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Software Tool Implementing the Fuzzy AHP Method in Ecological Risk Assessment

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Abstract **– Due to the increased spread of invasive animals and plants in the territory of Latvia, the necessity of ecological risk assessment related to such kind of spread has grown lately. In cases with sufficient statistical data, the risk assessment may be successfully performed on the basis of statistical methods. The amount of statistical data in the context of spread of invasive animals and plants is pretty poor; therefore, the only method of ecological risk assessment remains subjective judgements of experts. The present paper proposes using a programming tool for ecological risk analysis elaborated by the authors. With the help of this programming tool the method of Fuzzy Analytical Hierarchical Process is implemented. The elements of the pair-wise comparison matrix are allowed to be expressed by triangular and trapezoidal fuzzy sets. The presented tool makes it possible to design the fuzzy pair-wise comparison matrix and process the results in a user-friendly way.**

Keywords **– FAHP, fuzzy logic, fuzzy representation of knowledge, risk assessment.**

I. Introduction

Due to the increase in the spread of invasive animals and plants and growth of factors causing the aggravation of environment, there is the necessity of ecological risk assessment.

The monitoring of spread of invasive plants in the territory of Latvia is implemented within the framework of various programmes, for example, “Nature Counting” (LV “*Dabas skaitīšana*”) or “Influence of Forest Management on Services of Forest and Related Ecosystems” (LV “*Mežsaimniecības ietekme uz meža un saistīto ekosistēmu pakalpojumiem*”), which envisage the collection and analysis of statistical data. The results of implemented investigations are reflected in [1] and [2]. The advantage of using statistics in ecological risk assessment is represented by the simplicity of introduced assessments of such risks, an opportunity to use them in direct comparison with other types of risks, and their comprehension by a wide range of users. The disadvantage of the process is the high price of collection of necessary primary information and its statistical processing. In case of a lack of the volume of objective primary information about the object of investigation needed for statistical analysis, the methods of expert assessment may be used. Experts are able to provide data necessary for the analysis on the basis of their professional knowledge and experience. Different methods of the expert assessment analysis may be applied, such as interval probabilities, second-order probabilities, etc. Disadvantage of these methods is complicated and bad interpretation of their results.

The problem may be solved by using a multiple criteria decision-making (MCDM) methodology. More detailed information on the methodology can be found in [3]. Analytic hierarchy process (AHP) is one of the most popular methods of MCDM group elaborated by Saaty, and was first mentioned in [4] and [5]. AHP method is based on the precondition that the process of taking a global decision in complicated tasks may be preceded by dividing and structuring the complicated task into many simple tasks, reproducing it in form of a demonstrative hierarchical structure.

Voluminous literature has applied the framework of AHP for modelling unstructured problems in economics [6], [7], social sciences [8], and industrial sectors [9]. Due to its effectiveness and popularity, commercial software such as Expert Choice, Web-HIPRE, Criterium DecisionPlus and ERGO are adopting their systems and designs based on the AHP framework.

In practice, experts may face difficulties in providing accurate assessments of results of paired comparisons. It may be caused by the lack of sufficient knowledge and experience in a certain field of subject, by the uniqueness of a task or insufficient basis for comparison. In order to cope with such kind of uncertainties, fuzzy versions of AHP may be applied, where instead of determinative results of paired comparisons their fuzzy analogues are used.

There are different approaches of fuzzification of relevant assessment in AHP and data processing. A historical method of expanding AHP into uncertain environment is the method of van Laarhoven and Pedrycz [10], where the results of paired comparisons are reproduced in form of fuzzy numbers, and the logarithmic least squares method is used for calculating the value of vectors of priorities. Another famous method of Buckley [11] envisages that the uncertainties of results of paired comparisons are modelled with the help of trapezoidal fuzzy numbers, but the values of vectors of priorities are calculated by special calculation procedures. Disadvantage of the method is the difficulty of the proposed calculation procedures.

