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Application of analytical hierarchy process for emergency managers selection

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Abstract

The selection of the most qualified staff for the performance of responsible duties in the field of emergency management is an extremely sensitive task. By excluding some external factors and focusing exclusively on the professional domain, the application of certain mathematical tools significantly facilitates the work of decision makers. One of the most commonly used tools for solving multi-criteria decision-making problems in the analytical decision-making approach is Analytical Hierarchy Process. Through the paper, the theoretical basis of this method is explained in more detail through the basic steps and the mathematical basis is described for easier understanding emphasizing advantages and disadvantages of the method. The application of the method is practically presented on the example of the selection of the best candidate for a management position in the emergency management sector.

Keywords: Analytical Hierarchy Process (AHP), criteria, alternatives, emergency manager, candidate.

1. Introduction

Real life problems and situations are characterized by a large number of, mostly conflicting, criteria whose strict optimization is almost impossible. Making the right decisions is one of the main issues and a big challenge for managers, since the effectiveness of the organization depends on those decisions. Deciding itself carries great responsibility and a certain risk. In addition to being challenging, decision-making requires detailed knowledge of the problem. The development of new technologies in the time we live in greatly helps managers in the area of decision-making. The effectiveness of the applied unlearning method depends on the nature of the problem being solved. If there is a large selection of alternatives, then the multi-criteria decision-making method is applied. The application of decision support systems, based on multi-criteria analysis, helps the decision-maker to bring the best or potentially the best solution by harmonizing all criteria, different preferences and conflicting interests. These systems have proven to be an irreplaceable tool in the decision-making process because by saving time on solving mathematical operations, the possibility of efficient analysis of the obtained solutions and their adequate visualization greatly facilitates the decision-making process. The paper presents the

[#] The initial version of the research was published at the 10th Security and Crisis Management - Theory and Practice (SeCMan), Belgrade, Serbia (Maksimović, 2024).

application of the Analytical Hierarchy Process (AHP) of multi-criteria decision-making to a practical problem. The main goal of the method is the selection of the best alternative for the set criteria, i.e. specifically the application of the AHP method in the selection of candidates for a responsible position in the management sector in emergency situations

2. Multi-criteria analysis and decision-making

Making a decision in selection of one of several possible solutions to a problem requires the application of one of the multi-criteria decision-making models. This implies the procedure of choosing one of several possible alternative solutions, for which specific goals are set (Saaty and Vargas, 2012). In addition to setting goals, it is necessary to define criteria to which appropriate weights are attached, on the basis of which it is possible to evaluate the achievement of those goals (Biswas et al., 2024). The weights are used to define the importance of the participation of certain criteria when making a decision on choosing the most favorable alternative solution to the problem. The final decision on the selection of criteria and definition of their importance is made by an expert, usually based on his expert knowledge and professional experience (Madić, et al., 2024). The selection of criteria and defining their importance is the most delicate task in multi-criteria decision-making. With this method, all data on decision-making elements, for each alternative solution, are combined into one numerical value, based on which their ranking list is formed, using appropriate procedures.

Multi-criteria decision-making (MCDM) is one of the most well-known branches of decision-making and refers to situations in which there is a large number of, most often, conflicting criteria, which enables solving real problems, while classic optimization methods use only one criterion for decision-making, i.e. solving, which drastically it diminishes the reality of problems that can be solved (Saaty, 1980). The spectrum of multi-criteria decision-making problems is wide, but even so, all these problems have some common elements:

1) A greater number of criteria (goal function, criterion function), i.e. attributes for decision-making;
2) Conflict between criteria, as the most common case in real problems;
3) Incomparable units of measure for different criteria;
4) A greater number of alternatives to choose from;
5) The process of choosing the final solution, which can be the design of the best alternative, or the selection of the best alternative from a set of previously defined final alternatives.

Decision support systems are information systems, which are similar and complementary to standard information systems and aim to support, mainly, business decision-making processes. They represent the symbiosis of information systems, the application of a range of functional knowledge and ongoing decision-making processes (Suknović and Delibašić, 2010). Decision support systems are interactive computer systems intended to help managers or decision makers identify, structure, and/or solve semi-structured and unstructured problems and make choices among alternatives (Power, 2002).

Therefore, the task of decision support systems is to provide decision support with an emphasis on solving unstructured or poorly structured problems. They provide decision support at all levels of decision-making, but are particularly important at the tactical and strategic levels. Easy to use, manageable so they can be constructed by end-users themselves and full control over all steps in the decision-making process improves the efficiency of decision-making, thereby significantly assisting, not replacing, the decision-maker.

