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Research paper

Analysis of bridge structure selection using a hybrid decision-making technique

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Abstract: Implementation of sustainability principles in civil engineering has increased the substantive range of bridge engineering. The consideration of additional criteria, in particular ecological and social ones, requires the design process to be supported by appropriate tools. It refers especially to large bridge elements which affect their load-bearing capacity, e.g. girders or decks. The aim of this paper is to develop an original MCDA (Multi-Criteria Decision Analysis) method as a potential tool to support a decision-making process in the selection of material and design alternatives for bridge main girders. Therefore, an advanced hybrid algorithm was created consisting of the following methods: EA FAHP+FDEMATEL+ZUM (Extent Analysis Fuzzy Analytic Hierarchy Process + Fuzzy Decision-Making Trial and Evaluation Laboratory + Zero Unitarization Method), applied at the structure design stage. The pre-dimensioned alternatives selected for analysis were then subjected to an evaluation process based on a complex set of criteria arranged in a hierarchical control structure (HCS). The algorithm has been applied based on the example of a medium span slab-and-girder bridge, assuming 6 alternative concepts of girders, different in material and dimensions. The hybrid method was compared with the EA FAHP method. Analysis results obtained based on judgments from 3 teams of Decision Makers (DM) indicate effectiveness of the proposed algorithm and its practical aspect, which may contribute to improved quality and safety of bridge structures.

Keywords: bridge design, girder, hybrid model, MCDA, multi-criteria optimization, span

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1. Introduction

As the most energy- and material-intensive sector of the economy, the building industry has been the focus of much of the global sustainability strategy of recent years [1,2]. Satisfactory results have not yet been achieved despite the measures taken. Adopting sustainable development principles requires changing the entire investment process, starting with design and ending with recycling of post-demolition materials. A design phase is particularly important as it determines the expected service life of a civil structure. Sustainable designing is a difficult process mainly due to its interdisciplinary nature, depending on growing requirements, a growing number of industries involved, as well as consideration of social, environmental and economic factors, etc. Sustainable design requires development of a new type of designers' awareness, but also creating helpful tools and procedures.

This issue is particularly relevant for small and medium span road bridges, which are the most common. According to current statistics, there are approx. 38,600 road bridges and viaducts in Poland [3]. The average span of single-span bridges in use is between 12 and 24 metres, which in statistical terms is not significantly different from other Central and Eastern European countries [4]. Concrete structures (reinforced and pre-stressed, including precast structures) account for 87%; the share of steel and composite structures (steel – concrete) account for approx. 8% of all road structures [5]. This trend is also true for newly built bridges and therefore, technical, technological, economic, and environmental factors force administrators to optimise the implementation process of road investment projects.

The above points to the need to introduce tools into the design process that allow for multi-criteria optimisation of key decisions that are taken. MCDA methods, in particular Fuzzy Group Decision Making (FGDM), appear to be helpful in this respect, when applied to cases where solutions from "classical" mathematics are difficult to find. These methods, which have been developed since the 1970s, are increasingly being used in the building industry, and their range of applications is growing, covering a relatively wide range of issues. [6,7]. The most common are basic methods (e.g. Analytic Hierarchy Process (AHP)) and their fuzzy variants [8,9]. Fuzzy methods together account for almost 50% of all published applications, while aggregate methods are used much less frequently [10–12], but both groups of methods have certain limitations.

