VOL. 11, NO. 17, SEPTEMBER 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

ANALYSIS OF INNOVATIVE SOLUTIONS BASED ON COMBINATORIAL APPROACHES

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ABSTRACT

Objectives of innovative design of complex systems involve searching for objects, characterized by the maximum degree of originality, and, consequently, competitiveness. To solve this problem, it is necessary to apply the methodology of cluster analysis that uses mathematical measures of similarity and inclusion of sets. Information about the analyzed object class is represented in the form of a morphological matrix, columns of which are the options for the implementation of generalized subsystems. For variants of subsystems, represented in the rows, is determined by numbers of structural and functional features. Selection of promising solutions uses criteria: matching originality determines the novelty for this class of combinations of functional subsystems; the originality of the elemental determines the number of new for this class of implementations of the functional subsystems involved in this combination; the measure of inclusion of features in the many other signs of the synthesized structures characterizes the degree of its originality. Generalized criterion of the promising solutions is the target function, the structure of which includes the criteria and the coefficients of their significance. The search technique decisions based on the calculation of a measure of inclusion consists a series of stages. During implementation the formal model, morphological matrix is constructed; for each trait the i-th row in the column corresponding to alternative implementations of the subsystem, is binary rating enable option. The relative number of matching relations is calculated; a matrix of the elemental composition of solutions is built; a description of the decisions by functional features is built; measures which enable the features of each object in the array of attributes of all synthesized solutions are determined. The analysis results are shown in the component table; they identify the objective function value, i.e. the degree of perspective of all possible solutions in the morphological matrix. The solution with the maximum objective function value is selected as the most promising for further analysis.

Keywords: innovative design, mathematical measures of similarity, inclusion of sets, morphological matrix, functional subsystems, objective function, coefficients of importance.

1. INTRODUCTION

In the field of innovative design systems, it is possible to use approach based on the methodology of cluster analysis. This methodology involves the classification of the studied objects according to the group of key attributes, through the use of mathematical and political measures of inclusion of sets. Thus, for the purpose of synthesis, it is possible to apply a method of organizing objects on the basis of a measure of inclusion of features that characterize objects of design.

Let us specify a set of objects $S = \{S_i\}$; i=1... N, where N is the number of elements in S. To describe the objects in S, a set of attributes $F=\{f_j\}$, j=1...M are formed. These signs should adequately and clearly describe each object S_i, reflecting its general and specific properties. Each object S_i is assigned the vector of variables $X_i = (x_{1i},...,x_{ji}\ ,...,\ x_{Mi})$, reflecting the inclusion of the traits object from the set F. the Variable $x_{ji} \in \{0,1\}$ takes the value 1 if the object i includes symptom j, and 0 if it doesn't.

This model describes a set of objects can be represented in the form of a table:

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Table-1. Summary description of the objects by the signs.

	S_1	...	S_i	...	S_N
f_1	x_{11}	...	x_{1i}	....	x_{1N}
...	...	...	...	...	...
f_j	x_{j1}	...	x_{ji}	...	x_{jN}
...	...	...	...	...	...
f_M	x_{M1}	...	x_{Mi}	...	x_{MN}

When comparing two objects, which measure of inclusion is less or more original, that is, its signs are the least included in the other object involved in the comparison. Objects with relatively small measure of inclusion, in relation to other objects of the set, have a different organization, which may mean that they have new properties. On the other hand, objects that have a comparatively large measure of inclusion correspond to the sample solutions that are optimal in problems of production with minimal development costs and flexibility. The calculation of the measures of inclusion on the basis of which solves the problem of finding the original object from the set under consideration is made by the formula:

$$W(S_i, S_j) = \frac{\sum_{k=1}^{M} x_{ki} \cdot x_{kj}}{\sum_{k=1}^{M} x_{ki}}, \tag{1}$$

where S_i and S_j describe objects by characteristics; M is the number of features that make up these descriptions; x_{ki}, $x_{kj} \in \{0,1\}$ - variable, which takes value 1 if the i-th or j-th object, respectively, include a sign from the set F that describes all of the objects, and 0 if it doesn't include.