The Chang method [12] is the most popular method of synthetic expansion. It was used in [13] for the analysis of risk of flood, but in [14] for determining the relative importance of risk factors in operative mortality after coronary artery bypass surgery. In this method, the uncertainties related to the results of paired comparisons are modelled by triangular fuzzy numbers. Values of vectors of priorities are determined on the basis of special calculation procedures. Apart from solving a general task – choosing optimal decisions –, AHP and its fuzzy versions are used for solving other tasks, particularly for the assessment of relative importance of factors of different types of risks.

While analysing the opportunity of application of the Chang and Buckley methods in practice, the authors of the paper did not manage to find a simple and visually understandable instrument of their usage. Therefore, a decision to work out their own programme product, using opportunities of graphical interface in order to simplify experts' work, has been taken.

The aim of the paper is to present the software elaborated by the authors that allows making the process of experts' ecological risk assessment automatic. The description of structure and functions of the elaborated software has been implemented on the basis of risk analysis related to the spread of invasive animals and plants in the territory of Latvia.

II. Software Development

The software has been worked out in the C# programming language, in Visual Studio graphical programming environment aimed for Windows operating system, and applying .NET technology, which is ideal for the development of graphical applications.

The proposed software has got a visually understandable graphical interface, includes step-by-step instructions and functions providing an opportunity for experts of different fields and with different levels of informative and computer competencies to introduce the needed information and to obtain experts' assessments in form of diagrams demonstrating the level of risk.

The main aspects of FAHP methodology have been implemented in the functions of software and they are the following: 1) linguistic scale definition; 2) formulation of the hierarchical tree; 3) definition of the fuzzy judgement matrix; 4) final risk factor ranking. Other aspects have been integrated and implemented parallelly. The software architecture design and the usage of case diagram are illustrated in Figs. 1 and 2.

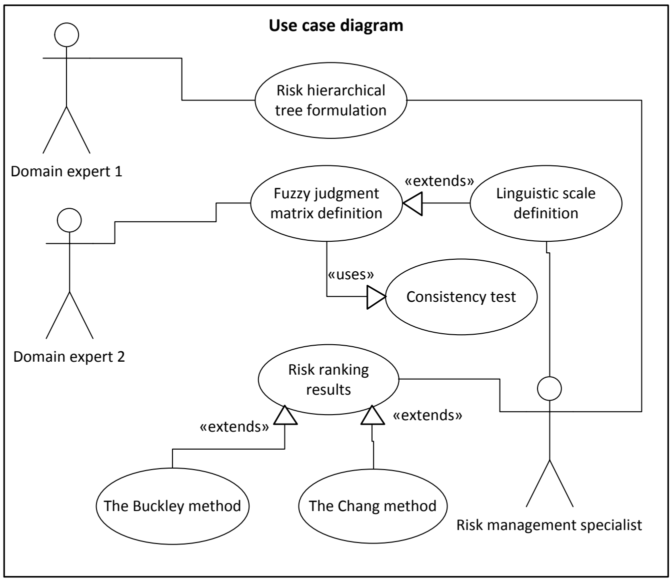

Fig. 1. Use case diagram of UML software.

