Research Article

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Selection of the optimal solution of acoustic screens in a graphical interpretation of biplot and radar charts method

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Abstract: The choice of an optimal solution among various available technological and material undertakings often becomes a problem of the engineering community. A multi-criteria technical and economic analysis is used in order to facilitate decision making. The objective of this article is to present biplot methods and radar charts as a possibility of graphic presentation of research results by obtaining an optimal solution on the example of an analysis of technological and material undertakings of acoustic screens. The research consisted in identifying technological and material solutions of the selected acoustic screens, and then defining features (criteria) and cases (technological and material solutions). The results were presented in radar charts and biplot-type graphs. The methodology consisted in generating a data matrix, which is then processed, decomposed and finally scaled. The calculations were carried out in the Statistica programme. The carried-out analysis showed that the spider web and biplot methods differ from each other. The biplot graph more precisely describes the solutions, and it presents the correlations between variables and cases.

Keywords: acoustic panels, spider web, graph, two-dimensional, vectors

1 Introduction

The road network development and the dynamic automotive industry development are associated with traffic noise. One of the most effective, fast and economical ways to reduce the noise level associated with car traffic are

acoustic screens [4]. The design of acoustic screens is related to the fulfilment of effectiveness conditions, *i.e.* maximum noise reduction, while maintaining the aesthetics, fitting the screen in the natural landscape and obtaining the desired durability that provides the long-term functioning and undemanding maintenance. The technological and material solution of the acoustic screens should be chosen in a way that ensures appropriate operational effects at low costs [7]. The choice of a specific technological and material solution among the selected types of the acoustic screens requires the analysis of environmental, technological, functional, structural and economic factors. In practice, the decision is made unreasonably, taking into account only investment costs, the result of which is the selection of inefficient solutions and those disturbing the natural landscape. The filling, which determines acoustic insulation, is considered the most important element of the acoustic screen construction [16].

In the classification, in terms of the material, the screens can be divided into:

- metal,
- concrete,
- timber,
- plastic,
- glass ones,
- other.

The group of metal screens includes aluminium and steel covers. Metal cassettes are often used in Poland. The filling of such a panel is made of mineral wool which is covered by a perforated aluminium or steel layer. The acoustic properties of this type of screens are relatively good. Both sound absorbing and reflecting screens are produced. The housing is available in any colour. Perforated screens with large holes allow for growing with climbing plants [6]. The price of metal screens is relatively low, but it should be noted that such panels require maintenance and use of anti-corrosion agents, which entails additional costs [4].

Concrete panels are among the oldest solutions protecting from noise. The technical properties allow for making the load-bearing structure elements and filling of con-

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crete. The panels are usually built from a load-bearing reinforced concrete slab, to which it is possible to fix the noise insulation slabs, e.g. such as sawdust concrete, gravelite-concrete or timber-concrete. The concrete panels have a large mass, thanks to which they perfectly reduce noise. The concrete panels are resistant to the action of weather conditions and they are very durable. The timber-concrete slabs can be permanently dyed in the mass to any colour within the RAL range. The price of the timber-concrete screens is affordable, in addition, it should be taken into account that they do not require maintenance [6, 15, 17].

Mineral wool is used as a filling element of the timber screen. The screens made of wood are environmentally friendly and very well received by local communities. The disadvantage of the timber solution is flammability and additional costs associated with maintenance (impregnation), as well as the possibility of biological corrosion [4]. With proper operation and the use of cyclic impregnation, wood is a durable material. The acoustic insulation of the timber solution is quite good when using climbing plants. The insulation increases on the surface of the screen.

The example of the plastic screen is a polyvinyl chloride (PVC) panel. The PVC screens are filled with mineral wool enclosed with a polyvinyl chloride layer. This type of solution is characterised by good acoustic parameters. A huge disadvantage of PVC panels is their deformability under the influence of sunlight. The polyvinyl chloride screens are very aesthetic [4, 6].