Consider approaches to synthesis innovative solutions, which must have a high level of competitiveness in a given segment. Many variants of the IR are generated on the basis of morphological synthesis. Information about the analyzed object class is represented in the form of a morphological matrix, columns of which are the options for the implementation of generalized subsystems or parameters selected during the process of system analysis. For variants of subsystems, represented in the rows, are determined by many structural and functional characteristics which adequately and unambiguously characterize each variant.

Then we build a formal model of the morphological matrix, the rows of which correspond to the set of attributes characterizing options for the implementation of subsystems, and the columns that correspond to the vector solutions include signs describing a generic functional subsystem. For a wide class of objects, even a small matrix can contain thousands of a solution, which significantly impedes or makes impossible the analysis from the point of view of quality indicators. To solve this problem, variants are selected on the basis of cluster analysis that promise further consideration. The search solutions uses the following criteria: matching originality; element originality; measures of incorporate features that make up the description of the analyzed object, in the remaining objects of class.

The first criterion determines the novelty for this class of objects combinations of functional subsystems which together constitute an integral unit. The system has the maximum matching degree of originality, if none of the coefficients of its elements wasn't in combination with any other element in the framework presented in the morphological matrix of solutions. Accordingly, the system lacks novelty if all its items make up the combination which was realized within the analyzed class. Thus, the matching degree of newness determines how new the combinations involving each element of the system are and what - on this basis - the overall novelty of the system is.

The elemental originality determines the number of new for this class of IS implementations of functional subsystems involved in this combination.

The measure of inclusion of holistic characteristics of the considered system in a variety of other characteristics of the synthesized structures characterizes the degree of its originality compared to other options. The minimum value means that in the framework of the generalized functional structure of the object has a specific organization, and therefore high consumer qualities and competitiveness.

The method assumes the construction of a generalized criterion for the prospects of IS. This proposed objective function, the structure of which includes the coefficients of significance of factors. It is possible to choose different subsets of solutions for a more complete realization of the subjective requirements.

Target function using measures of inclusion characteristics, has the form:

$$d_w^*(X_i^*) = \max_{\overline{X}_i \in E^n}((1 - W(S_i, S)) \cdot k_w + d_k(X_i) \cdot k_k + d_e(X_i) \cdot k_e) \tag{2}$$

i=1, ..., M,

where En is the set of features of dimension n; $X_i = (x_{1i}, ..., x_{ni})$ is the vector of discrete variables, reflecting the inclusion of the i-th decision the characteristics from the set $F=\{f_1,...,f_n\}$, $x_{ji} \in \{0,1\}$; M - number of vector descriptions of solutions; $dw^*(X_i^*)$ is the maximum value of the degree of perspectivity, corresponding to the feature

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vector X_i*; $W(S_i, S)$ is a measure of the inclusion of features that make up the description of the solution S_i in the description of all solutions S; $d_k(X_i)$ and $d_e(X_i)$ is the matching degree of novelty and element, respectively, k_w , k_k , ke - coefficients of importance of the factor of originality structurally-functional implementation of the solution, and the matching element of originality, respectively.

Identification of vectors descriptions IS at the stage of development of the morphological matrix. Each alternative implementation of the generalized $A_{s,p}$ is assigned the vector of variables $X_{s,p}$, reflecting the inclusion of the alternative signs of the many $Fs \in F$ characterizing the considered generalized functional subsystem, where s = 1...N_s is a line number, p is the column number, Ns is the total number of rows in the morphological matrix.

The matching degree of originality, numerically characterizing new for presents in the matrix of the combination, is determined by the formula

$$d_k(X_i) = 1 - 2 \cdot \frac{\sum_{s=1}^{N-1} \sum_{p=s+1}^{N} k_{s_i,p_i}^{s,p}}{N \cdot (N-1)}, \tag{3}$$

where N is the number of rows in the morphological matrix; s_i and p_i are the numbers of the columns in the morphological matrix in the strings s and p, respectively, alternatives of which are included in the i-th IS; $k_{s_i,p_i}^{s,p}$ - a variable which takes the value 1 if the alternative of row s and column s_i formed a combination with the alternative of row p and column p_i within the class IR, and 0 if not.

The degree of element originality, numerically characterizing new for presented in the morphological matrix class objects functional subsystems forming the integrated system, is determined by the formula

$$d_e(X_i) = 1 - \sum_{s=1}^{N} e_{s,s_i}, \tag{4}$$

where s_i is the column number of the morphological matrix in the string s, the alternative of which included in i-th IS; e_{s,s_i} - a variable which takes the value 1 if the alternative of strings s and s_i column was used within the class and IS, and 0 if not.

