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Application of AHP method in the process of evaluation of supporting structures for placing traffic signs

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Abstract
This paper presents the application of the Analytic Hierarchy Process (AHP) method in the process of evaluating of conceptual variants at the conceptual stage. Using the requirement list and the morphological matrix, three conceptual variants of supporting structures were created for placing traffic signs. With the AHP method, the conceptual variants (alternatives) were compared. Then a set of six criteria was defined according to which the conceptual variants were evaluated. A variant with the highest weight factor, is also the chosen design solution that will be formed as a final product in the phase of detailed design.

Key words: AHP, conceptual design, morphological matrix, requirement list

1. Introduction

Design process begins by defining a design task that describes requirements, which the product must accomplish after the design process is finished [1, 2]. According to [3], design process takes place through four phases. From the point of view of this paper, the conceptual phase is covered. Before starting the conceptual phase, it is necessary to clarify the requirements relating to the design task. It is necessary to collect information on the requirements and constraints of the design solution.

At the conceptual phase, it enters with defined requirements covered by the requirement list. Requirements, according to the certain rules and methods [4, 5], are transforming in the functional requirements. Functional decomposition method defines main function and partial functions that form functional structure of the design solution [6]. By using design tools, like morphological matrix [7], QFD method [8], matrix of function and functionality [9], etc. the principles of solutions for system of partial functions are searching. Conceptual variants are generating by linking principles of solutions. Among such structured variants, it is necessary to choose one that is, according to certain criteria of the most acceptable. For choosing the most acceptable variant, different methods of decision-making are using, like Promethee method, potential method, AHP method, Morra method, Electre method, etc. During the evaluation process (decision-making), it is necessary to define a set of criteria according to which the best variants (solutions) are chosen.

Paper presents a multi-criteria evaluation process using the AHP method in the example of three conceptual variants of supporting structures for placing traffic signs. According to the requirement list, a set of functions is defined, for which the principles of solutions are found in the morphological matrix. By linking the principles of solutions, three conceptual variants of supporting structures for placing traffic signs are obtained. According to the defined set of criteria, the best variant of the supporting structure is selected.

2. Requirement list of supporting structures for placing traffic signs

In order to increase safety, roads must be marked with prescribed traffic signs. In this way, traffic participants warn of the dangers that threaten them on certain sections of the road. Traffic signs and signalization are thus placed on supporting structures (Figure 1).

Figure 1. An example of supporting structure for placing traffic signalization

Supporting structures who carrying ordinary traffic signs are differ from supporting structures that carrying variable traffic signalization. For variable traffic signalization, it is necessary to enable the implementation of electricity through the construction, to allow the supply of luminous diodes. The light traffic sign is connected to own power source 230V (50 Hz). It is therefore necessary to ensure the autonomy of the electric meter, located close to the traffic sign inside the green area. The electrodeposition cable is placed in a channel wide 400 mm and deep 800 mm.

Alternative to the inability to connect to the power grid is the use of renewable energy sources, i.e. solar power. Solar power is possible to place on the construction, traffic sign or in addition to the same construction. Traffic signs with solar power have great lightness and are better for reading. They save electricity, because of using ecologically acceptable solar power technology.

According to collected information during market analysis, a requirement list of for supporting structures for placing traffic signs is defined (Table 1).

Table 1. Requirement list for supporting structures

REQUIREMENT LIST		
Requirement (R) / Wish (W)	List of requirements and wishes	Category
R	Minimum height above roadway: 4500 mm	GEOMETRY
R	Minimum frame support length: 11500 mm	
R	Minimum console support length: 5000 mm	
R	Maximum support length: 12500 mm	
R	Maximum height of structure: 7000 mm	
R	Three digital traffic signs	
R	Dimensions of traffic signalization: 1300 x 210 x 1300 mm	
R	Supports for traffic signalization	
R	Using LED traffic signalization	
W	Solar cells support	
W	Platform for maintenance of construction	
W	Maximum load of platform is 100 kg	
W	Platform dimensions: 11500 x 600 x 1000 mm	
W	Ladder for workman transport on the platform	
R	Connecting elements with the screw connection	
R	Wind and snow resistance	FORCES
R	Traffic signalization weight	
R	Own construction weight	
W	Weight of solar panels and their supports	
W	Reduce the mass of the construction	
W	Renewable energy sources	ENERGY
W	Solar cells	
W	Power: 3330 W	
W	Total surface of solar cells: 3 m^2	
R	Material: steel	MATERIAL
R	Concrete foundation	
R	Corrosion protection	
W	Protective hoop on the platform and ladder	SAFETY
R	Easy montage / deconstruction	ASSEMBLAGE
R	Control and management of traffic signalization	MAINTENANCE
R	Easy maintenance	
R	Lens cleaning every 12 months	
R	Review of construction every 6 months	
W	Possibility of recycling	RECYCLING
W	Minimum costs	COSTS
R	Applying standard profiles	