The implementation of single multi-criteria methods for bridge designs has been addressed in relatively few papers, which include [13–15]. The authors, for the evaluation of different structures, used different methods, in some cases comparing the results with alternative methods. For example, Melakely and his team [15] analysed material and design solutions of spans for small and medium–span bridges of various designs. In the initial phase, the Quality Function Deployment (QFD) method was used to identify the investor's needs before deciding on the design alternatives. Evaluation was carried out using a limited set of 4 criteria and the ranking of alternatives was performed using the Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) method. In the paper [14] design solutions of single and multi-span reinforced concrete motorway bridges were analysed. Eight variants of girders were adopted for the analysis, selected for obstacle span up to 100 m, averaged for conditions in Poland. They were evaluated on the basis of criteria grouped on two levels of the hierarchical tree with 5 main criteria. The analysis was carried out using the FAHP method. To sum up, hierarchical decision trees with two levels of criteria, with 5 and 3 main criteria respectively, and a total of 16 and 9 sub-criteria were applied only in papers [14, 16]. Too small number of criteria contributes to less precise assessment or necessity to apply criteria with a high level of generalisation. FGDM methods that allow group judgments or uncertainty to be considered are only found in the following papers [13, 14]. The publications presented, dealing with bridge issues, contain analyses of optimal solutions using single methods and are therefore limited by imperfections of these algorithms, e.g. a limited number of alternatives/criteria depending on the method, or inability to validate pairwise comparisons. These limitations may be partly eliminated by implementation of hybrid methods [17].

The presented review of literature indicates importance of the issue and significant market demand for development of improved MCDA methods At the same time, a small number of such works is noticeable, as well as the mentioned drawbacks of methodologies proposed so far, which include (in addition to those mentioned) application of crisp values, which neither reflect real evaluation processes nor allow for ambiguity in judgement to be considered.

The hybrid methodology allows the aggregation of MCDA methods to achieve a synergistic effect of integrating the different features of each method, leading to a comprehensive view of the issue under analysis [17–22]. These publications define the hybrid model as aggregation of two or more MCDA methods or other optimisation techniques applied at the same stage of analysis (e.g. FAHP+FVIKOR (Fuzzy Vise Kriterijumska Optimizacija I Kompromisno Resenje) with FMEA (Failure Mode and Effect Analysis) and Shannon Entropy, VIKOR+DEMATEL+AHP. However, their use does not relate to construction issues. Hybrid methods will be particularly beneficial when applied to issues with conflicting objectives among different stakeholders and in decision-making procedures with long-term consequences.

Based on the literature review presented, there is a lack of papers on the application of hybrid methods in the field of civil engineering and especially bridge construction. It was therefore considered advisable to extend related research by developing an original MCDA methodology as a potential design optimisation tool to support the decision-making process in the selection of material and design alternatives for bridge girders. In the design phase, the aggregated EA FAHP+FDAMATEL+ZUM method was adopted, with pre-optimisation of alternatives based on static strength calculations. A stage of procedure application in the design process is shown in Fig. 1. Application of the hybrid algorithm in question is presented based on 6 alternative design solutions for main girders of a representative road bridge. Effectiveness of the proposed algorithm was verified by means of the selected single FGDM method.

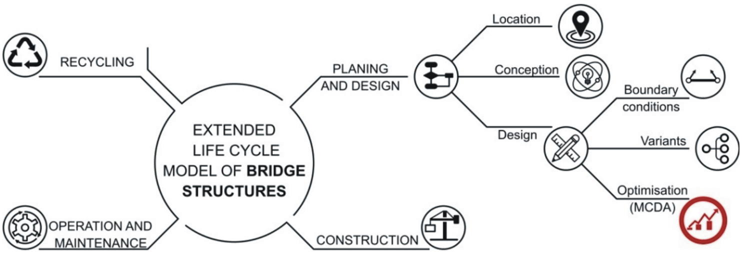

Fig. 1. An extended life cycle model of bridge structures with a design phase and indication of application of the proposed calculation algorithm

2. Subject of analysis and alternatives description

The methodology proposed in this paper has been applied to single span girder bridges with reinforced concrete or steel deck.

The following technical assumptions have been made for the bridges in question:

- average span 20 m, average performance parameters: 2-lane roadway and sidewalks, width of 8 m +2 × 2 m respectively (Fig. 2a),
- the bridge designed as traffic load model LM1, located in a medium used traffic route (averaged traffic category), with the intensity of 7.3–22 × 10^6 axle (N_{100}) for vehicles with the axle load of 100 kN [23],
- typical location of a bridge over a natural obstacle (e.g. a river) where the angle of intersection of the bridge axis with the obstacle axis is 90°.