The expression (1 - $W(S_i,S_j)$) in the objective function (2) has the following meaning. The aim of selection is to find solutions with a maximum degree of novelty, as well as a minimal measure of inclusion. The measure of inclusion is a value lying in the range [0...1], and you can go from the expression $W(TR_i,TR\rightarrow)$ min to (1 - $W(TR_i,TR\rightarrow)$ max) that allows presenting the principle of finding a common formula.

According to the model of a specific problem situation, the decision-maker can establish the degree of influence of criteria for determining the prospects allocated to the decision matrix, the contents of the resulting subsets, and to determine the specific values of the coefficients of their significance directly. The purpose of the coefficients is subject to the following rules:

$k_w + k_k + k_e = 1$, $k_w \geq 0$, $k_k \geq 0$, $k_e \geq 0$;

Implementation of models, given the objective function (2) allows us to analyze the morphological variety of solutions with the purpose of obtaining information about the properties characterizing the novelty and the degree of closeness of each element to the objects of the class in question.

Defining the stages of finding solutions on the basis of the calculation of a measure of inclusion.

Step 1: To build the morphological matrix, the rows of which correspond to generalized functional subsystems; the columns of matrix correspond to alternative implementations of subsystems. In rows it is advisable to present the current IS, which are widely used in relevant fields.

Step 2: Select signs sufficiently complete and clearly reflect the properties presented in the matrix solutions. Functional signs, which are used to describe variants of implementations of subsystems, allow us to build a holistic model of a system, they complement and clarify the structural description, allowing reflecting the dynamics of functioning of the device.

The selected set of features allows you to build a formalized model of the morphological matrix that has N rows. Each line i can incorporate mi features. For each trait the i-th row of f_{ij} in the column corresponding to alternative implementations of a subsystem A_i, rated enable alternative A_{ij}: becomes 1 if the given feature of a subsystem is present; 0 if absent. Illustration of the descriptions given in Table-2.

Step 3: Determined by the degree of originality of the solutions presented in the matrix. To determine the degree of matching of the novelty of each IS, we use matrix matching ties alternatives. The construction according to the principle: for all alternatives A_{ij} line i need to formally reflect matching context with all the other alternatives of all the rows of the matrix. This idea is easily represented in the form of the scheme shown in Table-3.

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Table-2. Sample description of alternatives.

Generalized functional subsystems	Attributes	Alternatives A_{ij}			
A_1	f_{11} … f_{1m1}	0A_{11} 1	…	1 A_{1j} 1	…
…	…	…	…	…	…
A_N	f_{N1} … f_{NmN}	1 A_{N1} 0	…	0 A_{Nk} 1	…

Table-3. Relationship between alternatives.

	A_1	…	A_j	…	A_N
A_1		…	+		+
…	…	…	…	…	…
A_i		…	+		+
…		…			
A_N		…			

Pros marked the relationship between the lines that you want to submit in a formal way. Links area of the lines lies above the main diagonal of the matrix, on the principle of symmetry: if the alternative line i participates in combination with the alternative to row j, then the alternative row j is involved in combination with alternative row i (i<j). Every two matching rows of the morphological matrix A_i and A_j to put into correspondence the matrix matching ties C= $\{k_{lrij}\}$, l = 1... n_i; r = 1... n_j, where n_i is the number of alternatives in row i, n_j, respectively, the number of alternatives in the row j. The number of matrices K =$\{K_{ij}\}$can be computed by the formula: Nk= N(N - 1)/ 2; where N is the number of rows in the morphological matrix.

Imagine the search of promising solutions with the help of a small morphological matrix (Table-4).

Table-4. Example of a morphological matrix.

Generalized functional subsystems	Attributes	Alternatives		
A_1	f_{11} f_{12}	1 A_{11} 0	1 A_{12} 1	
A_2	f_{21} f_{22} f_{23}	1 A_{21} 0 1	1 A_{22} 0 0	
A_3	f_{31} f_{32}	0 A_{31} 1	1 A_{32} 0	1 A_{33} 1

To establish the correspondence between the alternative A_{ij} and A_{ab} , it is necessary to determine the value of the matrix element K_{jbia}, which equals 1 if these alternatives consist of combinations; and 0 – if not. For the matrix in Table-4, it is possible to build Nk = 3 · (3-1)/2 = 3 matrix matching ties. They are presented in Tables 5, 6, 7.