The glass screens include panels made of natural tempered glass and polymethylmethacrylate (PMMA), colloquially called acrylic ones. The glass screens are used in places where the achievement of a transparent acoustic screen is required. The glass screens are glued of one or several slabs, depending on the needs. Additional layers increase acoustic properties, mechanical strength and they are associated with an increase in price. The disadvantage of glass screens is slender resistance to damage. The polymethylmethacrylate slabs are characterised by very good insulating properties with a high light transmission coefficient. These types of screens do not absorb sounds. The polymethylmethacrylate screens are very expensive. They belong to the most expensive solutions available in the market. When selecting the screens made of glass, frequent maintenance should be taken into account [4, 6, 16].

The “green wall” type screens consist of a galvanized frame, a mineral wool filling covered with a green plastic mesh and a steel grid. The steel grid is used in order to enable creepers to climb the construction, improving aesthetics and additionally the noise insulation. The “green

wall” is very often used in Polish cities due to the low price and good acoustic insulation. The climate prevailing in Poland is not conducive to the development of creepers. An additional obstacle to the growth of vegetation includes the measures used for de-icing the surface during winter [4, 6].

The variety of available screens justifies the analysis of individual technological and material solutions. The objective of this article is to compare the biplot methods and radar charts as a possibility of graphic presentation of the research results by obtaining an optimal solution on the example of an analysis of the technological and material undertakings of the acoustic screens.

2 Methods

The decision-making process is extremely complicated and difficult. The choice is always accompanied by possible variants. The assessment of the accuracy of choice during the decision-making time is practically impossible. The accuracy and effects of the decision can be assessed from the perspective of time. The indication of proper conduct is inherently associated with a risk [1, 3, 10, 13].

The multi-criteria decision analysis (MCDA) is characterised by the active participation of the decision maker. The decision maker chooses the criteria and assigns weightings to them. The multi-criteria decision analysis is subjective assessment. The multi-criteria decision analysis consists of three stages: structuring the decision-making level, analysing the decision-making problem and the solution implementation [10, 11].

The first stage – the decision level structuring starts with the analysis of the environment of the decision problem. It involves the observation of the surroundings in order to thoroughly know and identify the problem [2, 9]. After conducting the analysis, it is important to formulate a decision problem, that is to determine the decision subject and purpose. Then, the decision variants and components of the possibilities are determined. The last stage of structuring the decision problem is the selection of criteria for assessing individual variants. The variants are usually evaluated on the basis of several criteria or one of them (single-criterion analysis). The criteria should not overlap [12]. The most effective analysis contains 7 ± 2 criteria of a quantitative nature [5].

The next component, that is the analysis of the decision problem, consists of two stages: assessment and selection of a decision-making variant. At this stage, it is important to choose a method that will support the decision-

making. When choosing a method, it is crucial to consider the restrictions that may relate to a given method. The methods used in case of multi-criteria decision-making that support the decision-making process are based on the methodology of operational research, which allows to determine a set of acceptable solutions, and then to select an optimal solution from this set. It is carried out on the basis of the assessment of the solutions taken into account, using a set of defined criteria. The selection of an optimal variant follows the synthetic evaluation of the option, to which the partial assessment was assigned [9].

The solution implementation and the assessment of effects constitute the final stage of the decision analysis. The result of the carried-out analysis should be a decision that takes into account the preferences of a decision-making person or persons. The decision-making analysis processes held information with the use of quantitative methods with active human participation [10].

The Compositional Data Analysis method is used for statistical data preparation. It was introduced in 1986 by Aitchison. CDA presents complex data in the form of vectors. The components of vectors are percentages or proportions, the sum of which is contained in a certain whole (100%). The components belong to dependent variables.

The following features are characteristic for a set of component data:

- row of matrices refers to a single solution,
- columns present criteria,
- matrix components are non-negative,
- rows of matrices add up to unity,
- the correlation coefficient between components will change after removing one of the variables [8].

For the graphic interpretation of the CDA method, among others, the spider web and biplot graphs are used.