3. Generating conceptual variants of supporting structures

Using morphological matrix (Figure 2), the transformation of the requirements into functional requirements was performed. With the process of the functional decomposition, partial functions were generated. They are necessary to solve the main function of the supporting structure for placing traffic signalization.

MORPHOLOGICAL MATRIX				
PARTIAL FUNCTIONS	PRINCIPLES OF SOLUTION 1. Variant-▲ 2. Variant-♣ 3. Variant-●			
1. To form the construction	Bracket ♣	Frame ▲●	Pillar	
2. To use standard profiles	I profile	Square profile ♣●	Tube profile	Combination ▲
3. To attach the signalization	Bolted joint ▲♣●	Welded joint	Glue joint	Swirling joint
4. To attach design elements	Bolted joint ▲♣●	Welded joint	Glue joint	Swirling joint
5. To joint construction on the concrete	Dissociative bond ▲♣●	Firm bond		
6. To protect against corrosion	Galvanizing ●	Chroming ♣	Tinning ▲	
7. To protect the bolts from corossion	Galvanizing ●	Chroming ♣	Tinning ▲	
8. To ensure power supply	Urban electrical network ♣	Renewable energy sources ▲●		
9. Tamp the cables	Through the construction♣	With the construction ▲●		
10. To ensure power supply from renewable energy sources	Sun (solar cell) ▲●	Wind (windmill)		
11. To set solar cell carriers	To the construction ▲●	To trafic signalization	Beside of construction	
12. To connect carriers with the construction	Bolted joint ▲●	Welded joint		
13. To enable the maintennance	Platform ▲●	Crane ♣		
14. To transport operator to the platform	Ladder ▲●	Crane ♣		
15. To protect operator when is lifting	Protective metal rim ▲●	Safety belt ♣		
16. To protect operator while moving on the platform	Protective fence ▲●	Safety belt ♣		
17. To control traffic	Wired ♣	Wirelessly ▲●		
18. To transport design elements	Truck vehicle ▲♣●	Special truck vehicle		

Figure 2. Morphological matrix of supporting structures for placing traffic signalization

Variant 1 Variant 2 Variant 3

Figure 3. Conceptual variants of supporting structures

For some partial functions, the principles of the solution were found. By their connection, three variants of the bearing structure for variable traffic signalization were obtained (Figure 3). By applying multi-criteria decision making, using the AHP method, the best variant will be chosen. This variant then enters in the process of detailed design.

4. Multi-criteria evaluation of conceptual variants

4.1. AHP method

The Analytic Hierarchy Process (AHP) method is used to decide when the decision-making process, or choice of some of the available alternatives, is based on multiple attributes of varying importance. The analytical process consists of four steps. In the first step, goals, criteria, sub-criteria and alternatives (variants) are defined. The second step, using Saaty's scale, compares criteria and alternatives to each criterion. In third step are calculated the local weighting of the criteria (sub-criteria) and the priority alternatives. The fourth step involves sensitivity analysis.

