The result of research has shown the next type of experts in the considered group of people: 6 inner-directed individuals, 1 other-directed individual, 6 success-oriented individuals, 1 individual willing to eliminate failures, 4 individuals with the need of avoiding impressions, 3 individuals preferring stimulation in action. Finally, 3 groups of experts have been created, to which weights according to the characteristics resulting from psychological traits have been attributed (Table 5).

Stage 3. Individual linguistic evaluation of the importance of particular criteria for each expert

A further stage of the conducted research was to elaborate a list of experts' evaluations. In order to do it, experts were asked to evaluate the importance of particular criteria with the linguistic description. The results of this research have been presented in the Tables 2 and 3. These evaluations were converted to 7-point scale.

Stage 4-5. Determination of the general and detailed criteria weights in accordance with the suggested method

The calculation of weights for 5 general criteria and 14 detailed criteria in accordance with the presented methodology has been made separately for three groups of experts (Group 1, Group 2, Group 3). Calculations of pairwise criteria comparison matrix have been illustrated with an example of results obtained from Expert 1 ($k = 1$) from Group 1 ($e = 1$) for the general criteria (Table 6). The results have been presented as a matrix $A^1 = (a^1_{ij})_{5\times 5}$ (Eq. (2)).

Table 5
A characteristic of experts' groups.

Number of group	Characteristic	The number of people	Weight	Comment
Group 1	The inner-directed individuals, success-oriented and avoiding strong impressions.	3	0.6	The most wanted group of experts, potentially ensuring stable, reasonable decisions.
Group 2	The inner-directed individuals, success-oriented and preferring stimulation in action.	2	0.3	Experts having the needed traits in the scope of making strategic decisions and at the same time having an increased level of resistance to stress.
Group 3	1 other-directed individual, success-oriented and preferring stimulation in action and 1 inner-directed individual, preferring the avoidance of failures and at the same time, avoiding strong impressions.	2	0.1	This is the most differentiated group of experts. However, each of them has the needed traits from the point of view of the decision-making process of an innovative character.

Table 6
An example of calculations of the matrix A^1 for the general criteria with taking into consideration the criteria importance evaluations compared in pairs for Expert 1 ($k = 1$, $e = 1$).

General criteria – matrix							
			c_j^1				
			CG1	CG2	CG3	CG4	CG5
			3	7	6	2	3
c_i^1	CG1	3	**1**	0.2	0.3	2	1
	CG2	7	5	**1**	2	6	5
	CG3	6	4	0.5	**1**	5	4
	CG4	2	0.5	0.2	0.2	**1**	0.5
	CG5	3	1	0.2	0.3	2	**1**

On the basis of the matrices $A^k = (a_{ij}^k)_{n \times n}$, $k = 1, 2, 3$, which have been created from subjective evaluations of the importance of three experts, the triangular fuzzy comparison matrix for Group 1 has been calculated. Dependences (5)–(8) have been used for this purpose. Addition of fuzzy numbers in rows (Eq. (10)) and the further normalization of the obtained results (Eq. (11)), makes it possible to present objective, fuzzy weights of criteria, obtained on the basis of the experts' knowledge from Group 1. Figure 1 illustrates charts of normalized fuzzy weights for the general criteria with the application of triangular fuzzy numbers. The wide support of fuzzy numbers demonstrates the differentiation of experts' evaluations. In order to determine crisp weights, the Eqs. (12)–(14) are used.

The presented procedure of calculating has been repeated for the remaining two groups of experts (Group 2 and Group 3). The list of results is presented in the Tables 7 and 8.

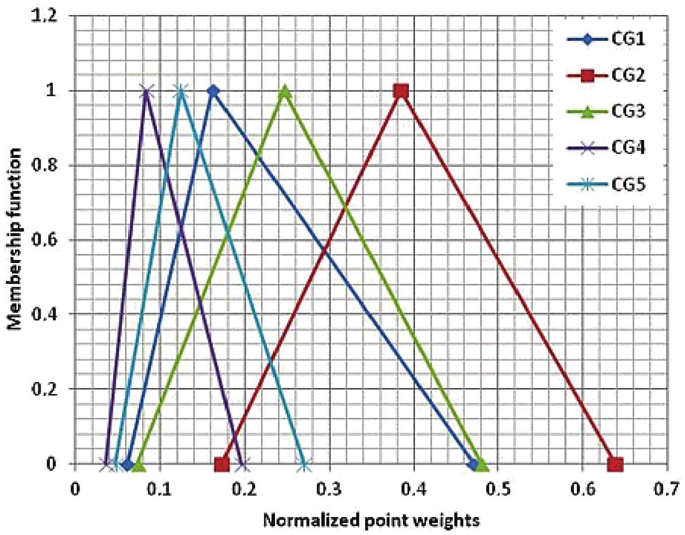

Fig. 1. Normalized fuzzy weights of general criteria.