To verify the proposed algorithm, typical main girder types were selected based on a comprehensive review of existing road bridges built in Poland between 1980 and 2015. A scope of assessed test sample covered nearly 140 road bridges, including bridges, viaducts and overpasses designed and constructed as part of investment projects financed or co-financed from the European Union funds.

The analysis covers six alternative design solutions for bridge main girders (Fig. 2b), i.e. monolithic reinforced concrete girder and deck (G1) and precast prestressed concrete girder with RC deck (G2), steel plate girders with steel deck (G3), composite girders (steel + concrete) of rolled beams (G4) and plate girders (G5), as well as composite girder in a form of a fibre reinforced polymer beam and RC slab [24, 25].

The beam design alternatives were selected to be representative of solutions commonly used in Poland and abroad, also in terms of the span length adopted [26]. They were adapted to

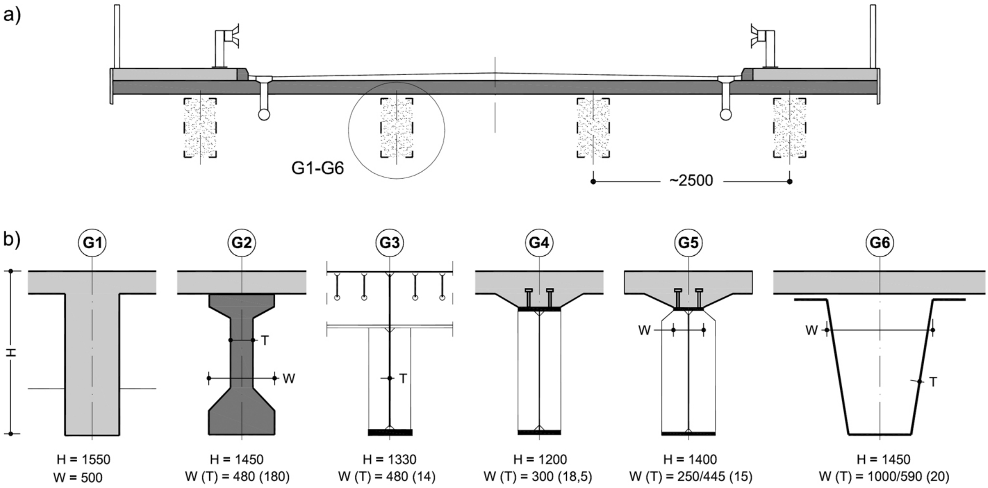

Fig. 2. Cross-section of the analysed bridge span (a) and selected alternatives for G1 – G6 girders with dimensions (description in the text) (b)

the harmonised European standards by being designed for a minimum service life of 100 years. Rolled beams were made of S275 steel and the bridge deck of C30/37 concrete. The G2 girder was designed using φ 15.5 steel strands, strength 1800 MPa. Bridge spans designed that way were then modelled as beam grids (2D) and relevant calculations were carried out. For RC and RC prestressed alternatives, rheological effects within the assumed service life after 100 days and after 100 years were taken into account, as well as the environmental impact of the construction technology, e.g. in the form of minimum material consumption. For calculation of the precast beam bridges it was assumed that the spans would be constructed without the use of temporary supports, except for the monolithic reinforced concrete span (G1). Depending on the alternative a reinforced concrete or steel (orthotropic) deck was adopted, as a repeatable element with thickness of 200 mm and 12 mm respectively.

The first phase of the analysis based on the methodology adopted, consisted in static strength calculations made for selected alternatives in terms of ultimate limit state and serviceability limit state [27–29]. The cross-section of girders was selected assuming their constant stress of 80% and a maximum deflection of 1/250 and 1/300, for RC and RC prestressed (G1, G2), steel (G3–G5) and fibre reinforced polymer (G6) beams respectively. Based on the geometry of cross-sections (Fig. 2), material consumption (concrete, reinforcing steel, prestressing steel, structural steel, etc.) was also calculated and the optimum fabrication technology was selected.