3 Results

The spider web method allows for selection, if multiple variants are available. The decision is made after selecting the appropriate assessment criteria and assigning the weightings to them. The variables used for the optimal solution selection among the selected types of acoustic screens are:

- DV1 – Durability (durability determined during the exploitation, without the use of additional safeguards),
- DV2 - Performance economy (purchase price with assembly and maintenance costs),

- DV3 - Acoustic insulation (class of acoustic absorption and isolation from airborne sounds according to the norm PN-EN 1793-2:2001),
- DV4 - Required maintenance (use of additional security and cleaning),
- DV5 - Aesthetic values (fitting into the natural landscape).

Specific criteria presented desirable, undesirable and neutral values. The above criteria were assigned weightings, the sum of which was included in the whole (1.00). The higher the weighting, the greater the impact of a given criterion on the final result of the analysis. The durability gained the highest weighting. It was defined as the most important criterion. The aesthetic values obtained the lowest weighting, reaching a minimal impact on the analysis result. The weightings of the criteria were presented in Table 1.

Table 1: Weights assigned to criteria.

Number	Symbol	Weight
1	DV1	0,30
2	DV2	0,25
3	DV3	0,20
4	DV4	0,15
5	DV5	0,10

The criteria were expressed in medians from 1 to 5. The highest value meant the most favourable solution. The Table 2 presents the ratings together with justification. The assessment of each solution was the product of a given weighting and the criterion subjected to the weighting. The results are shown in Table 3.

As the technological and material undertakings, the cases, one of each type of the acoustic screens, were chosen:

- timber-concrete screen,
- green wall panel,
- aluminium panel,
- natural tempered glass screen,
- timber panel.

The data presented in Table 3 were normalized and transformed according to the Compositional Data Analysis. Rows of matrices add up to unity. The graphs (Figure 1-5) in the polar axis system show the surface areas of individual technological and material solutions of the acoustic screens: 1-timber-concrete screen, 2-”green

Table 2: Justification of the assessment.

DV1		DV2		DV3		DV4		DV5	
Timber-concrete	The most durable solution, >50 years	5	relatively low price	4	B3 (43 dB), A4 (13 dB)	5	maintenance is not required	5	Fairly aesthetic solution (the possibility of coloring plates in any color)
Green wall	Durable solution but exposed to acts of vandalism	3	very cheap solution, the cheapest of the analyzed cases	5	B3 (33 dB), A4 (12 dB)	4	required maintenance (partial replacement of the filling and cleaning)	1	aesthetic solution (boards can grow on climbing plants)
Aluminium	susceptible to corrosion	2	very cheap solution, the cheapest of the analyzed cases	5	B3 (26 dB), A3 (10 dB)	3	required maintenance (use of corrosion protection and cleaning)	1	Fairly aesthetic solution (the possibility of coloring plates in any color)
Tempered glass	high durability, with increased thickness of the board, durability increases	4	the most expensive solution (the price increases with the thickness of the plate)	1	B3 (33 dB), A4 (12 dB)	4	required maintenance (frequent cleaning)	1	very aesthetic solution (transparent plates do not curtain the natural landscape)
Timber	without impregnation, not durable (biological corrosion)	2	wood is a common material and is relatively cheap. However, the price of cyclic impregnation should be taken into account	3	B3 (31 dB), A3 (10 dB)	3	susceptible to vandalism in the form of graffiti and need to be painted over each time to restore the original look	3	Aesthetic solution that fits into the natural landscape

Table 3: Evaluation of solutions including weights.

Number	Type of acoustic screen	Evaluation of solutions including weights				
		DV1	DV2	DV3	DV4	DV5
1	Composite (timber-concrete)	1,50	1,00	1,00	0,75	0,30
2	Green wall	0,90	1,25	0,80	0,15	0,40
3	Aluminum	0,60	1,25	0,60	0,15	0,30
4	Tempered glass	1,20	0,25	0,80	0,15	0,50
5	Timber	0,60	0,75	0,60	0,45	0,40

Figure 1: Radar chart for timber-concrete screen.
 $A_1 = 0,105$

Figure 3: Radar chart for aluminum.
 $A_3 = 0,102$

Figure 2: Radar chart for “green wall”.
 $A_2 = 0,103$

Figure 4: Radar chart for tempered glass.
 $A_4 = 0,096$

wall”, 3-aluminium panel, 4-tampered glass screen, 5-timber panel.

