QUALITY ASSESSMENT METHOD FOR DESIGN SOLUTIONS OF AUTOMOBILE SERVICE STATION

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ABSTRACT

The continuous growth of the motorization level of the society and the dynamically changing vehicle and automobile service markets require appropriate development of the transport and automobile service infrastructure. The drastic changes in the vehicle design produce additional or new requirements to the infrastructure intended for the maintenance, service, repair and parking of vehicles. In accordance with these requirements the existing structures are retrofitted and new ones are designed and built in line with the already developed and approved designs. Due to requirements to the infrastructure and numbers of factors to be taken into consideration, the design, as a rule, have different solutions. Decision making involves several steps: formulation of a set of variants, search and selection of the preferable variant among the variants set. But this search is limited by time and computers capacities so the chosen variant is not always the optimal or rational one. The search procedure has become more complicated by parameters and requirements expressed qualitatively. The quality assessment method for the design solutions allows to reduce the search area, and thus to scan considerably greater numbers of variants and to find the best solution. This paper represents a multi-attribute method that allows to assess the quality of design solutions for automobile service station layout and to choose the best solution out of the suggested set.

Keywords: multiple attribute decision making, quality assessment, TOPSIS, layout, automotive service station

INTRODUCTION

The production plant designing is a complex task considering many factors and requirements [1]. The design is developed by various specialists trying to achieve different tasks and objectives. These task and objectives come into collision. Because of numbers of factors considered and requirements to the infrastructure the design has a multivariant solution that is formulation of the variants set, search and choice preferable variant among the variants set. The solution has become more complicated of some significant parameters and requirements are expressed qualitatively.

The conflict and limits are taken into account for selecting the preferable variant of the layout design. So the problem of the production room layout design is the multicriteria decision making task. It has been known a great number of methods fro solving such problem [2], [3].

In this paper the multi-attribute method that allows selecting the preferable variant of the automotive service station layout design among the set of variants developed previously is considered.

METHOD DESCRIPTION

A design solution can be assessed by means of well-known method called the technique for order of preference by similarity to ideal solution (TOPSIS). Description of the method is given in [4], [5]. The best variant is selected among a set of alternatives. An alternative is characterized by several attributes.

The method suggested is simple enough in application. One of the most important stages in the method application is the quantitatively and qualitatively correct choice of subject matter experts.

TOPSIS as a multi-criteria decision making method is based on the idea that the best alternative should have the least distance from the ideal solution and the largest one from the ideal negative solution.

Consider the decision matrix D, shown below:

$$D = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_i \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccccc} C_1 & C_2 & \dots & C_j & \dots & C_n \end{array} \\ \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1j} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2j} & \dots & x_{2n} \\ \vdots & \vdots & \iddots & \vdots & \iddots & \vdots \\ x_{i1} & x_{i2} & \dots & x_{ij} & \dots & x_{in} \\ \vdots & \vdots & \iddots & \vdots & \iddots & \vdots \\ x_{m1} & x_{m2} & \dots & x_{mj} & \dots & x_{mn} \end{bmatrix} \end{array},$$

where A_i is the i-th alternative; C_j is the j-th attribute; x_{ij} is the value of the j-th attribute of the i-th alternative.

The decision matrix D contains m alternatives A_1, A_2, …, A_n evaluated by n attributes C_1, C_2, …, C_n. The columns indicate the attributes, and the rows — the alternatives. An element x_{ij} of the matrix is the performance indicator of the i-th alternative associated with the j-th attribute.

Attributes of non-numeric type should be reduced to the numeric one. In the general case attributes possess various importance, so the importance weight is assigned to each attribute.