3. Analytical hierarchy process

Analytical Hierarchy Process is a decomposition of multiple-attribute decision-making (MADM) method, developed by Saaty (1980), to represent human decision-making process and achieve better judgments based on hierarchy, pair-wise comparisons, judgment scales, allocation of criteria weights, and selection of the best alternative from a finite number of variants by calculation their utility functions. AHP has three primary

functions: structuring complexity, measurement, and synthesis which make it a general methodology with a wide variety of applications (Abdollahi et al., 2024). There is a need to closely examine the term of the Analytical Hierarchy Process. The adjective "analytical" means that this method is used numerologically, while the adjective "hierarchical" means that this model sets goals, criteria, sub-criteria and alternatives, while the word "process" means solving problems in a certain continuity (Dragičević, 2007). In recent years, the AHP method has become increasingly popular and one of the most used because it is similar to the way an individual solves complex problems and breaks them down into simpler components. The method helps the decision maker in solving complex problems of multi-criteria decision making. By using this method, the decision maker independently sets criteria by importance and based on them chooses the best alternative, which is the goal of the model itself and which makes the AHP method widely applicable (Dragičević, 2007). This method helps measure the importance of several options relative to each other using pairwise comparisons when objective data for decision-making is not available (Komazec et al., 2024). Sometimes the data provided by decision-makers are incomplete, and there are various reasons for this, including the following: lack of enough time for decision-making, unwillingness to express an opinion and uncertainty about the opinion (Sharabiani et al., 2023).

The procedure for applying the AHP method could be shown in several steps (Saaty, 1980). A hierarchy describes a complex problem in a structure arranged in stages. In the first stage the decision-maker defines the final goal to be achieved with the method and then determines the alternatives that satisfy the set of requirements, and then defines the priorities of the requirements (Pamučar et al., 2012). Basically, a hierarchical model of the problem is set, starting with the goal at the top, criteria at the next level, sub-criteria and then alternatives. Such a hierarchy, with three levels, represents the basic structure of the analytical hierarchical process. After the hierarchical structure has been defined, using Saaty's scale of relative importance, elements are compared in pairs at all levels of the hierarchical structure that has been set (Đukić et al., 2022). In the third stage, using a mathematical model, priorities are calculated at a certain level of the hierarchical structure. Among other things, the weights of criteria, sub-criteria and alternatives are calculated, which are then synthesized into the total priorities of the alternatives. When the priorities are weighted with the weights of the multi-level elements, the overall priority of the alternatives is obtained. Finally, a sensitivity analysis is carried out for the purpose of visibility of the impact of changes in input data on changes in the overall priorities of the alternatives (Figure 1).

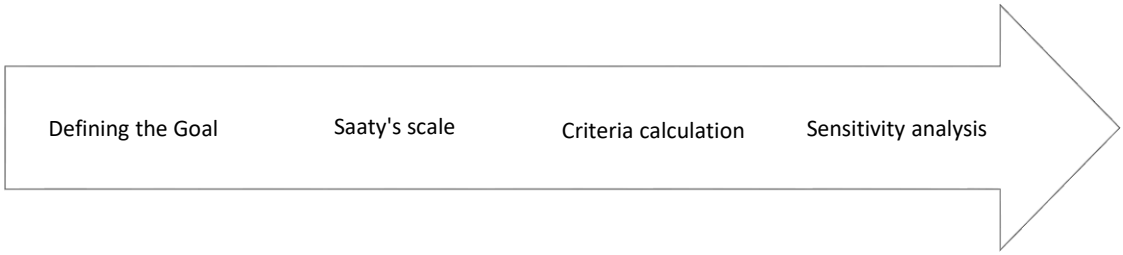

Figure 1. Steps in AHP method application

After the levels in the structure are set, each element (or criteria or alternative) is compared with each element of the same level. The decision-maker evaluates the criteria and sub-criteria and thus compares them in pairs. The preference of one criterion over another depends on the decision-maker and his ability to assess. Most often, such a comparison is made according to Saaty's scale of relative importance (Table 1).

Table 1. Saaty's scale of relative importance (Saaty, 1980)

Importance	Definition	Explanation
1	Of the same importance	The two elements are of identical importance in relation to the goal
3	Low dominance	Experience or judgment slightly favors one element over another
5	High dominance	Experience or judgment strongly favors one element over another
7	Demonstrated dominance	The dominance of one element confirmed in practice
9	Absolute dominance	Absolute dominance of one element
2, 4, 6, 8	Intermediate values	Compromise or further division required

Saaty's scale of relative importance contains nine degrees by which elements are compared through verbal ratings. The intensity of importance is shown by numbers, of which odd numbers show basic values and even numbers describe their intermediate values. By using the reciprocal values in the scale, ratings opposite to those given are given.