Table 7
The final crisp weights for the general criteria.

					All experts
		Gr 1	Gr 2	Gr 3	$\sum_{e=1}^{3} w_i^e \cdot w'^e$
		w'^1	w'^2	w'^3	
Weights for groups of experts		0.6	0.3	0.1	
		w_i^1	w_i^2	w_i^3	
Weights for general criteria	CG1	0.2196	0.2067	0.3116	0.2249
	CG2	0.3837	0.2571	0.1711	**0.3245**
	CG3	0.2648	0.2571	0.0137	0.2374
	CG4	0.0278	0.0724	0.2333	0.0617
	CG5	0.1041	0.2067	0.2703	0.1515
Σ					1.0000

Table 8
The final crisp weights for the detailed criteria.

					All experts
		Gr 1	Gr 2	Gr 3	$\sum_{e=1}^{3} w_i^e \cdot w'^e$
		w'^1	w'^2	w'^3	
Weights for groups of experts		0.6	0.3	0.1	
		w_i^1	w_i^2	w_i^3	
Weights for detailed criteria	CD1	0.0633	0.0781	0.0302	0.0644
	CD2	0.1083	0.0760	0.0634	0.0941
	CD3	0.1087	0.0760	0.0648	0.0945
	CD4	0.0741	0.0731	0.0924	0.0757
	CD5	0.0558	0.0673	0.0000	0.0537
	CD6	0.0819	0.0702	0.0430	0.0745
	CD7	0.0327	0.0617	0.0430	0.0425
	CD8	0.0125	0.0652	0.0648	0.0335
	CD9	0.1050	0.0762	0.0424	0.0901
	CD10	0.0683	0.0714	0.1209	0.0745
	CD11	0.0683	0.0690	0.0753	0.0692
	CD12	0.0500	0.0662	0.0924	0.0591
	CD13	0.0429	0.0674	0.1209	0.0581
	CD14	0.1283	0.0821	0.1466	**0.1162**
	Σ				1.0000

Results and discussion

The comparison of weights for the criteria obtained on the basis of the proposed method with the division into groups of experts by their psychological conditions and without the division into groups of experts is presented in the Figs. 2 and 3.

As it is visible from the obtained results, after including decision-makers in psychological forms, the hierarchy of importance of criteria has been significantly changed. It is caused by weights which have been introduced for particular groups due to the various traits of experts' character. However, the first criterion (the innovation scale) remained unchanged in both methods. The other weights have changed. Using the earlier experience connected with the analysis of innovative projects, it is possible to state that weights determined in the division into groups of experts reflect more precisely the aspect of the projects' innovative nature than conditions of the enterprise operation.

The analysis in particular groups makes it possible to purposefully determine weights with keeping the most needed decision-maker's personality traits. Moreover, the application of weights for a given group of experts causes that higher weights are obtained for the most important criteria and significantly lower ones for less important criteria. Such an approach makes it possible to sharpen the evaluation of the innovation project in the context of the most important aspects.

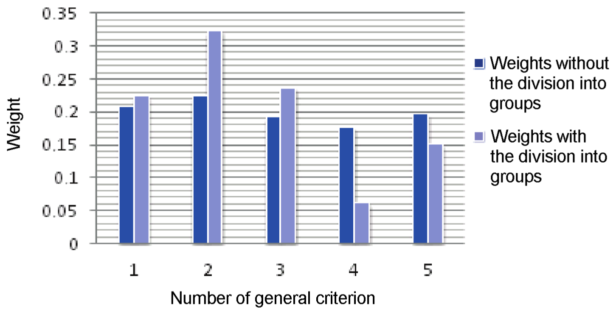

Fig. 2. Weights of the general criteria calculated without taking into consideration the division into groups of experts and with taking into consideration the division into groups of experts.