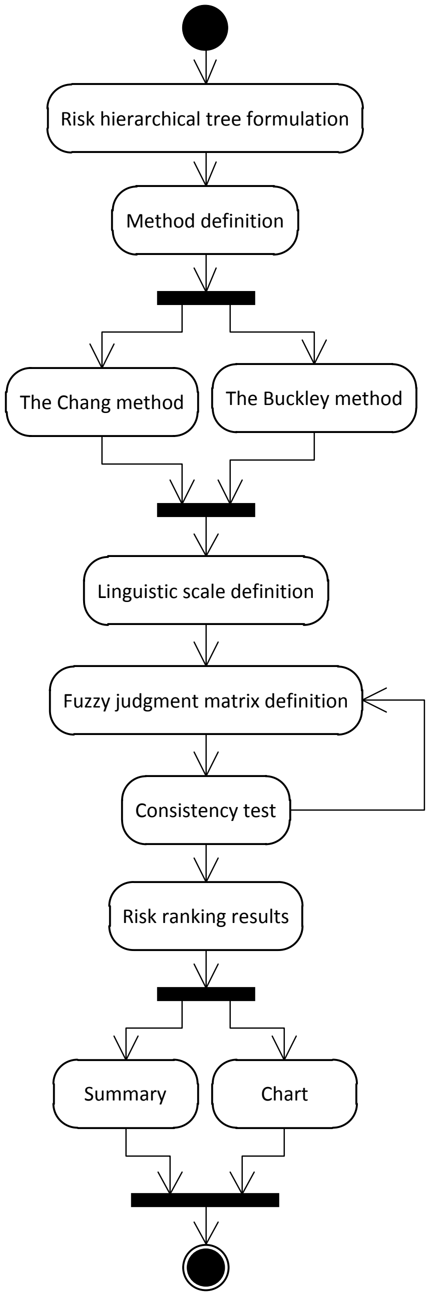

Fig. 2. Activity diagram of UML software.

III. Case Study

Functional opportunities and interface of the proposed software are practically demonstrated on the example of the FAPR Chang method for ranging risks by their level of affecting ecology in case of spread of invasive species. In order to achieve the result that would solve the indicated task by applying the mentioned software, the following steps should be implemented.

A. Step 1: Hierarchical Tree Formulation

At the first stage, an expert of the subject field should identify risks related to the spread of invasive species and structure them hierarchically. The introduction of hierarchical structure of risks is represented as a tree with an opportunity of using Drag and Drop technology.

In accordance with specifics of the ecological risk analysis on the basis of experts' experience, 19 risk factors, which affect ecology because of spread of invasive species, have been identified. In compliance with the FAHP methodology, the risk factors have been grouped into 5 categories. All factors and categories are illustrated in Fig. 3.

B. Step 2: Linguistic Scale Definition

At the second stage, a user (an expert in the field of risk assessment) should choose one of the two methods to use for the risk analysis. It is related to restrictions caused by the chosen method. For example, the Chang method works only with triangular fuzzy numbers. An expert has also an opportunity to apply new or re-determine the existing definitions of paired comparisons.

According to the specifics of the FAHP methodology, an expert needs to determine only the basic value. In order to keep the consistency, the inverse value of comparison is generated automatically. In case of necessity, the inverse value may also be re-determined manually.

Table I presents a fuzzy version of T. L. Saaty's common fuzzy scale [15], which is indicated as standard values in the programme, and is aimed for the paired comparison of risk factors. Linguistic values, according to the Chang methodology, are reproduced by a triangular fuzzy number and its inverse equivalent.

To make the process of using the system more convenient, an expert is able to come back to this stage without losing any data and in case of necessity make corrections during next steps.

TABLE I
LINGUISTIC SCALE FOR RELATIVE IMPORTANCE

Linguistic scale for relative importance	Triangular fuzzy scale	Reciprocal of triangular fuzzy scale
Exactly the same	(1, 1, 1)	(1, 1, 1)
The same importance	(1/2, 1, 3/2)	(2/3, 1, 2)
Slightly important	(1, 3/2, 2)	(1/2, 2/3, 1)
Serious importance	(3/2, 2, 5/2)	(2/5, 1/2, 2/3)
More serious importance	(2, 5/2, 3)	(1/3, 2/5, 1/2)
Absolute importance	(5/2, 3, 7/2)	(2/7, 1/3, 2/5)