Table-5. Ties of the 1st and 2nd rows of matrix.

	A_{21}	A_{22}
A_{11}	1	1
A_{12}	0	0

Table-6. Ties of the 1st and 3rd rows.

	A_{31}	A_{32}	A_{33}
A_{11}	1	1	0
A_{12}	0	0	0

Table-7. Ties of the 2nd and 3rd rows.

	A_{31}	A_{32}	A_{33}
A_{21}	1	1	0
A_{22}	0	0	0

Matrix K^{11} reflects the fact that the alternative A_{11} participated in combinations with alternatives A_{21} and A_{22}, and A_{12} did not participate in combinations with either A_{21} or A_{22} with.

The number of matching relations for solutions that you can synthesize on the morphological matrix is

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calculated as follows. Is first determined by matching the composition of each solution Si; for our example it is summarized in table 8.

The number of matching relations that have characterized the alternative to the A_{11}, turn on solution S_1, is determined by the formula (5):

$$C^{S1}(A_{11}) = C(A_{11}, A_{21}) + C(A_{11}, A_{31}) , \quad (5)$$

here $C(A_{11}, A_{21})$ and $C(A_{11}, A_{31})$ - communication functions of the alternatives involved in the combination. Accordingly, the number of relationships alternative to A_{21} can be determined on the basis of the following expression

$$C^{S1}(A_{21}) = C(A_{21}, A_{31}) \quad (6)$$

The total number of matching relations that have characterized IS S_1:

$$C^{S1} = C^{S1}(A_{11}) + C^{S1}(A_{21}) \quad (7)$$

Table-8. Structure of solutions variants.

Solution	Combination of the alternatives composing the solution
S_1	A_{11} A_{21} A_{31}
S_2	A_{11} A_{21} A_{32}
S_3	A_{11} A_{21} A_{33}
S_4	A_{11} A_{22} A_{31}
S_5	A_{11} A_{22} A_{32}
S_6	A_{11} A_{22} A_{33}
S_7	$A_{12}A_{21}$ A_{31}
S_8	A_{12} A_{21} A_{32}
S_9	A_{12} A_{21} A_{33}
S_{10}	A_{12} A_{22} A_{31}
S_{11}	A_{12} A_{22} A_{32}
S_{12}	A_{12} A_{22} A_{33}

The "sum values" shows the result of establishing the necessary correspondences between the alternatives in the set of matrix K. Thus, for S1 in the matrix K^{11} (PL.5) element is found at the intersection of the rows A_{11} and A_{21}; it equals 1. Then found the matrix element K^{12} at the intersection of the rows A_{11} and A_{31}; and the matrix K^{23} (PL.7) defines the value that is contained in the intersection of line A_{21} and A_{31}, is equal to 1. These three values and entered in the row corresponding to S_1 Table-9. The relative numbers matching ties (dk'(Xi)) obtained by dividing the amount in column "sum values" in the number N(N - 1)/2, 3. Thus, as a result, a vector of the relative number of matching relations is built.

Consider the defining element of novelty of synthesized solutions. Each of the alternatives in the morphological matrix can be put into correspondence with a value, characterizing its novelty for this class of objects. We represent the set of ratings of novelty items in the form of a matrix E = {eij}, where i = 1... N; (N is the number of rows in the morphological matrix), j = 1, ni, where ni is the number of values in row i. On the structure of E is identical to the morphological matrix; element e = 1, if subsystem in row i and column j is used in the test class, and 0 if not.

Here is a matrix of the elemental composition S-class for this example:

Table-9. Evaluating element of novelty.

Line of morphometric	The values of e_{ij}		
1	1 A_{11}	0 A_{12}	-
2	1 A_{21}	1 A_{22}	-
3	1 A_{31}	1 A_{32}	0 A_{33}

It is evident that new for this class are alternatives A_{12} and A_{33} (E_{12} и E_{33}); the other alternatives do not possess the element of novelty. The maximum number used in this class of alternatives included in any combination of S_i, is N (morphological matrix comprising N rows).

