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APPLICATION OF MULTI-CRITERIA DECISION-MAKING IN THE SELECTION OF A LOCATION FOR THE DISPOSAL OF FLUORESCENT TUBES CONTAINING MERCURY IN THE TERRITORY OF THE CITY OF NIS

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Abstract: *Disposal of hazardous materials is a procedure that has been a problem since its inception. According to the variety of dangerous substances, there are also different methods of disposal. However, the goal during disposal is always the same, so that people, the environment and other goods are not endangered. This paper deals with the problem of disposal of fluorescent tubes containing mercury in the territory of the city of Nis. One of the problems related to this type of hazardous materials is the choice of location for disposal after use. In this regard, multi-criteria decision-making methods can help in deciding the location. In this paper, the problem of choosing a location for the disposal of this type of hazardous waste is addressed using the AHP and TOPSIS methods. The first method determines the weight coefficients of the criteria, while the second method determines the choice of one of the three alternatives.*

Key words: *Hazardous substances, decision-making, AHP and TOPSIS*

1. INTRODUCTION

The development of human society has always flowed in the direction of creating relief in everyday functioning. Unfortunately, progress itself has not always brought improvement in all spheres. Such is the example of dangerous substances. The benefits, which they brought on the one hand, speeding up certain processes, would always be matched by a bad impact on people's lives and health, the environment and other goods.

The influence and production of dangerous substances grew with the development and the desire of society itself. The turning point is definitely represented by the industrial revolutions that accelerated various production processes. Seen from the aspect of environmental protection, in an inversely proportional relationship, starting from that period, was the very development and concern of man about the disposal of that hazardous waste that appeared. In other words, as the industry developed, so did the endangerment of the environment, as well as the lethality of dangerous substances. Therefore, the choice of location for their disposal is of great importance.

In this paper, in the domain of hazardous materials, fluorescent tubes containing mercury and the problem of their disposal in the territory of the city of Nis will be dealt with. First of all, it should be mentioned that this type of light bulbs was discovered way back in 1840, and that in Serbia their recycling started ten years ago and on a smaller scale (eKapija.com, 2010). So, the disposal is in a way inevitable, with a strict procedure.

Another part of the problem is determining the location on the territory of the city of Nis. At first glance, making this decision is the easier part of the job, however, the harmful impact of hazardous substances in general must not be ignored, therefore a scientific approach must be taken when it comes to the selection of locations for the disposal of hazardous waste. Taking all this into account, the Analytical Hierarchical Processes (AHP) method and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method of multi-criteria decision making were used in the work. The essence of the problem is the choice of one variant of use, which the decision maker (DO) will choose based on the comparison of all elaborated variants (Saaty, 1980). The first method was used to determine the weighting coefficients of the criteria, while the second method was used to determine the best alternative for the source location for the disposal of fluorescent tubes containing mercury in the territory of the city of Nis.

2. PROBLEM DESCRIPTION

Fluorescent tube is a light source in which visible light is produced on a fluorescent layer excited by ultraviolet radiation created by an electric charge in a mixture of noble gases. Compared to an ordinary light bulb, it is characterized by a higher degree of electrical energy conversion into light and a longer lifespan. These bulbs are very economical, in addition to favorable energy characteristics, different light color temperatures are an additional advantage. There is a wide range of powers, shapes and light intensities that provide the optimal solution for different applications. In short, these features have led to the mass use of these consumers of electricity, which further leads to their disposal being a problem due to their mercury content. Mercury belongs to the group of substances of the 1st danger class. Therefore, disposal of these products is mandatory. The amount of mercury can vary depending on the type of light bulb and is 3-5 mg per unit (Satoshi, 2022).

In accordance with the above, the Rulebook on the method and procedure for managing fluorescent tubes containing mercury was adopted. The provisions of this rulebook refer to fluorescent tubes containing mercury, namely:

1) compact fluorescent light sources with a mercury content of up to 5 mg;

2) flat fluorescent light sources for general purposes in which the content of mercury compounds does not exceed the following values (Brown, Richard & Hyun, 2013):

- halo phosphates 10 mg;
- triphosphates with a normal shelf life 5 mg;
- triphosphates with a long shelf life 8 mg and

3) flat fluorescent light sources for special purposes containing mercury.