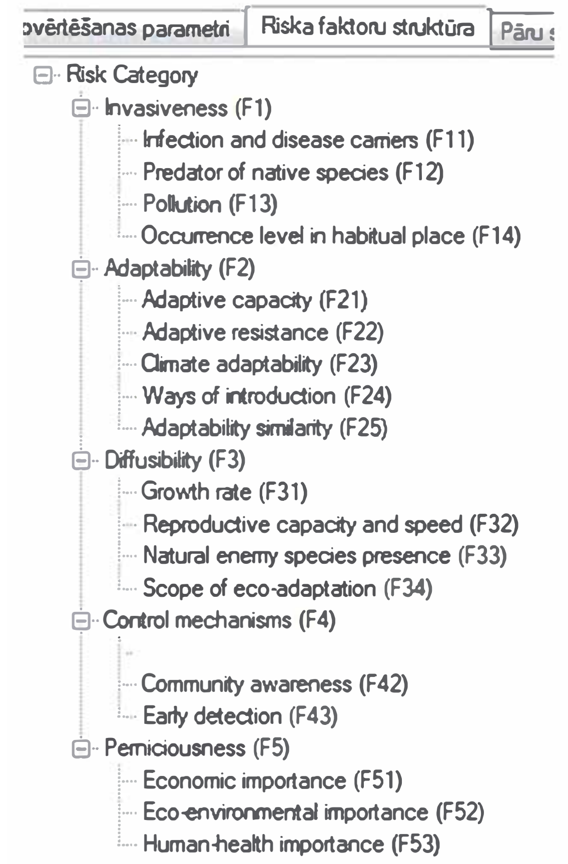

Fig. 3. Software user-interface of the hierarchy of the risk factors affecting the level of ecological risk caused by the spread of invasive species.

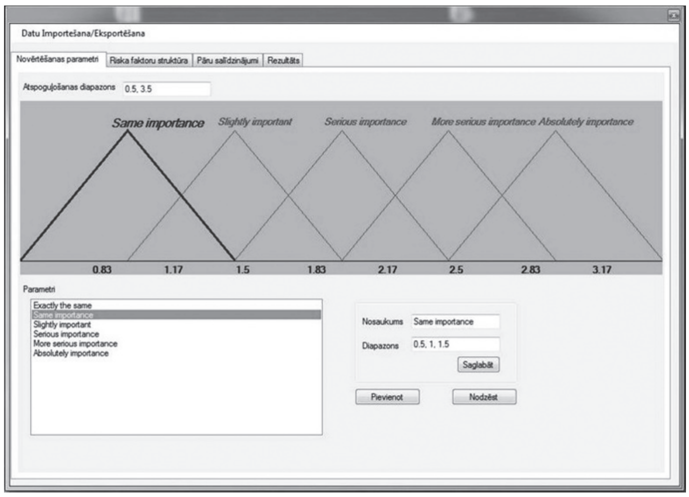

Fig. 4. User interface of linguistic scale definition.

C. Step 3: Definition of Fuzzy Judgment Matrix

The third step of the FAHP method envisages the paired comparison of risks in accordance with hierarchical structure illustrated in Fig. 3.

In the paired comparison, the linguistic values of fuzzy numbers determined at the previous stage, as well as their inverse values are used. In case of needed corrections, an expert may make them without losing any data and then come back to continue the work.

An example of one comparison for a segment of hierarchy of risks is illustrated in Fig. 5.

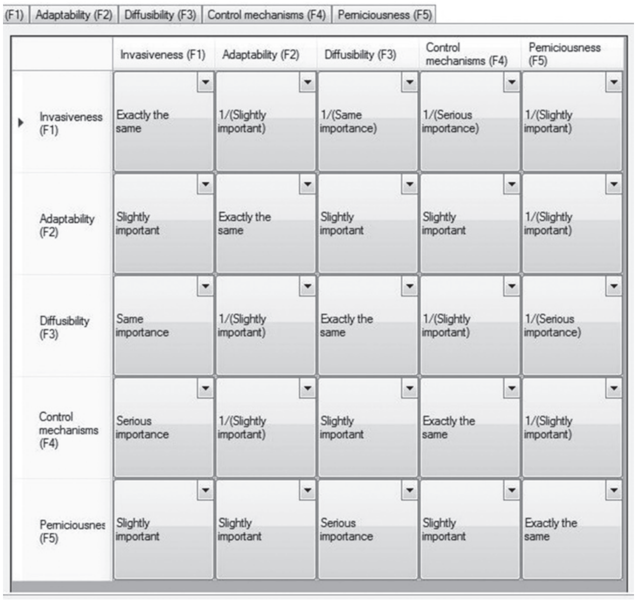

Fig. 5. User interface of expert fuzzy judgment matrix.