4.2. Mathematical description of AHP method

If n is number of criteria whose weights w_i need to determine by estimating the value of their ratios which are marked as $a_{ij}= w_i/w_j$. The relative importance matrix has the following form:

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

In the case of consistent estimates it is valid $a_{ij} = a_{ik} \cdot a_{kj}$. Matrix **A** then satisfies the equation $\mathbf{A} \cdot \mathbf{w} = n \cdot \mathbf{w}$, where **w** is the vector of priorities:

$$\begin{bmatrix} w_1/w_2 & w_1/w_2 & \dots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \dots & w_2/w_n \\ \dots & \dots & \dots & \dots \\ w_n/w_1 & w_n/w_2 & \dots & w_n/w_n \end{bmatrix} \cdot \begin{bmatrix} w_1 \\ w_2 \\ \dots \\ w_n \end{bmatrix} = n \cdot \begin{bmatrix} w_1 \\ w_2 \\ \dots \\ w_n \end{bmatrix} \tag{2}$$

Problem of weight is solving by equation:

$$\mathbf{A} \cdot \mathbf{w} = \lambda \cdot \mathbf{w} \tag{3}$$

In equation (3) it must be $\lambda \neq 0$. Matrix **A** is positive, reciprocal and with rank value $r(\mathbf{A})=1$. Sum of inherent values of positive matrix is equal to the trace of the matrix, i.e. the sum on the diagonal with the value n:

$$\lambda_{max} = n \tag{4}$$

If **A** contains inconsistent estimations, vector **w** is possible to obtain by solving the following equations:

$$(\mathbf{A} - \lambda_{max}) \cdot \mathbf{w} = 0 \tag{5}$$

$$\sum \mathbf{w}_t = 1 \tag{6}$$

Where λ_{max} is largest inherent value of **A** matrix. If we take in consideration preliminary expressions, then follows:

$$\sum_j a_{ij} \cdot w_j = n \cdot w_i \tag{7}$$

$$\sum_i a_{ij} = \frac{w_1 + w_2 + ... + w_n}{w_j} \tag{8}$$

Therefore it is:

$$w_j = \frac{1}{\sum_i a_{ij}} \tag{9}$$

The weight of each alternative is equal to:

$$w_j = \frac{1}{n} \sum_j \frac{a_{ij}}{\sum_i a_{ij}} \tag{10}$$

The synthesis of priorities is done in a way that local priority of alternatives wights with the weights of all the knots to which they belong. Then global priorities for the highest level are summed and the overall priority for each alternative is constructed.
The consistency of the assessment is achieved by comparing the pair of alternatives and the criteria pairs. The consistency index is $CI = (\lambda_{max} - n) / (n-1)$. The CI calculates the consistency ratio $CR = CI / RI$. RI represents a random index (consistently index for matrixes with the n order, randomly generated comparisons in pairs). Determined by table (Table 2).

Table 2. Values of *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	1,4	1,45	1,49

If for matrix **A** is $CR \leq 0{,}10$, assessments of the relative importance of the criteria (priority of alternatives) are considered as acceptable. Otherwise, it is necessary to consider the reasons why the consistency of the estimations is unacceptably high.

4.3. The best conceptual variant determination

For the choice of the best variant, a system of six criteria was defined and three conceptual variants (Figure 4). According to the criterion system, evaluation of conceptual variants (alternatives) was performed.
Also, it is necessary to determine the importance and importance of certain criteria. This is achieved by comparing the criteria and determining the factors of significance (Figure 5).
Then comparison of individual alternative with criterions has performed. With this comparison, we want to determine how much an individual alternative to each criterion is better than any other alternative (Figure 6).
After all relations between alternatives and criteria have been set, it has obtained a solution with the best alternative. That solution is a third conceptual variant (Figure 3). Its factor amount is 0,4338 (Figure 7). The second best alternative is the first conceptual variant with factor amount 0,3338. The second variant has a factor amount 0,2324 and is in third place.

The consistency ratio is 0,0406. This means that estimations of the relative importance of the criteria are acceptable.