During normalization the attributes, which have different units of measurement, are transformed into comparable non-dimensional values allowing their comparability. One of the approaches is to present an element of the normalized matrix R as:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}. \qquad (1)$$

The weights, obtained previously, $w = (w_1, w_2, \ldots, w_j, \ldots, w_n)$, $\sum_{j=1}^{n} w_j = 1$, are assigned to the normed matrix R. An element v_{ij} of the weighted normalized decision matrix is obtained by:

$$v_{ij} = w_j r_{ij}. \tag{2}$$

Thus, the weighted normalized decision matrix is:

$$V = \begin{bmatrix} v_{11} & v_{12} & \cdots & v_{1j} & \cdots & v_{1n} \\ v_{21} & v_{22} & \cdots & v_{2j} & \cdots & v_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ v_{i1} & v_{i2} & \cdots & v_{ij} & \cdots & v_{in} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ v_{m1} & v_{m2} & \cdots & v_{mj} & \cdots & v_{mn} \end{bmatrix} = \begin{bmatrix} w_1 r_{11} & w_2 r_{12} & \cdots & w_j r_{1j} & \cdots & w_n r_{1n} \\ w_1 r_{21} & w_2 r_{22} & \cdots & w_j r_{2j} & \cdots & w_n r_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ w_1 r_{i1} & w_2 r_{i2} & \cdots & w_j r_{ij} & \cdots & w_n r_{in} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ w_1 r_{m1} & w_2 r_{m2} & \cdots & w_j r_{mj} & \cdots & w_n r_{mn} \end{bmatrix}.$$

Determine two artificial (ideal) alternatives A^+ and A^-:

$$A^+ = \{(\max_i v_{ij} \mid j \in J), (\min_i v_{ij} \mid j \in J') \mid i = 1, 2, \ldots, m\} = \{v_1^+, v_2^+, \ldots, v_j^+, \ldots, v_n^+\},$$

$$A^- = \{(\min_i v_{ij} \mid j \in J), (\max_i v_{ij} \mid j \in J') \mid i = 1, 2, \ldots, m\} = \{v_1^-, v_2^-, \ldots, v_j^-, \ldots, v_n^-\},$$

where $J = \{j = 1, 2, \ldots, n \mid j$ is a set of attributes connected with benefits$\}$; $J' = \{j = 1, 2, \ldots, n \mid j$ is a set of attributes connected with losses$\}$.

These two alternatives A^+ and A^- are the most preferable (positive ideal solution) and the least preferable (negative ideal solution) alternatives correspondingly.

The distance of each alternative from the positive ideal solution is calculated as:

$$S_{i+} = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^+\right)^2}, \tag{3}$$

where $i = 1, 2, \ldots, m$.

Similarly, the distance from the negative ideal solution is:

$$S_{i-} = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^-\right)^2}, \tag{4}$$

where $i = 1, 2, \ldots, m$.

The similarity of the alternatives A_i to A^+ is:

$$C_{i+} = \frac{S_{i-}}{S_{i+} + S_{i-}}, \tag{5}$$

where $i = 1, 2, \ldots, m$. Thus, $0 \le C_{i+} \le 1$.

It is evident, that $C_{i+} = 1$, if $A_i = A^+$ and $C_{i+} = 0$, if $A_i = A^-$. The closer C_{i+} to 1, the closer A_i to A^+.

The alternatives can be ranked in accordance to C_{i+} values in descending order. The chosen solution will be the alternative with maximum C_{i+} value.

CASE STUDY

Let us consider the method described in solving the problem of choosing the most preferable variant of production shop reconstruction at the automobile technical service station.

Let a certain number of technological planning decisions for a production plant have been made (in the example six variants are being considered). Each variant is characterized with a set of important criteria, for example, the structure and the area of the production zones, the number of working places, positional relationship of shops, etc. These criteria are presented in terms of numbers. The value of criteria is obtained either by direct measuring (e.g. zone area) or by expert evaluation (e.g. the level of the customer support). The set of the criteria should not be too large, 5–10 are enough.

The decision matrix is being compiled on the base of data given in Table 1.