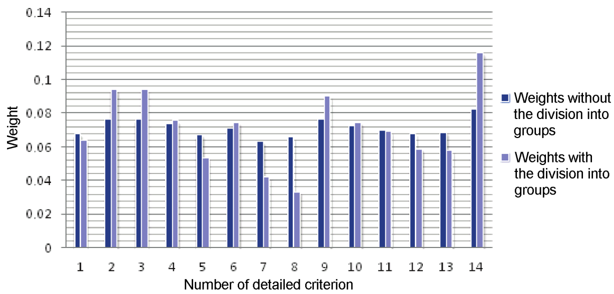

Fig. 3. Weights of detailed criteria calculated without taking into consideration the division into groups of experts and with taking into consideration the division into groups of experts.

Conclusion

In the paper, the method of determining weights for the assumptive criteria with the use of fuzzy logic and division into experts' groups with specific personality traits has been proposed. Using the proposed approach we expect more rational and objective scores of the criteria importance for the assessment of innovative projects risk.

The way of choosing experts has guaranteed the objective carrying out the study. The presented method has improved process of weight calculation and departed from the subjectivity, which appears in the case of stating weights by the expert. The use of particular personality traits of an expert has caused introducing some elements of rationality into a decision-making method. In the paper, only necessary traits have been characterized. Moreover, an application of this method makes it possible to emphasize the evaluation of the most important criteria by means of stating each time a greater weight for the most important criteria in comparison with the weights which have been elaborated without taking into consideration the purposeful choice of groups of experts. The other advantage of the proposed approach is that the obtained weights are more diversified. It causes that decision-making for innovative projects or investments is less onerous.

This technique can be applied for determining the weights in the innovation risk analysis. Furthermore, the presented weights can be used to the assessment of risk innovation in different production firms as an alternative method of analysis new products. In the future, it is planned to make the similar research in service firms.

References

[1] Arrighi P.-A., Le Masson P., Weil B., *Managing radical innovation as an innovative design process: generative constraints and cumulative sets of rules*, Creativity and Innovation Management, 24, 3, 373–390, 2015.

[2] Rudnik K., Deptuła A.M., *System with probabilistic fuzzy knowledge base and parametric inference operators in risk assessment of innovative project*, Expert Systems with Applications, 42, 6365–6379, 2015.

[3] Tidd J., Bessant J., *Managing innovation: integrating technological, market and organizational change*, Chichester: John Wiley & Sons, 2009.

[4] Alves J., Marques M.J., Saur I., Marques P., *Creativity and innovation through multidisciplinary and multisectoral cooperation*, Creativity and Innovation Management, 16, 1, 27–34, 2007.

[5] Marmier F., Gourc D., Laarz F., *A risk oriented model to assess strategic decisions in new product development project*, Decision Support Systems, 56, 74–82, 2013.

[6] Mardani A., Jusoh A., Nor K. MD., Khalifah Z., Zakwan N., Valipour A., *Multiple criteria decision-making techniques and their applications – a review of the literature from 2000 to 2014*, Economic Research-Ekonomska Istraživanja, 28, 1, 516–571, 2015, https://doi.org/10.1080/1331677X.2015.1075139.

[7] Adamus W., Greda A., *Multiple criteria decision support in organizational and management chosen problems solving*, Operations Research and Decisions, 2, 5–36, 2005.

[8] Lin C.J., Wu W.W., *A causal analytical method for group decision-making under fuzzy environment*, Expert Systems with Applications, 34(1), 205–213, 2008.

[9] Brans J.P, Vincke Ph., Mareschal B., *How to select and how to rank projects: the Promethee method*, European Journal of Operational Research, 24, 228–238, 1986.

[10] Roy B., *The outranking approach and the foundations of Electre methods*, Theory and Decision, 31, 49–73, 1991.

[11] Linton J., Walsh S.T., Morabito J., *Analysis, ranking and selection of R&D projects, in a portfolio*, R&D Management, 32(2), 139–148, March 2002, doi: 10.1111/1467-9310.00246.

[12] Lin C.J., Wu W.W., *A causal analytical method for group decision-making under fuzzy environment*, Expert Systems with Applications, 34(1), 205–213, 2008.

[13] Englund R.L., Graham R.J., *From experience: linking project to strategy*, Journal of Product Innovation Management, 16(1), 52–64, 1999.

[14] Calantone R.J., Benedetto C.A., Schmidt J.B., *Using the analytic hierarchy process in new product screening, in an international publication of the product development & management association*, Elsevier, 16(1), 65–76, 1999.