The main mathematical tool used in the AHP method is matrices. The element a_{ij} of matrix A indicates the relative importance of criterion *i* in relation to criterion *j*. If it is assumed that *n* is the number of alternatives or criteria whose weights, i.e. priorities w_i need to be determined based on the assessment of the value of their ratios, which are indicated according to the following:

$$a_{ij} = w_i / w_j \tag{1}$$

From the above, the relative importance ratio matrix A is derived:

$$A = \begin{bmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \dots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \dots & \frac{w_2}{w_n} \\ \dots & \dots & \dots & \dots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \dots & \frac{w_n}{w_n} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix}$$

$$\begin{bmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \dots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \dots & \frac{w_2}{w_n} \\ \dots & \dots & \dots & \dots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \dots & \frac{w_n}{w_n} \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \\ \dots \\ w_4 \end{bmatrix} = n \begin{bmatrix} w_1 \\ w_2 \\ \dots \\ w_4 \end{bmatrix}$$

In the case of consistent estimates $a_{ij} = a_{ik} \cdot a_{kj}$ is valid, which fulfils the condition of the equation,

$$A * w = n * w \tag{2}$$

where *w* denotes the priority vector (Saaty and Vargas, 2012).

Matrix A is a positive reciprocal matrix due to the elements that meet the condition of the equation $a_{ij}=1/a_{ij}$, that is, the element above the main diagonal is equal to the reciprocal value of its symmetrical element below the main diagonal. Matrix A has rank 1 ($r(A)=1$) and has an eigenvalue equal to n. Since the sum of the eigenvalues of a positive matrix is equal to the trace of that matrix, the non-zero eigenvalue has the value n:

$$\lambda_{\max} = n \tag{3}$$

Moreover, AHP is used for consistency checking. It allows the decision makers to check the quality of the results in comparison matrix. Consistency is concerned with the compatibility of a matrix of the ratios constructed from a principal right eigenvector with the matrix of judgments from which it is derived. Since any deviation from consistency affects the change of eigenvalues, the consistency index CI is defined using the AHP method (Saaty and Vargas, 2012)

$$CI = \frac{\lambda_{\max} - n}{n-1} \tag{4}$$

The non-zero eigenvalue λ_{max} denotes the largest value of the comparison matrix, while n is the number of criteria or alternatives being compared. The smaller the difference between λ_{max} and n, the higher the consistency. The consistency ratio (CR) was calculated by dividing the consistency index (CI) by the random consistency index (RI), Table 2. If the consistency ratio is 0.10 or less, then the assessment, that is, the decision maker's response is consistent, however, if the consistency ratio is higher than 0.10, it is necessary to investigate what caused the inconsistency.

$$CR = CI / RI \tag{5}$$

The random consistency index (RI) represents the calculated values shown in Table 2 and is used only in the case when n is greater than 3.

Table 2. Random Consistency Index (*RI*)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

The AHP method has numerous advantages, some of the most important of which are:

- The AHP method uses an absolute scale to measure quantitative and qualitative homogeneous criteria that are based on the subjective assessments of decision makers;
- The AHP method, similar to an individual, solves a specific problem by dividing it into smaller and simpler problems;
- The AHP method is almost completely insensitive to estimation errors due to its comprehensiveness when comparing two criteria or alternatives;
- This method increases knowledge about the problem and increases and accelerates the motivation of decision makers. Having in mind the most meetings, problems are solved more quickly and with significantly reduced expenses when making decisions. Already existing results could also be taken as input for making even more complex decisions;
- The decision-maker is enabled to analyze the sensitivity of the results, by means of which it is visible how much changes in the importance of a particular criterion can affect the final results and change them;
- The AHP method helps in simulating the decision-making process starting from defining the goal, criteria and alternatives to comparing the criteria and alternatives with each other and obtaining the results of the alternatives in relation to the set goal;
- If this method were to be used during group decision-making, it will play a major role in improving communication between individual teams, as it requires agreement and agreement regarding the setting of each criterion and alternative, as well as a joint assessment of their importance;
- A great advantage of using the AHP method is provided by quality software tools such as Expert Choice, which, through simple application, help the decision maker reach the desired goals.