Management of waste fluorescent tubes containing mercury is a set of measures that include collection, sorting, transport, storage and treatment of waste fluorescent tubes containing mercury or disposal of residues after treatment. The management of waste fluorescent tubes containing mercury is carried out in a way and according to a procedure that does not pose a risk of water, soil or air pollution, and which can be avoided, in order to protect human health and the environment. Waste fluorescent tubes containing mercury are sorted and classified in the prescribed manner and stored until handed over to the collector and/or person who transports waste fluorescent tubes containing mercury, i.e. the person who stores and/or treats waste fluorescent tubes containing mercury. Waste fluorescent tubes containing mercury are marked in accordance with the regulation governing the management of electrical and electronic products. In the warehouse of waste fluorescent tubes containing mercury, pre-treatment and treatment of waste fluorescent tubes containing mercury is not carried out. Collected waste fluorescent tubes containing mercury, before reuse or disposal, are treated in a treatment facility that has a permit, in accordance with the law governing waste management and the regulation governing the management of electrical and electronic products. The treatment of waste fluorescent tubes containing mercury is carried out in a manner and according to a procedure that ensures the protection of human health and the environment, in accordance with the law and special regulations (Official Gazette of RS No. 97/2010).

3. DESCRIPTION OF APPLIED METHODS

Multi-criteria decision-making is one of the most well-known areas in decision-making theory. It can be defined as a structured framework for analysing and solving decision problems characterized by multiple objectives. Multi-criteria decision-making uses a set of mathematical methods and tools to support the decision-maker in solving real problems in various fields, and in situations where there is a large number of, most often, conflicting criteria, that is, goals. In everyday real decision-making problems, there is almost no "ideal" alternative that would be optimal in relation to each criterion or goal. So, for example, an alternative that is more useful is usually more expensive. As there is almost always a conflict of goals, the main purpose of multi-criteria decision-making is to determine a "good" compromise, that is, an alternative that satisfies all set goals to the greatest extent (Gajovic & Radivojevic, 2014).

Although multi-criteria analysis as a scientific discipline has relatively short history, about 50 years, a large number of different methods have been developed to date, and the literature continuously records the development of new multi-criteria analysis methods (Nikolic & Borovic, 2000). In parallel with the development of multi-criteria analysis methods, the number of scientific and professional works that deal with the application of methods for solving various decision-making problems is also increasing. Each method has some unique characteristics, logic, advantages, and disadvantages. The choice of the method that will be used to solve the specific problem of multi-criteria analysis depends on the nature of the problem being solved, the availability of information about the problem, the number of alternatives, as well as the knowledge, previous experience, and preferences of the decision maker (Cupic & Sukanovic, 2010).

The paper used the AHP-TOPSIS hybrid model, where the AHP method was used to determine the weighting coefficients, while the TOPSIS method was used to rank the alternatives. Table 1 shows how to solve the problem using this hybrid model (Djukic, Petrovic, Bozanic & Delibasic, 2022):

Table 1: Display of model phases and steps

<table>
<tr><th colspan="5">Phase 1: Defining criteria</th></tr>
<tr><td colspan="2">Problem description</td><td colspan="3">Step 2: Defining specific criteria</td></tr>
<tr><th colspan="5">Phase 2: Determination of weight coefficients using the AHP method</th></tr>
<tr><td colspan="2">Step 1: Comparison of criteria by experts</td><td colspan="3">Step 2: Calculation of weight coefficients criteria</td></tr>
<tr><th colspan="5">Phase 3: Selection of the best alternative using the TOPSIS method</th></tr>
<tr><td>Step 1: Defining alternatives</td><td>Step 2: Testing alternatives according to criteria</td><td>Step 3: Determination of ideal positive and negative solutions</td><td>Step 4: Calculation of the relative distance from the ideal solution</td><td>Step 5: Ranking the alternatives</td></tr>
</table>

The table shows how to solve the problem using the hybrid AHP-TOPSIS model. This model has been successfully applied in many works according to the principle shown in the table.