3. The proposed hybrid method for design alternatives

3.1. Procedure algorithm

The procedure algorithm is presented in Fig. 3. The objective (STAGE I) is to evaluate design alternatives for selected structural elements of the bridge. This is a typical decision making problem where the alternatives need to be ranked so that they can be compared. The ranking is carried out using ranks generated by a group of experts (also herein after referred to as decision-makers) and awarded based on criteria. A specific nature of judgments presented forces their representation with the use of fuzzy values due to their subjective character, various precision and frequent lack of complete information along with its ambiguity. The assumed evaluation scale is presented in Table 1. The second stage (STAGE II) consists in determination of decision alternatives (item 3.2) together with construction a HCS for the given issue (item 3.3). In the next stage (STAGE III) computational algorithms of both EA FAHP [30, 31] and FDEMATEL+ZUM [32–34] methods are applied in parallel. The first method was used for the complete HCS analysis, including decision alternatives, and the second method was used to determine the relationship between criteria and sub-criteria. The EA FAHP computational algorithm goes as follows: step 1 – create the matrix of assessment using triangular fuzzy number (TFN) $A = [A_{ij}]_{n\times m} = (l_{ij}, m_{ij}, u_{ij})$, step 2 – check for consistency ratio (CR ≤ 0.1) (for modal value TFN), step 3 – calculate the indicator of synthetic measurement of assessment as follows:

$$S_i = \frac{\widetilde{RS_i}}{\sum\limits_{j=1}^{n} \widetilde{RS_j}} = \left(\frac{\sum\limits_{j=1}^{n} l_{ij}}{\sum\limits_{j=1}^{n} l_{ij} + \sum\limits_{k=1,\,k\neq i}^{n} \sum\limits_{j=1}^{n} u_{kj}}, \frac{\sum\limits_{j=1}^{n} m_{ij}}{\sum\limits_{k=1,\,k\neq i}^{n} \sum\limits_{j=1}^{n} m_{kj}}, \frac{\sum\limits_{j=1}^{n} l_{ij}}{\sum\limits_{j=1}^{n} u_{ij} + \sum\limits_{k=1,\,k\neq i}^{n} \sum\limits_{j=1}^{n} l_{kj}} \right) \tag{3.1}$$

and step 4 – calculate the weight matrix Eq. (3.2):

