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ESTIMATION METHOD FOR DESIGN DECISIONS QUALITY OF AUTOMOTIVE SERVICE STATION

METODA ESTYMACJI JAKOŚCI DECYZJI KONSTRUKCYJNYCH SAMOCHODOWEJ STACJI OBSŁUGI

Abstract

The continuous growth of the motorization level of the society, the dynamical changing of the vehicle and automotive service markets require the appropriate development of the transport and automotive service infrastructure. The drastic changes in the vehicle design produce new or additional 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 developed and approved design. Because of numbers of factors considered and requirements to the infrastructure design decisions have contradictory solution. So the search procedure of the decision solutions consists of several steps: formulation of the variants set, search and choice the preferable variant among the variants set. But the search is limited by time consumption 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 estimation method for the design decisions quality allows to reduce the area search thus to scan considerably larger numbers of variants and to find the best solution. In this paper the multi-attribute method that allows estimating the design decisions quality of the automotive service station layout among the set of variants developed previously is considered.

Keywords: multi-attribute method, layout, automotive service station, design decisions quality

Streszczenie

Stały wzrost poziomu motoryzacji w społeczeństwie i dynamiczne zmiany rynków obsługi pojazdów samochodowych wymagają odpowiedniej organizacji transportu oraz infrastruktury obsługi samochodów. Drastyczne zmiany w konstrukcji pojazdów stwarzają nowe lub dodatkowe wymogi odnośnie do infrastruktury przeznaczonej do eksploatacji, obsługi, naprawy i parkowania pojazdów. Zgodnie z tymi wymogami struktury istniejące zostały zmodernizowane, a nowe struktury są projektowane i budowane wg nowych zasad. Ze względu na liczbę czynników oraz wymagania dotyczące projektowania infrastruktury decyzje konstrukcyjne mają różne rozwiązania. W związku z tym procedura rozwiązań decyzyjnych składa się z kilku etapów: formułowanie zestawu wariantów, badanie i wybór najlepszego wariantu w tym zestawie. Badanie jest jednak ograniczone czasowo, a także przez możliwości komputerowe, wskutek czego wybrany wariant nie zawsze jest optymalny lub racjonalny. Procedurę badania komplikują parametry i wymagania jakościowe. Metoda oceny jakości decyzji konstrukcyjnych pozwala na redukcję przeszukiwania obszaru, dzięki czemu można przeszukać znacznie większą liczbę wariantów i znaleźć najlepsze rozwiązanie. W artykule przedstawiono metodę wieloatrybutową, która pozwala na ocenę jakości decyzji konstrukcyjnych projektu technicznego stacji obsługi samochodów wśród wielu wariantów uprzednio opracowanych.

Słowa kluczowe: metoda wieloatrybutowa, projekt techniczny, stacja obsługi samochodów, jakość decyzji konstrukcyjnych

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1. 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 the preferable variant among the variants set. The solution has become more complicated if some significant parameters and requirements are expressed qualitatively.

The conflicts 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 for 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.

2. Method description

The method description 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.

Consider the decision matrix, shown in Eq. (1), that contains m alternatives $A_1, A_2, \ldots, A_n$ evaluated by n attributes $C, C, \ldots, C_n$. 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.

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

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.

Attributes of non-numeric type should be reduced to the numeric one. In the general case attributes possess various importances 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:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \tag{2}$$

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:

$$v_{ij} = w_j r_{ij} \tag{3}$$

Thus the weighted normalized decision matrix is:

$$V = \begin{bmatrix} v_{11} & v_{12} & \ldots & v_{1j} & \ldots & v_{1n} \\ v_{21} & v_{22} & \ldots & v_{2l} & \ldots & v_{2n} \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ v_{i1} & v_{i2} & \ldots & v_{ij} & \ldots & v_{in} \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ v_{m1} & v_{m2} & \ldots & v_{mj} & \ldots & v_{mn} \end{bmatrix} = \begin{bmatrix} w_1 r_{11} & w_2 r_{12} & \ldots & w_j r_{1j} & \ldots & w_n r_{1n} \\ w_1 r_{21} & w_2 r_{22} & \ldots & w_j r_{2j} & \ldots & w_n r_{2n} \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ w_1 r_{i1} & w_2 r_{i2} & \ldots & w_j r_{ij} & \ldots & w_n r_{in} \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ w_1 r_{m1} & w_2 r_{m2} & \ldots & w_j r_{mj} & \ldots & w_n r_{mn} \end{bmatrix} \tag{4}$$

Determine two artificial 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 artificial 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:

$$S_{i+} = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^+\right)^2} \tag{5}$$

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

Similarly, the distance from the negative ideal solution is:

$$S_{i-} = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^-\right)^2} \tag{6}$$

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

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

$$C_{i+} = \frac{S_{i-}}{S_{i+} + S_{i-}} \tag{7}$$

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

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

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.

3. Case study

Let's 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 6 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 bee too large, 5–10 are enough.

Then the decision matrix is being compiled by the formula (1). The matrix is shown in Table 1.

Table 1

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, m2	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. As rule the size of the expert group is 4–5.

The results of reviewing are included in the 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

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

Table 4

The weighted normalized 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

According to the algorithms described above on the first step the decision matrix are normalized with formula (2). The normalized matrix is shown in the Table 3.

On the next step the weighted normalized matrix is determined (see the Table 4) multiplying elements of the normalized matrix by the weight coefficients using (3).

After that the two artificial 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 (5) and (6) the distance of each alternative A_i from A^+ and A^- is calculated. The results of calculations are in Table 5.

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 (7). The results are given in the Table 6.

Table 5

The distance of alternatives from A^+ and A^-

Variants	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

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 preferable variant of the automotive service station layout design and it is selected for further designing.

4. Conclusions

According to the case study the method considered is vital for handling the automotive service stations design problem. But there are some weak points in the problem that they will be discussed below.

The most important step of the method is the selection of experts to determine the attributes, which will be used to evaluate alternatives, and weight coefficients. If a solution could be assessed for robustness to the weight coefficients but the more complex task is to identify the influence on the solution.

Thus the procedures of the attribute selection and weight coefficients determination is the prospective lines of the method improvement.

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