The control of accordance of experts' assessments is implemented parallelly to elaborating the matrix of comparison. Consistency is important in human thinking and enables us to order the world according to dominance [16]. The same method for control has been used in [4] and [5]. In this software implemented consistency testing method was proposed by T. L. Saaty for the classic AHP method, and is shown in equation (1), where CR – consistency ratio, λ_{max} – the maximum eigenvalue and n – the dimension of the judgment matrix. RI is a random index obtained by averaging the CI of a randomly generated reciprocal matrix [5]. Value of RI for matrices of various dimensions is reflected in Table II [3].

$$CR = \left(\frac{\lambda_{max} - n}{n-1} \right) \Big/ RI \tag{1}$$

TABLE II

RANDOM INDICES FOR *N* DIMENSIONAL MATRIX

n	1	2	3	4	5	…
RI	0.00	0.00	0.52	0.89	1.11	…

According to [5], the maximum allowable value of consistency ratio is 10 %. If the consistency ratio exceeds the allowable value, a system informs a user about the necessity to eliminate inconsistency.

D. Step 4: Risk Factor Weight Calculation and Ranking

This stage envisages the calculation of weight of factors and categories of risks. Different actions are implemented in the matrix of paired comparisons in accordance with the chosen method. For example, in case of the Chang method the Fuzzy Extent Analysis is applied. Applying this theory in a fuzzy comparison matrix, one can calculate the value of fuzzy synthetic extent with respect to the object as follows:

$$S_i = \sum_{j=1}^{k} \tilde{c}_{ij} \otimes \left[\sum_{k=1}^{k} \sum_{j=1}^{k} \tilde{c}_{kj} \right]^{-1}, \tag{2}$$

where

$$\sum_{j=1}^{k} \tilde{c}_{ij} = \left(\sum_{j=1}^{k} l_j, \sum_{j=1}^{k} m_j, \sum_{j=1}^{k} u_j \right), \tag{3}$$

and

$$\left[\sum_{i=1}^{k} \sum_{j=1}^{k} \tilde{c}_{ij} \right]^{-1} = \left(\frac{1}{\sum_{j=1}^{k} u_j}, \frac{1}{\sum_{j=1}^{k} m_j}, \frac{1}{\sum_{j=1}^{k} l_j} \right). \tag{4}$$

The normalized row sums S_i are then compared applying the degree of possibility values using (5)

$$V(\tilde{S}_i \geq \tilde{S}_j) = \\ = \begin{cases} 1, & \text{if } m_i \geq m_j; \\ 0, & \text{if } l_i \geq u_j; \\ \frac{l_j - u_i}{(m_i - u_i) - (m_j - l_j)}, & \text{otherwise.} \end{cases} \tag{5}$$

To obtain a global vector of weights, D. Chang offered to apply equation (6)

$$\boldsymbol{w_i} = \frac{V(\tilde{S}_i \geq \tilde{S}_j \mid j = 1,2,...,K, j \neq i)}{\sum_{k=1}^{K} V(\tilde{S}_k \geq \tilde{S}_j \mid j = 1,2,...,K, j \neq k)}, i = 1,2,...,K. \tag{6}$$

For more detailed information on the method and rules of application of formulas, see [12].

In case of using the Buckley method in a comparison matrix, the geometric mean procedure takes the form of equation (7) and therefore local weights are calculated using (8)

$$\tilde{r}_i = (\tilde{c}_{i1} \otimes ... \otimes \tilde{c}_{iK})^{1/K}, i = 1,...,K. \tag{7}$$

$$\tilde{\boldsymbol{w}}_i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus ... \oplus \tilde{r}_K)^{-1}, i = 1,...,K. \tag{8}$$

To calculate the final resulting vector, one should use (9)

$$\tilde{\boldsymbol{w}}_i^{A|G} = (\tilde{w}_i^{A|C_1} \otimes \tilde{w}_1^{C|G}) \oplus ... \oplus (\tilde{w}_i^{A|C_K} \otimes \tilde{w}_K^{C|G}). \tag{9}$$