3.1. AHP method

Analytical Hierarchy Processes (AHP) method was used to determine the weighting coefficients of the criteria. It was developed by Tomas Saaty in the early eighties of the last century and it represents a tool in decision analysis. It was created to provide assistance to decision-makers in solving complex decision-making problems involving a large number of DOs, there are a large number of criteria in several specific time periods. The field of method application is multi-criteria decision-making, where based on a defined set of criteria and attribute values for each alternative, the most acceptable solution is selected, i.e. the complete distribution of the importance of the alternative is displayed in the model (Madic, Nedic & Radovanovic, 2015). Due to the simpler application of the method, software from the Expert Choice decision support system class was developed on a concrete example. In doing so, four stages of the method application were recorded (Cupic & Sukanovic, 2010):

1) structuring the problem;

2) data collection;

3) assessment of relative weights and

4) determining the solution to the problem.

Problem structuring consists of decomposing a decision problem into a series of levels. In this step, it is necessary to decompose the problem, define the goal, criteria, sub-criteria and alternatives. A graphic representation of the problem structuring is presented in Figure 1 (Cupic & Sukanovic, 2010):

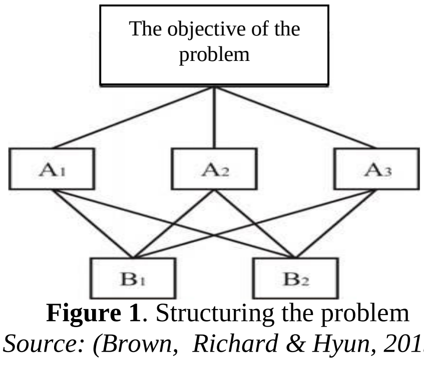

Figure 1. Structuring the problem
Source: (Brown, Richard & Hyun, 2013.)

With the collection of data and their measurement, the second phase of the AHP method begins. The decision maker assigns relative scores to pairs of attributes of one hierarchical level, and for all levels of the entire hierarchy. In doing so, the most famous nine-point scale (Saaty's scale) is used, presented in Table 2 (Cupic & Sukanovic, 2010):

Table 2. 9 point scale

Scale	Explanation/Ranking
9	The absolute most significant/preferred
8	Very strongly towards the absolute most significant/preferred
7	Very strongly towards very important/preferred
6	Strong to very strong
5	Stronger more significant/preferred
4	Weaker to stronger
3	Weaker more significant/preferable
2	Equally to the weaker more
1	Equally important/desirable
0.50	Equally to the weaker minor
0.33	Weaker less significant/preferred
0.25	Weaker to strongly minor
0.20	Strongly less important/preferred
0.17	Strong to very strong/minor
0.14	Extremely strong less significant/preferred
0.13	Very strongly to absolutely minor
0.11	Absolute least important/preferred

Upon completion of this phase, the appropriate pairwise comparison matrix corresponding to each level of the hierarchy is obtained. Determining the relative weights is the third stage of applying the AHP method. The pairwise comparison matrix is transferred into the problem of determining the eigenvalues – the normalized and unique eigenvectors. Weights are obtained for all attributes - for all levels of the hierarchy (Pamucar, 2018). You can read more about the AHP method in numerous scientific and professional works (Pamucar, Djorovic, Bozanic & Cirovic, 2012), (Bozanic, Pamucar & Komazec, 2016), (Petrovic, Sakovic, Marinkovic, 2017), etc.

3.2. TOPSIS method

The TOPSIS method was developed by Hwang and Yoon in 1991. It is based on the concept that the optimal method should have the smallest Euclidean distance from the positive-ideal solution and the largest from the negative-ideal solution (Pamucar, 2018). Positive-ideal solution is a hypothetical solution for which all attribute values of the alternative correspond to the most desirable attribute values in relation to all criteria (Cupic & Sukanovic, 2010). On the other hand, negative-ideal solution is a hypothetical solution for which all attribute values correspond to the most undesirable attribute values in relation to all criteria. Therefore, the solution determined by the TOPSIS method is "closest" to the hypothetical best solution and at the same time "farthest" from the hypothetical negative-ideal solution (Pamucar, 2018).

The basic procedure for changing the TOPSIS method can be summarized in the following steps (Pamucar, 2018):

- Step 1: Normalizing the decision matrix;
- Step 2: Weight normalization of the performance matrix;

- Step 3: Determination of ideal solutions;
- Step 4: Determining the distance of alternatives from ideal solutions;
- Step 5: Determining the relative proximity of alternatives to the ideal solution;
- Step 6: Ranking matrix.

The TOPSIS method is a well-known method and applied to a large number of scientific and professional works, in which you can read more about it (Pamucar, Bozanic & Kurtov, 2016), (Djukic, Petrovic, Bozanic & Delibasic, 2022), etc.