According to the radar chart (spider web), the optimal solution is a timber-concrete screen. It is not possible to read the significance of the criteria for individual cases from the radar charts. The radar charts present the results

for individual cases on separate charts, making it impossible to compare them in one figure.

In the radar charts, it is not possible to show relationship of variables and cases.

The multidimensional analysis tools, which include the biplot graphs, allow to determine the relationship be-

Figure 5: Radar chart for timber.

$A_5 = 0,101$

Table 4: Surface areas of radar charts.

Number	Type of acoustic screen	Area
1	Timber-concrete	0,105
2	Green wall	0,103
3	Aluminum	0,102
4	Tempered glass	0,096
5	Timber	0,101

tween cases (types of acoustic screens) and characteristics (criteria). The biplot graphically presents the elements of rows and columns in one graph, which facilitates the analysis of correlations [13].

In the biplot, the criteria assigned in the spider web method were used. The partial criteria were presented on a scale from 1.00 to 5.00. The value of 5.00 most accurately determines the compliance with the criterion. Data transformed in accordance with the CDA were used.

The main coordinates of the biplot contain nearly 89% of the total variance of five active variables involved in the analysis. In order to present the criteria (variables) and cases (technological and material solutions), 2W graphs were made (Figures 6 and 7). The graphs were then superimposed on each other, facilitating the analysis. The common graph (Figure 8) contains variables (sections) and points presenting the technological and material solutions.

The biplot interpretation indicates relationship between aesthetic values (DV5) and performance economy (DV2), as well as between acoustic insulation (DV3) and required maintenance (DV4). The other criteria are separated from each other, they are not connected with each other. The feature – DV2 (performance economy), which explains almost 73% of the total variance, is tilted to the

Figure 6: Chart 2W factors for criteria.

Figure 7: Graph 2W of coordinates of technological and material projects.

Table 5: Symbols of acoustic screens on the biplot map.

Symbol	Type of acoustic screen
1	Timber-concrete
2	Green wall
3	Aluminum
4	Tempered glass
5	Timber

horizontal axis. It is a very important criterion. The remaining variables contain 16% of the total variance. The longest segments belong to DV1, DV2 and DV4 variables. The length of the segment is responsible for the feature strength. The DV3 and DV5 variables are not important. The map shows that the timber-concrete (1) and timber screens (5) are indeed durable (DV1). DV1 segment has a position close to points 1 and 5. The screens made of tem-

Figure 8: Common coordinate diagram of criteria factors and technology and material factors.

pered glass require the maintenance. The “green wall” and aluminium panels belong to economic solutions. In addition, the aluminium panel is aesthetic.

4 Conclusions

The presented analysis raises the following conclusions:

- The critical literature analysis has distinguished the main criteria for assessing the technological and material solutions of the acoustic screens
- The radar charts make it impossible to show relationship between variables and cases. It is also not possible to determine the significance of the criterion for individual cases.
- The biplot maps allow to determine relationship between features and technological and material solutions.
- The comparison of the graphical interpretation of radar chart and biplot methods allowed to assess the biplot method as more accurate.
- The optimal technological and material solutions for acoustic screens according to the radar charts is a timber-concrete panel.
- The biplot solution gives a broader concept of optimisation. According to this interpretation, the timber-concrete and timber panels is an important technological and material solution for the criterion of durability, glass for the feature of the required maintenance, and the “green wall” for the performance economy. Other criteria are less important. Summing up, the most important criterion also con-

sidering the weighting is the economy of performance that explains almost 73% of the total variance. This feature is assigned to the case: “green wall”.

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