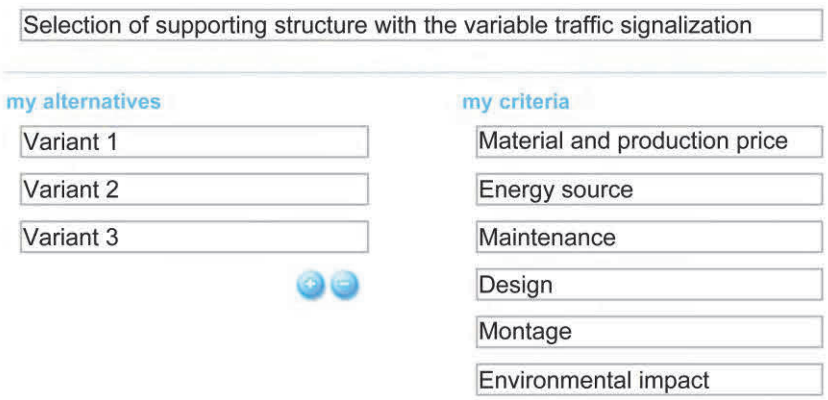

Figure 4. Determination of aim, alternative and criterion

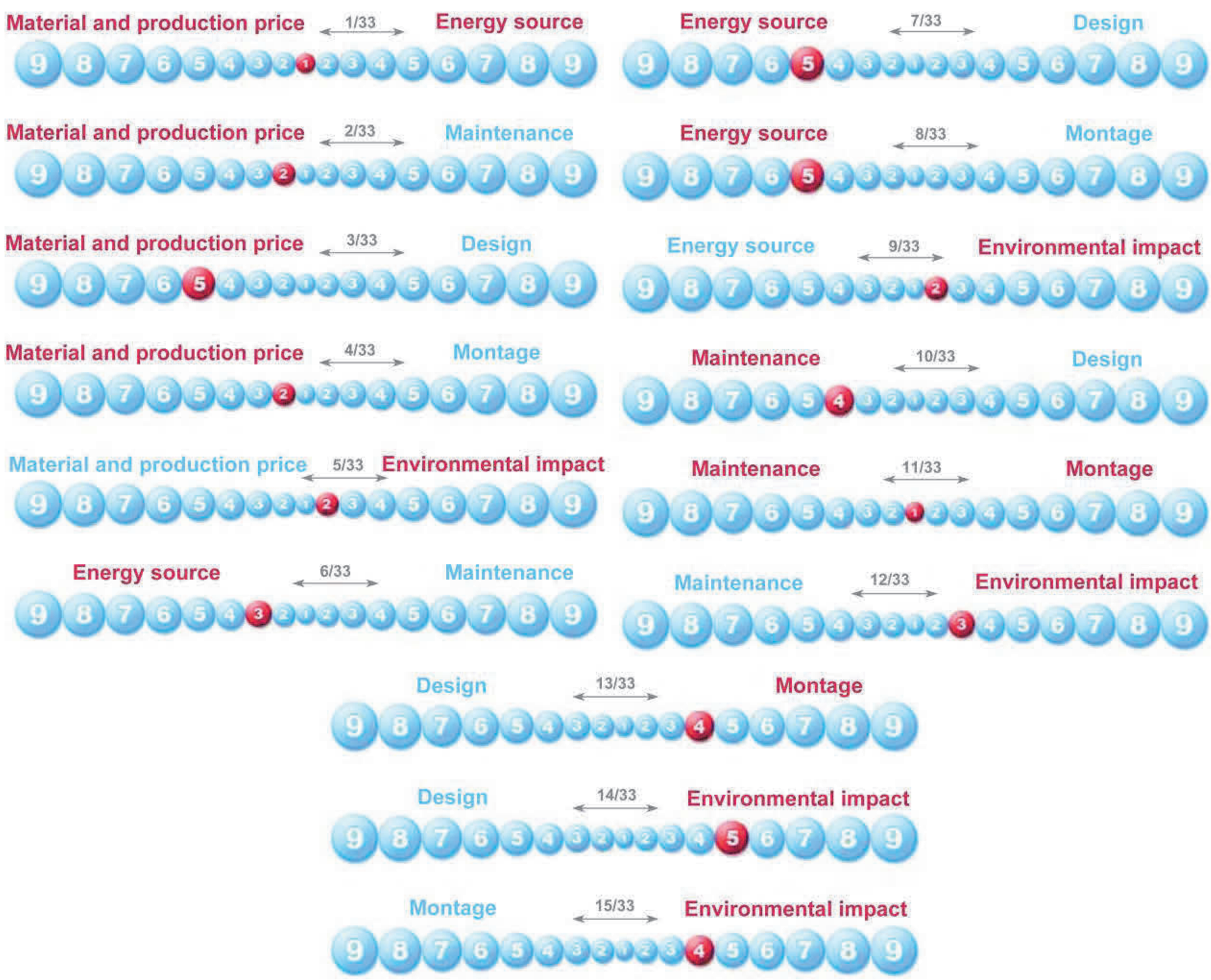

Figure 5. Mutual relations of criteria

In figure 8 is presented rank of criteria. It is possible to see the importance of a particular criterion in the decision-making process. The most influential criterion is *environmental* *impact* whose factor amounts is 0,3307. The least influential criterion is *design* whose factor amounts is 0,0384.