4. USE OF THE MODEL

Before using the multi-criteria decision-making model, the locations for the disposal of hazardous substances must be defined, as well as the criteria that will be the parameters for decision-making. Taking into account the location of the largest places for collecting a given type of hazardous waste, as well as the population density, three potential locations were chosen for the disposal of fluorescent tubes containing mercury in the territory of the city of Nis. The first location that was chosen for a potential station is located on Camurlijski put. The second location is located on the road leading to Niska Banja, while the third potential location is land near the Nis Penitentiary. The location of all three locations is shown in Figure 2:

Figure 2. Waste disposal locations on the territory of Nis
Source: https://a3.geosrbija.rs/

Before starting the application of the method, the basic criteria are defined on the basis of which the risk assessment is carried out. The criteria for risk assessment in this model for a specific problem are as follows:

Criterion 1 (K_1) - Distance and impact on water systems;

Criterion 2 (K_2) - Population density in that area,

Criterion 3 (K_3) - Possible impact on the environment;

Criterion 4 (K_4) - Distance from transport corridors;

Criterion 5 (K_5) – Construction costs.

4.1. Calculation of the weight coefficients of the criteria

The calculation of the weighting coefficients is carried out using the already mentioned AHP method. First, **the initial decision matrix (X)** should be mentioned. Alternatives are shown by vectors within it $A_i = (x_{i1}, x_{i2}, ..., x_{in})$, where x_{ij} is the value of the *i-th* alternative according to the *j-th* criterion (i=1,2,...,m; j=1,2,...,n). In order to determine the weight coefficients, the given criteria are compared in pairs, as shown in table 3 (Borovic & Milicevic, 2001):

Table 3: Pairwise criteria comparison matrix

	K_1	**K_2**	**K_3**	**K_4**	**K_5**
K_1	1	5	3	7	9
K_2	(5)	1	5	(3)	5
K_3	(3)	(5)	1	9	7
K_4	(7)	3	(9)	1	3
K_5	(9)	(5)	(7)	(3)	1

Using the mathematical model of the AHP method, **the weighting coefficients of the criterion - W** are calculated. The value of the weighting coefficients is shown in table 2:

Table 4: The value of the weighting coefficients of the criterion

Criterion	**W**
K_1	**0,4344**
K_2	**0,1955**
K_3	**0,2207**
K_4	**0,1175**
K_5	**0,0915**

4.2. Choosing the best alternative

The first step in choosing an alternative in the AHP-TOPSIS hybrid model is to evaluate the alternatives according to the criteria. This initial decision matrix is shown in Table 5:

Table 5: Values of criteria parameters and their weight coefficients

	K_1	**K_2**	**K_3**	**K_4**	**K_5**
Criteria charac.	max	min	min	min	min
A_1	4	178	83,6	5,5	17000
A_2	0,5	101	75,8	6,5	19500
A_3	4,9	631	92,4	6	11000

The value of the relative proximity of the alternatives and the ranking of the best alternative is determined using the TOPSIS method. The result of the calculation using the mathematical model is shown in table 6:

Table 6: Value of relative proximity of alternatives to the ideal solution and ranking

	Relative proximity	**Rank**
A_1	0,6352	**2.**
A_2	0,9192	**1.**
A_3	0,077	**3.**

Therefore, the final ranking of the alternatives is: $A_2 > A_1 > A_3$. With the fact that this ranking of alternatives according to the TOPSIS multi-criteria decision-making method does not necessarily represent the best solution. Therefore, after this part of the research, it would be necessary to look at the solution of this problem through some other multi-criteria decision-making methods and through the engagement of experts. This approach would ultimately provide a quality solution to the problem.

5. CONCLUSION

Finally, a conclusion can be made about the necessity of processing this topic. First of all, because the disposal of hazardous waste has become one of the most important modern problems, due to the fact that awareness about it is insufficiently developed, especially in this part of Europe, so until then, the selection of a location for the disposal of hazardous materials is a complex process that requires looking at the problems from multiple perspectives.

The paper shows the use of AHP and TOPSIS. From the attached, it can be seen that for those locations that are selected as alternatives for the disposal of fluorescent tubes, there must be certain criteria, the more criteria, the more objective the decision. In the end, the paper shows that by using appropriate mathematical models of the method, an adequate decision can be made.

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