Some of the disadvantages of the AHP method are:

- If the problem is not well structured, as a consequence there may be incomparable criteria and incomparable alternatives in the model, which will affect the final result;
- Achieving consistency in most cases is very difficult;

- Large number of comparative pairs in most problems;
- A scale for comparing elements in pairs that is not large enough, which leads to a low-quality description of the difference in importance between individual criteria and alternatives.

Comparing the advantages and disadvantages, it could be noted that the AHP method emphasizes its positive sides more than the negative ones. Due to its simple and easy implementation, many decision makers choose it precisely because it enables them to quickly and correctly arrive at the final solution to a problem that has arisen. Also, the method has a greater and better application in practice considering other methods for multi-criteria decision making. In addition to numerous advantages, the disadvantages of the method itself are negligible, but it should be noted that the biggest disadvantage is the small scale for comparing elements when matching them.

The combination of AHP and stakeholder analysis is a well-documented approach in several studies, including in marketing (Putri and Putro, 2024), environmental health aspects (Chompook et al., 2023), project management selection (Akhrouf and Derghoum, 2023), knowledge and human resource management (Poveda, 2023; Smith and Bayazit, 2024; Lu et al., 2024), transportation (Akhrouf et al., 2023), construction, production and agriculture (Srebrenkoska et al., 2023; Altaie and Dishar, 2024; Astriani and Siallagan, 2024) and sport (Teppa-Garran and Fernández-Da Costa, 2024). However, its application in emergency aspects problem-solving planning remains relatively underexplored. Additionally, AHP's capacity to rank criteria according to the needs of policymakers allows for more precise decision-making processes.

4. Method application on practical problem

An emergency management manager manages processes and operations involving personnel and assets. The management position carries with it a large and exceptional dose of responsibility and requires the possession of abilities, knowledge, experience, skills, but also certain personality characteristics (Gerginova, 2022). Therefore, the selection of candidates for this position is a responsible and serious task.

In public administration for emergency situation, one of middle ranked managers left organization due to retirement. In need to fulfil that position, the administration opened the position for applying. For this case, we had a competition for the position of security manager in the organizational unit of the public administration for emergency situations. In addition to the general conditions, the competition foresees the following special conditions: Bachelor's degree in social studies, minimum 3 years of work experience in the same or similar jobs, computer skills and category B driver's license. In this case, after testing phase in which candidates were subjected to psychological testing, language skills, communication skills and physical fitness test, out of 11 a 4 candidates were selected for the second round from all the applicants. Three candidates solved the tests the best and the fourth had the most work experience and was therefore invited to the next round. The aforementioned four candidates were invited to an interview led by a team of three experts who are in charge of the selection and selection of candidates. Each candidate had the opportunity to emphasize his virtues and explain why he is the right person for this position. In order for the decision to be as correct as possible, the AHP method will be applied, which will help the expert team when making an objective decision. This example will confirm one of the advantages of the AHP method, which improves relationships and increases communication among the employees themselves, because they come to the final decision together.

The first step foresees the hierarchical structuring of the problem. At the top of the hierarchy is the goal, which in this example is selecting the best of the four candidates. On the second level there are criteria, namely: success on tests, work experience gained and the impression left during the interview. At the bottom of the hierarchy there are alternatives, and they are: candidate A, B, C and D. After the goal has been determined and the problem has been set hierarchically, it is necessary to evaluate the importance ratios of the criteria first and

then the alternatives, that is, the candidates with each criterion individually (Table 3). In order to compare the mentioned pairs, Saaty's scale of relative importance will be used. The weighting of the criteria was determined by comparing in pairs and based on the assessment.

Table 3. Basic information about Candidates

	Criteria		
Alternatives	Test	Work experience	Interview
Candidate A	Average	6 years	The best
Candidate B	Average	6 years	The worst
Candidate C	Above average	3 years	Some better than Candidate B
Candidate D	Average	10 years	Some worse than Candidate A

The test success criteria is between of the same importance and low dominance in relation to work experience, while the interview criterion has low dominance than test success. The interview criteria is between low dominance and high dominance in relation to the work experience criteria (Table 4).

Table 4. Weight criteria evaluation

	Test	Work experience	Interview
Test	1	2	1 / 3
Work experience	1 / 2	1	1 / 4
Interview	3	4	1

After this step, the weight of each individual criterion is calculated from their estimated ratios. For that procedure, the approximate procedure for calculating the maximum eigenvalue and the maximum eigenvector will be used. First, the sum of each column is calculated and then all the elements of each column are divided by the sum of the column. After the sums of all elements for each column are calculated, the mean value of each row is determined (Table 5).