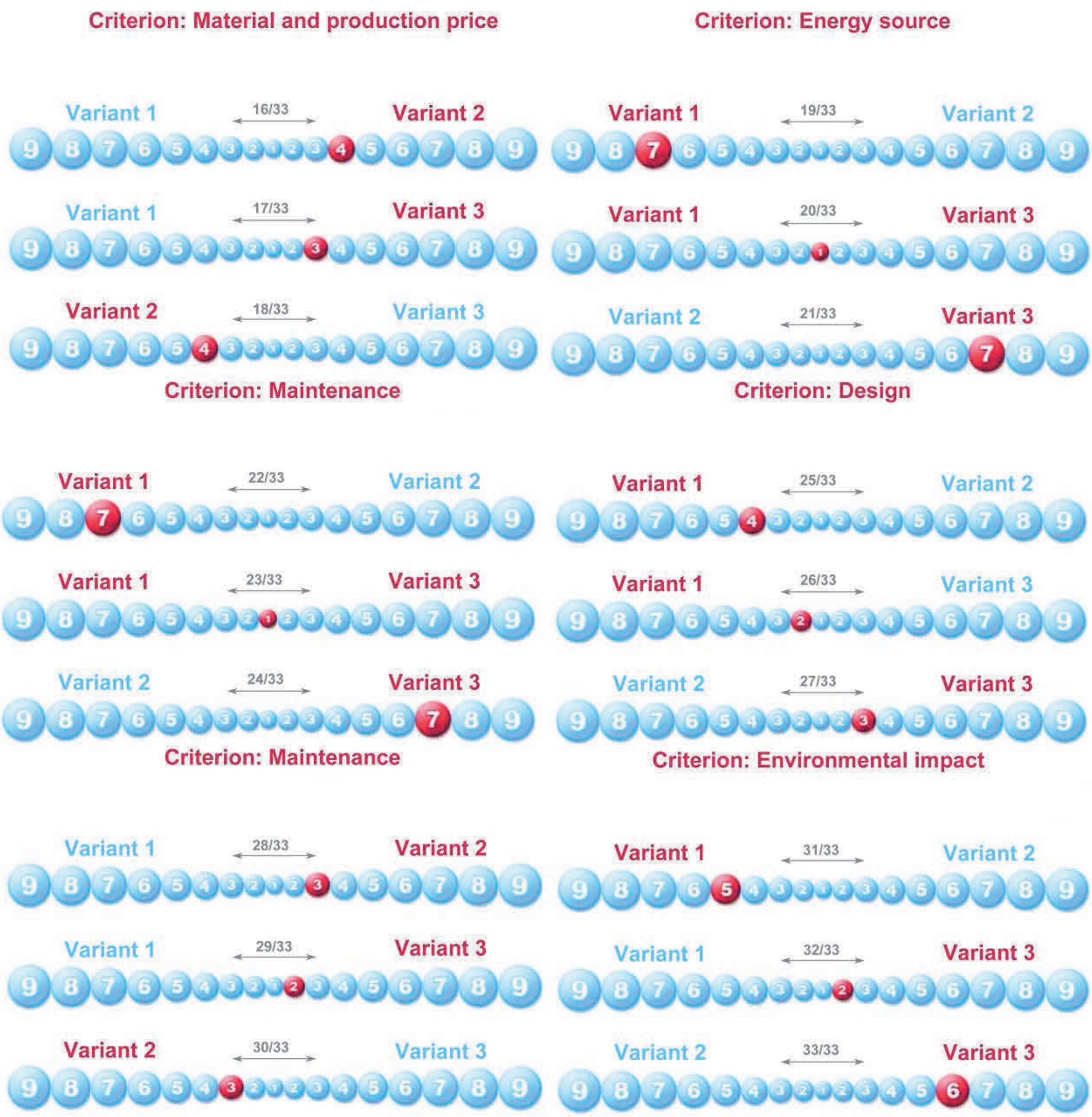

Figure 6. Relation between variants and criteria

Alternative structure	Material and production price	Energy source	Maintenance	Design	Montage	Environmental impact	Result
Variant 1	0,0213	0,1162	0,0473	0,0214	0,0144	0,1131	0,3338
Variant 2	0,1231	0,0166	0,0068	0,0047	0,0544	0,0258	0,2324
Variant 3	0,0444	0,1162	0,0473	0,0123	0,0229	0,1908	0,4338