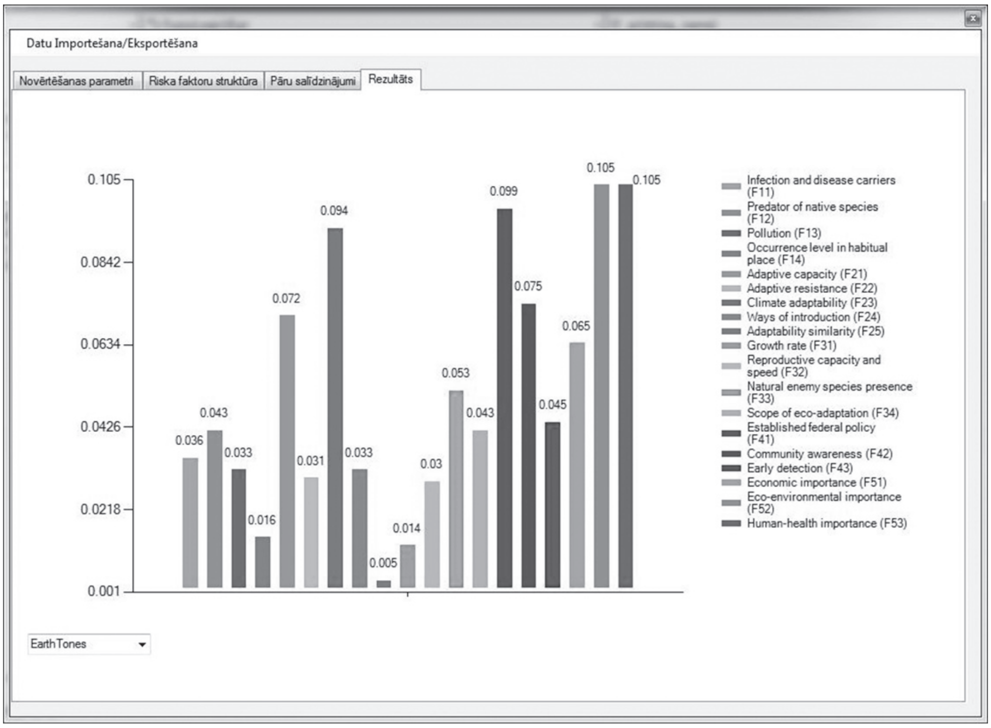

Fig. 6. User interface of summary diagram of risk analysis.

The ranging of risk factors is implemented at the very end. The ranging is proceeded on the basis of value of overall weight, which is equal to multiplication of local weight by the weight of its "father factor". Category importance weights and risk factors are represented in Table III and illustrated in Fig. 6.

Figure 6 shows the risk factors mostly affecting the level of ecological risk in case of the spread of invasive species. The higher the value is, the more significant the risk factor is.

IV. Conclusion

The software elaborated by the authors has allowed making the application of popular FAHP methods (e.g., the methods of Chang and Buckley) automatic. The proposed product may be used for the analysis of experts' assessments in different expert spheres. It significantly simplifies the application of the FAHP methods that makes the work of risk managers more effective.

The used example of risk analysis in case of the spread of invasive species has enabled the authors to demonstrate the process of adaptation of the proposed software towards a definite task, the simplicity of its application and visual and understandable representation of the gained results.

This programme achieves simplicity and abstraction with a fuzzy AHP algorithm that works behind the scene. The application of FAHP method with this tool allows making a complex algorithm of analysis more affordable in order to obtain a risk assessment in case of incomplete and reduced input data. This programme can be used as a preliminary risk assessment tool to expose situations where a more complete analysis is needed. This tool can also be used in the case when there is a need to make a thoughtful decision of risk level reduction.

TABLE III

Weight Table for Risk Factors

Risk factor	Local weight	Risk sub-factor	Local weight	Overall weight
F_1	0.13	f_{11}	0.283	0.036
		f_{12}	0.334	0.043
		f_{13}	0.258	0.033
		f_{14}	0.126	0.016
F_2	0.24	f_{21}	0.307	0.072
		f_{22}	0.133	0.031
		f_{23}	0.398	0.094
		f_{24}	0.139	0.033
		f_{25}	0.023	0.005
F_3	0.14	f_{31}	0.100	0.014
		f_{32}	0.215	0.030
		f_{33}	0.378	0.053
		f_{34}	0.307	0.043
F_4	0.22	f_{41}	0.450	0.099
		f_{42}	0.343	0.075
		f_{43}	0.207	0.045
F_5	0.28	f_{51}	0.237	0.065
		f_{52}	0.381	0.105
		f_{53}	0.381	0.105

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