To determine the relative numbers of tenured (used for systems of a given class) of the elements you intend to use the following formula:

$$d_e'(\overline{X}_i) = \sum_{s=1}^{N} e_{s,s_i} \quad (10)$$

Where de'(Xi) is the relative ordinariness of the elemental composition of the combinations S_i, s - the number of rows in the matrix E, and s_i is the column number in the row of s corresponding to S_i.

The relative ordinariness is opposite in meaning to the concept of novelty element. Formally, they are related by:

$$N \cdot d_e^{'}(X_i) = N - N \cdot d_e^{'}(X_i) , \quad (11)$$

For example, the number of new elements in combination is equal to the difference between the total number of elements and the number of ordinary, which has applications for systems of this class of elements.

The relative value of degrees of element ordinary for this example are shown in Table-11.

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Table-10. Ordinary solutions.

Number of solutions	The relative value of the degrees element of the ordinary
S_1	1
S_2	1
S_3	0.67
S_4	1
S_5	1
S_6	0.67
S_7	0.67
S_8	0.67
S_9	0.33
S_{10}	0.67
S_{11}	0.67
S_{12}	0.33

For the first R and d element of the ordinary degree was calculated:

$d_e'(X_1) = (e_{11} + e_{21} + e_{31}) / 3 = 3 / 3 = 1$

The results of the procedures performed on title type presented in Table-12.

Table-11. Degree of novelty solutions.

NumberS	The value of the matching degree of novelty of dk (X_i)	The value of the degree of novelty element de (X_i)
S_1	0	0
S_2	0	0
S_3	0.67	0.33
S_4	0.33	0
S_5	0	0
S_6	0.67	0.33
S_7	0.67	0.33
S_8	0.67	0.33
S_9	1	0.67
S_{10}	1	0.33
S_{11}	0.67	0.33
S_{12}	1	0.67

STEP 4: The calculation of the measures includes many of the features which describe each morphological synthesized on the matrix solution in the set of features which describes the other options. The calculation is carried out in accordance with the Formula (1). In the General case, assume that the synthesis of all possible combinations of the morphological matrix and build matrix of measures of inclusion. The description of each alternative with the help of signs is merged in the synthesis process of the holistic solution, with a different description of the alternatives. The combined list of features treated as a single unit. Here is an example of the synthesis of a variety of solutions based on the morphological matrix presented in Table-4.

Table-12. Description of options.

Number S	Combination of alternatives appropriate Si	Description decisions on signs
S_1	A_{11} A_{21} A_{31}	1 0 1 0 1 0 1
S_2	A_{11} A_{21} A_{32}	1 0 1 0 1 1 0
S_3	A_{11} A_{21} A_{33}	1 0 1 0 1 1 1
S_4	A_{11} A_{22} A_{31}	1 0 1 0 0 0 1
S_5	A_{11} A_{22} A_{32}	1 0 1 0 0 1 0
S_6	A_{11} A_{22} A_{33}	1 0 1 0 0 1 1
S_7	A_{12} A_{21} A_{31}	1 1 1 0 1 0 1
S_8	A_{12} A_{21} A_{32}	1 1 1 0 1 1 0
S_9	A_{12} A_{21} A_{33}	1 1 1 0 1 1 1
S_{10}	A_{12} A_{22} A_{31}	1 1 1 0 0 0 1
S_{11}	A_{12} A_{22} A_{32}	1 1 1 0 0 1 0
S_{12}	A_{12} A_{22} A_{33}	1 1 1 0 0 1 1

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The measure value of inclusion for S_1 and S_2, and S_2 and S_1 is calculated as follows (Table-13):

W $(S_1, S_2) = (1\cdot1+0\cdot0+1\cdot1+0\cdot0+1\cdot1+0\cdot1+1\cdot0) / (1+0+1+0+0+1) = 3/4 = 0.75$

W $(S_2, S_1) = (1\cdot1+0\cdot0+1\cdot1+0\cdot0+1\cdot1+0\cdot1+1\cdot0)/ (1+0+1+0+1+1+0) = 0.75$

According to the properties of the matrix elements measures the inclusion $W(S_i, S_i) = 1$. The matrix of measures of inclusion for this example is shown in Table-13.

Table-13. Significance of the inclusion.