Figure 7. Alternative structure

An overview of the final solutions of the decision-making process, using the AHP method, is shown in figure 9. It is possible to see that third alternative (conceptual variant) is the best variant of the evaluation process. The most influential criterion is *environmental impact*. The picture also shows the impact of a particular criterion on a particular alternative.

Criteria rank	Result
Material and production price	0,1888
Energy source	0,249
Maintenance	0,1014
Design	0,0334
Montage	0,0917
Environmental impact	0,3307

Figure 8. Criteria rank

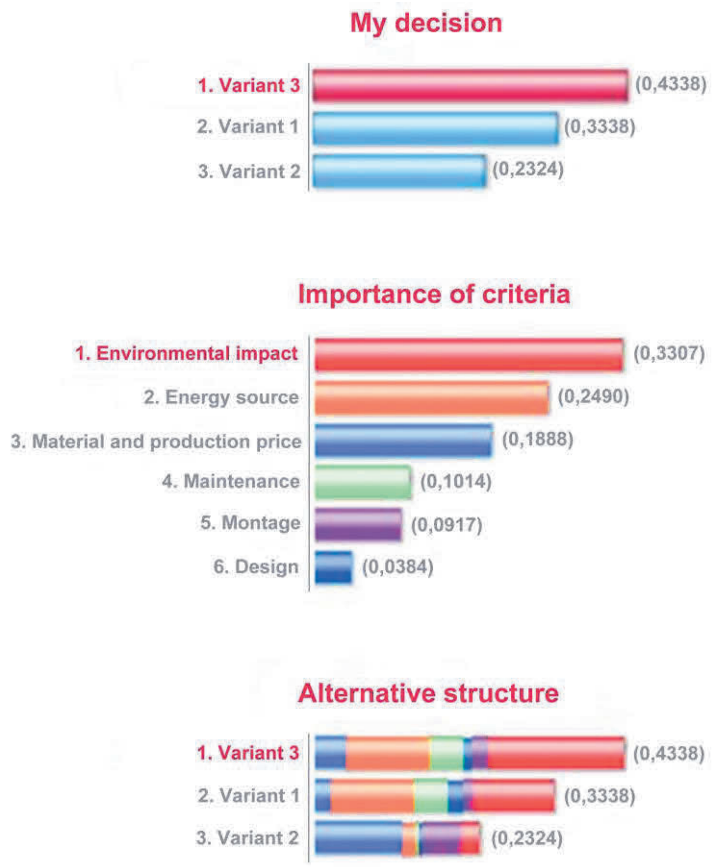

Figure 9. Results of the decision-making using the AHP method

5. Conclusion

In the paper is presented evaluation process of three conceptual variants of supporting structures for placing traffic signs. For evaluation was used Analytic Hierarchy Process (AHP) method. According to the requirement list, the functional structure is defined, which is described in the morphological matrix.

For each function, principal of the solutions are required. By linking the principle of the solutions, three conceptual variants of supporting structures for placing traffic signs have obtained.
To select the best variant (alternative), the evaluation process has begun. Numerous evaluation methods are using today like Promethee method, Electre, Morra, Potential methods, Conjunctive methods, Disjunctive methods, Topsis Vikor, AHP method, etc. In this paper we decided to apply the AHP method. The method is based on comparing pairs of alternatives with each other. The decision maker should express intensity, the weight of the preference of one alternative in relation to the other within the set of criteria. We have defined a system of six criteria and evaluated variants according to them.
It has found that the third conceptual variant has selected as the best variant of the AHP evaluation method. It is possible to expect that the system of criteria is extended with some new criteria so that the solution of the evaluation process will result in the selection of another alternative.
The currently selected variant also satisfies the requirement for power supply of traffic signalization by means of solar cells placed on the frame of the construction. Also, this variant has the ability to set variable LED traffic signs.

6. References

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