Table 5. Criteria weights ratio sum

	Test	Work experience	Interview
Test	1	2	1 / 3
Work experience	1 / 2	1	1 / 4
Interview	3	4	1
Sum	4.5	7	1.58

Table 6 shows the calculated weights of all criteria individually and the consistency ratio (CR) which is 0.02, which means that the criteria ratios are properly structured because it is less than 0.1.

Table 6. Weight criteria and CR

	Test	Work experience	Interview	Weight	Weight sum vector	Consistency vector	λmax	*CI*	*CR*
Test	0.22	0.29	0.21	0.24	0.72	3.01	3.02	0.01	0.02
Work experience	0.11	0.14	0,16	0.14	0.41	3.01	3.02	0.01	0,02
Interview	0.67	0.57	0,63	0.62	1.89	3.03	3.02	0.01	0.02
Sum	1.00	1.00	1.00	1.00					

The relative weight or the evaluation factor is the highest for the third criteria (interview) and is 0.62, while the lowest for work experience is 0.14.

When comparing the alternatives, the first criteria will be test success, which is ranked according to grades from 1 to 9. Grades from 1 to 3 indicate below average success, 4 to 6 average, and above average from 7 to 9. Candidates A and B achieved grade 6, candidate C got a grade 8, while candidate D got a grade 4. According to the achieved results, the priority ratios of the alternatives according to the test success criterion were estimated. (Table 3 and 7).

Table 7**.** Priority ratio according test success

	Candidate A	Candidate B	Candidate C	Candidate D
Candidate A	1	1	1 / 4	3
Candidate B	1	1	1 / 4	3
Candidate C	4	4	1	5
Candidate D	1 / 3	1 / 3	1 / 5	1
Sum	6.33	6.33	1.7	12

When discussing about assigning weights to the work experience alternative, the number of years will be taken. According to years of experience, the weights of the alternatives are presented in Table 8.

Table 8. Priority ratio according work experience

	Candidate A	Candidate B	Candidate C	Candidate D
Candidate A	1	1	3	1 / 3
Candidate B	1	1	3	1 / 3
Candidate C	1 / 3	1 / 3	1	1 / 5
Candidate D	3	3	5	1
Sum	5.33	5.33	12	1.87

The last criteria is the interview. It included questions about education, work skills, work experience, reasons for applying and expectations. According to the results of the interviews, the weights of the alternatives are presented in Table 9. Candidate A made the best impression during the interview, while candidate B made the worst impression.

Table 9. Priority ratio according interview

	Candidate A	Candidate B	Candidate C	Candidate D
Candidate A	1	4	3	2
Candidate B	1 / 4	1	1 / 2	1 / 3
Candidate C	1 / 3	2	1	1 / 2
Candidate D	1 / 2	3	2	1
Sum	2.08	10	6.5	3.83

According to the priority of the alternatives based on the criteria of success in the tests, the highest score is obtained for candidate C and the lowest for candidates A and B. When talking about the priority of alternatives according to the criteria of work experience, the highest score is obtained by candidate D and the lowest by candidate C (Table 10). Based on the results from Table 10, the alternatives could be ranked, so candidate A is the highest ranked while candidate B is the lowest ranked. Consequently, itcould be concluded that, based on the applied AHP method of candidate selection, candidate A is the best choice for the foreseen position.

Table 10. Local and sum priority alternatives for this case

	Test	Work experience	Interview	Weight: Test	Weight: Work experience	Weight: Interview	Total alternative (candidate) priority
Candidate A	0.18	0.20	0.47	0.24	0.14	0.62	0.361
Candidate B	0.18	0.20	0.10				0.130
Candidate C	0.57	0.08	0.16				0.247
Candidate D	0.08	0.52	0.28				0.262

5. Conclusion

The aim of the paper was to present the possibility of applying AHP method of decision-making to the problem of choosing the best candidate for a important management position in the emergency management sector. A decision is the result of a decision-making process where the decision-maker plays a major role and the method helps him to make the most correct and objective decision in an easier and simpler way. The key aspect of the application of the method is the correct setting of criteria or alternatives and their matching.

The AHP method is one of the various methods of multi-criteria decision-making and is applicable in almost all areas, including the selection of key personnel. Despite the potentially correct and objective setting and evaluation of the criteria, the best alternative is not always the result. The reason for this is subjectivity in the process of prioritizing the importance of criteria and their evaluation, which leads to different results.

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