	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}
S_1	**1**	**0.75**	**1**	**0.75**	**0.5**	**0.75**	**1**	**0.75**	**1**	**0.75**	**0.5**	**0.75**
S_2	0.75	1	1	0.5	0.75	0.75	0.75	1	1	0.5	0.75	0.75
S_3	0.8	0.8	1	0.6	0.6	0.8	0.8	0.8	1	0.6	0.6	0.8
S_4	1	0.67	1	1	0.67	1	1	0.67	1	1	0.67	1
S_5	0.67	1	1	0.67	1	0.67	1	1	0.67	1	1	1
S_6	0.75	0.75	1	0.75	0.75	1	0.75	0.75	1	0.75	0.75	1
S_7	0.8	0.6	0.8	0.6	0.4	0.6	1	0.8	1	0.8	0.6	0.8
S_8	0.6	0.8	0.8	0.4	0.6	0.6	0.8	1	1	0.6	0.8	0.8
S_9	0.67	0.67	0.83	0.5	0.5	0.67	0.83	0.83	1	0.67	0.67	0.83
S_{10}	0.75	0.5	0.75	0.75	0.5	0.75	1	0.75	1	1	0.75	1
S_{11}	0.5	0.75	0.75	0.5	0.75	0.75	0.75	1	1	0.75	1	1
S_{12}	0.6	0.6	0.8	0.6	0.6	0.8	0.8	0.8	1	0.8	0.8	1

After constructing the matrix of measures enable the calculation of measure values the inclusion of features of each object W many of the characteristics of all synthesized solutions $\{W(S_i, S)\}$, i=1...N, where i is the number of the IS, N is the number of IS synthesized on the morphological matrix, $S=\{S_i\}$be the set of all solutions.

The calculation is made according to the following formula:

$$W(S_i,S)=\frac{\sum_{j=1}^{N}W(S_i,S_j)}{N}, \tag{12}$$

The results of calculation of values of $W(S_i, S)$ shown in the following table:

Table-14. Measures of inclusion solutions.

Number of solution	Value of $\sum_{j=1}^{N} W(S_i,S_j)$	Value of W (S_i, S)
S_1	9.5	0.791
S_2	9.5	0.791
S_3	9.2	0.767
S_4	10.68	0.890
S_5	10.68	0.890
S_6	10	0.832
S_7	8.8	0.732
S_8	8.8	0.732
S_9	8.67	0.722
S_{10}	9.5	0.791
S_{11}	9.5	0.791
S_{12}	9.2	0.767

Step 5: The next step is the calculation of the degree of perspective synthesized on the morphological matrix of solutions. For further analysis you can select those solutions for which this degree is the highest. The calculation is carried out in accordance with the target function (3).

All factors will be considered equally preferred, respectively, the values of the weighting factors k_w, k_k, k_e

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equal to 0.33. The results of the calculations are presented in Table-16.

Table-15. Values of the components of the objective function.

Number S	(S_i,S)	$d_k(X_i)$	$d_e(X_i)$	The value of the degree of perspective $d_w(X_i)$
S_1	0.791	0	0	0.070
S_2	0.791	0	0	0.070
S_3	0.767	0.67	0.33	0.410
S_4	0.890	0.33	0	0.147
S_5	0.890	0	0	0.037
S_6	0.832	0.67	0.33	0.389
S_7	0.732	0.67	0.33	0.422
S_8	0.732	0.67	0.33	0.422
S_9	0.722	1	0.67	0.649
S_{10}	0.791	1	0.33	0.512
S_{11}	0.791	0.67	0.33	0.402
S_{12}	0.767	1	0.67	0.634

For example, the calculation of the degree of perspective S1 and S3:

$d_w(X_1) = (1 - 0.791) \cdot 0.333 + 0 \cdot 0.33 + 0 \cdot 0.33 = 0.07$

$d_w(X_3) = (1 - 0.767) \cdot 0.333 + 0.67 \cdot 0.333 + 0.33 \cdot 0.333 = 0.41$

As can be seen from the presented results, the most promising solution S_9 ($dw(X_9) = 0.65$), and the least - S_5 ($d(X_5) = 0.037$). If you want to select for further analysis and evaluation of the most promising solutions will be selected as follows: S_9, S_{12} ($dw(X_{12}) = 0.63$) and S_{10} ($dw(X_{10}) = 0.51$).

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