[15] Deptuła A.M., Knosala R., *Risk assessment modeling of technical innovation* [in Polish], Zarządzanie Przedsiębiorstwem, PTZP, Opole, 2, 2–8, 2015.

[16] Landwójtowicz A., Knosala R., *Criteria of an evaluation of technical innovations risk on the basis of chosen innovative solutions* [in Polish], Zarządzanie Procesami i Projektami, Marek

Wirkus [Ed.], Wydawnictwo Politechniki Gdańskiej, Gdańsk 2016.

[17] Füllbrunn S.C., Luhan W.J., *Decision making for others: the case of loss aversion*, Economics Letters, Elsevier, 161, 154–156, 2017.

[18] Andersson O., Holm H.J., Tyran J.-R., Wengström E., *Deciding for others reduces loss aversion*, Manag. Sci., 2461(13), 0–38, 2014.

[19] Chen W., Zou Y., *An integrated method for supplier selection from the perspective of risk aversion*, Applied Soft Computing, Elsevier, 54, 449–455, 2017.

[20] Jochemczyk Ł., Pietrzak J., Buczkowski R., Stolarski M., Markiewicz Ł., *You only live once: present-hedonistic time perspective predicts risk propensity*, Personality and Individual Differences, Elsevier, 115, 148–153, 2017.

[21] Rustichini A., *Dual or unitary system? Two alternative models of decision making*, Cogn. Affect. Behav. Neurosci., 8(4), 355–362, 2008.

[22] Oblak K., Ličen M., Slapničar S., *The role of cognitive frames in combined decisions about risk and effort*, Management Accounting Research, 2017, http://dx.doi.org/10.1016/j.mar.2017.07.001.

[23] He H., Villeval M.C., *Are group members less inequality averse than individualdecision makers?*, Journal of Economic Behavior & Organization, Elsevier, 138, 111–124, 2017.

[24] Bieniok H., Halama H., Ingram, M., *Making management decisions* [in Polish], Wydawnictwo Akademii Ekonomicznej im. Karola Adamieckiego w Katowicach, Katowice, 2002.

[25] Szymański I., *The influence of the decision-maker's type of mentality on the staff management decisions* [in Polish], Decision-making Processes in the Conditions of Uncertainty, Grzegorczyk A. [Ed.], Wyższa Szkoła Promocji, Warsaw, 96–109, 2012.

[26] Czarniawska B., *Decision making* [in Polish], Wydawnictwo Uniwersytetu Warszawskiego, Warszawa, 1980.

[27] Kozielecki J., *The psychological theory of decision-making* [in Polish], PWN, Warsaw, 1977.

[28] Porcelli A.J., Delgado M.R., *Stress and decision making: effects on valuation, learning, and risk-taking*, Current Opinion in Behavioral Sciences, 14, 33–39, April 2017.

[29] Saaty T.L., *The Analytic hierarchy process*, McGraw-Hill, New York, 1980.

[30] Chang D.Y., *Applications of the extent analysis method on fuzzy AHP*, European Journal of Operational Research, 95, 649–655, 1996.

[31] Wang Y. M., Chin K.S., *A linear goal programming priority method for fuzzy analytic hierarchy process and its applications in new product screening*, International Journal of Approximate Reasoning, 49(2), 451–465, 2008.

[32] Zhü K., *Fuzzy analytic hierarchy process: fallacy of the popular methods*, European Journal of Operational Research, 236(1), 209–217, 2014.

[33] Wang Y.M., Elhag T.M.S., *On the normalization of interval and fuzzy weights*, Fuzzy Sets and Systems, 157, 2456–2471, 2006.

[34] Buckley J.J., *Fuzzy hierarchical analysis*, Fuzzy Sets and Systems, 17, 233–247, 1985.

[35] Krejčí J., Pavlačka O., Talašová J., *A fuzzy extension of analytic hierarchy process based on the constrained fuzzy arithmetic*, Fuzzy Optim Decis Making, 2016, doi: 10.1007/s10700-016-9241-0.

[36] Deptuła A.M., Knosala R., *The role of experts in the assessment of risks of technical innovation*, Innowacje w Zarządzaniu i Inżynierii Produkcji, R. Knosala [Ed.], Oficyna Wydawnicza Polskiego Towarzystwa Zarządzania Produkcją, Opole, 38–46, 2015.