Table 1 – **Data for the decision matrix**

Criteria	Variants					
	1	2	3	4	5	6
1. Structure, units	12	14	16	14	20	20
2. Quantity of workstations, units	123	76	92	75	96	87
3. Working area, m^2	7160	7232	6696	5904	7064	6254
4. Positional relationship of shops, points	1	2	4	3	4	5
5. Safety and security, points	1	4	5	3	3	2
6. Customer service, points	1	2	3	4	5	5

The weight of each criterion is being defined. It allows taking into account the importance and influencing on the quality of the planning production plant decision.

The most critical part in solving the problem is to define the most significant criteria as well as the correct qualitative and quantitative choice of experts in the field under investigation. The weight coefficients for each criterion are obtained by the review of experts in the field of automotive service station process design decisions.

The results of reviewing are included in Table 2.

Table 2 – **The weight coefficients for each criterion**

Criteria	Experts					
	1	2	3	4	5	Ave
1. Structure	0.08	0.06	0.05	0.12	0.06	0.074
2. Quantity of workstations	0.16	0.18	0.25	0.16	0.21	0.192
3. Working area	0.26	0.25	0.25	0.18	0.23	0.234
4. Positional relationship of shops	0.05	0.13	0.10	0.10	0.10	0.096
5. Safety and security	0.20	0.15	0.15	0.16	0.22	0.176
6. Customer service	0.25	0.23	0.20	0.28	0.18	0.228

According to the algorithms described above on the first step the decision matrix are normalized with formula (1). The normalized matrix is shown in Table 3.

Table 3 – **The normalized decision matrix**

0.300753	0.350878	0.401004	0.350878	0.501255	0.501255
0.540541	0.333993	0.404307	0.329598	0.421885	0.382334
0.433921	0.438284	0.405801	0.357803	0.428103	0.379014
0.118678	0.237356	0.474713	0.356034	0.474713	0.593391
0.125	0.5	0.625	0.375	0.375	0.25
0.111803	0.223607	0.335410	0.447214	0.559017	0.559017

On the next step the weighted normalized matrix is determined (see Table 4) multiplying elements of the normalized matrix by the weight coefficients using (2).

Table 4 – **The weighted decision matrix**

0.022256	0.025965	0.029674	0.025965	0.037093	0.037093
0.103784	0.064127	0.077627	0.063283	0.081002	0.073408
0.101537	0.102559	0.094957	0.083726	0.100176	0.088689
0.011393	0.022786	0.045572	0.034179	0.045572	0.056966
0.022000	0.088000	0.110000	0.066000	0.066000	0.044000
0.025491	0.050982	0.076474	0.101965	0.127456	0.127456

After that the two ideal alternatives are found:

A^{+} = {0.037093, 0.103784, 0.102559, 0.056966, 0.110000, 0.127456};

A^{-} = {0.022256, 0.063283, 0.083726, 0.011393, 0.022000, 0.025491};

Using formulae (3) and (4) the distance of each alternative A_i from A^+ and A^- is calculated. The results of calculations are in Table 5.

Table 5 – **The distance of alternatives from A^+ and A^-**

Variant	A^+	A^-
1	0.020439	0.001958
2	0.009197	0.005505
3	0.003526	0.011898
4	0.005224	0.008317
5	0.002591	0.014306
6	0.005471	0.013305

Considering that the method consider not only the distance of an alternative A_i from A^+ but the distance of the alternative A_i from A^- thus the similarity of the alternative A_i to A^+ is calculated by using formula (5). The results are given in Table 6.

Table 6 – **The similarity of alternatives to A^+**

Variants	The distance from the positive ideal solution
1	0.087406
2	0.374429
3	0.771401
4	0.614221
5	0.846682
6	0.708615

The solution is the variant that have the highest value of the similarity of the alternative A_i to A^+. The variant 5 is the most preferable variant of the automotive service station layout design and it is selected for further designing.

CONCLUSION

According to the case study the method considered is vital for handling the automotive service stations design problem. The most important step of the method is selection of experts to determine attributes, which will be used to evaluate alternatives, and weight coefficients. A solution could be assessed for robustness to the weight coefficients, but more complex task is to identify its influence on the solution. Thus the procedure of attributes selection and weight coefficients determination is the prospective lines of the method improvement.

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