$$W_i = \frac{S_i}{\sum\limits_{i=1}^{n} S_i}. \tag{3.2}$$

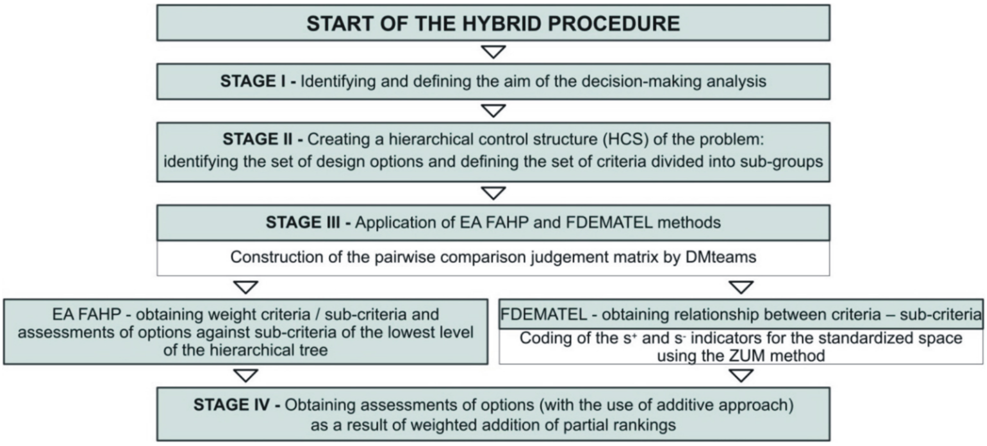

Fig. 3. The procedure algorithm in assessment of design alternatives

The EA FAHP method allows calculation of the criteria weights, but without information on the relations between them, which limits a range of the analysis. The FDEMATEL method was used to identify the cause-and-effect relationships between the criteria. It allows identification of relationships taking into account their long-term nature and analysis of the influence between the structure components (overall cause or effect nature of the individual components). They are determined by the resulting prominence indicators s^+ (gross impact indicator) and relation indicators s^- (net impact indicator). The FDEMATEL calculation algorithm proceeds as follows: step 1 – create the direct – relation matrix using TFN, step 2 – create the normalized fuzzy direct-relation matrix $X_{ij} = \frac{A_{ij}}{r}$, where:

$$r = \max_{i,j} \left[\max_{i \le i \le nj} \left(\sum_{i=1}^{n} u_{ij} \right), \max_{i \le j \le n} \left(\sum_{j=1}^{n} u_{ij} \right) \right], \tag{3.3}$$

step 3 – calculate the fuzzy total – relation matrix $T_{ij} = X_{ij}(I - X_{ij})^{-1}$ and step 4 – calculate matrices R_i, C_i and indicators of positions s^+ and relations s^-: $R_i = [\sum_{i=1}^{n} w_{ij}]_{n\times 1}$,

$C_j = [\sum_{i=1}^{n} w_{ij}]_{1\times n}$, and finally $s_i^+ = R_i + C_j$, $s_i^- = R_i - C_j$ (I – identity matrix). Coding of the Fuzzy DEMATEL method results into a normalized space $\langle 0, 1\rangle$, was carried out by a ZUM method [20]:

$$S_i^+ = \frac{s_i^+ - s_{i_{\min}}^+}{s_{i_{\max}}^+ - s_{i_{\min}}^+}, \tag{3.4}$$

$$S_i^- = \frac{s_i^- - s_{i_{\min}}^-}{s_{i_{\max}}^- - s_{i_{\min}}^-}. \tag{3.5}$$

The procedure ends with STAGE IV, i.e. application of an additive method, which results in aggregation of the criteria weights and thus ranking of the alternatives [18, 19, 22].

Table 1. Linguistic scales and corresponding numerical scales of both methods [17, 30, 35, 36]

Dominance scale/ linguistic scale		**EA FAHP**		**FDEMATEL**
EA FAHP scale	**FDEMATEL scale**	**Corresponding fuzzy number**	**Reversed fuzzy number**	
Equivalence	No influence	(1, 1, 1)	(1, 1, 1)	(0, 0, 0.25)
		(1, 2, 4)*	(1/4, 1/2, 1)	
Minor dominance	Very low influence	(1, 3, 5)	(1/5, 1/3, 1)	(0, 0.25, 0.50)
		(2, 4, 6)*	(1/6, 1/4, 1/2)	
Strong dominance	Low influence	(3, 5, 7)	(1/7, 1/5, 1/3)	(0.25, 0.50, 0.75)
		(4, 6, 8)*	(1/8, 1/6, 1/4)	
Very strong dominance	High influence	(5, 7, 9)	(1/9, 1/7, 1/5)	(0.50, 0.75, 1.00)
		(6, 8, 9)*	(1/9, 1/8, 1/6)	
Absolute dominance	Very high influence	(7, 9, 9)	(1/9, 1/9, 1/7)	(0.75, 1.00, 1.00)

* – linguistic ratings.

3.2. Construction of the hierarchical control structure

Classification of the suggested main and partial criteria are given in Fig. 4. Four main criteria were adopted for the analysis: environmental (A), safety and durability of the structure (B), technological nature of design solutions (C) and economical (D). The terms “safety” and “durability” adopted for Criterion B are synonymous terms, suggesting that design alternatives are assessed in terms of aspects indicated throughout the structure service life. Criterion A defines a degree to which the environmental impact of the structure can be minimised at the operation phase, Criterion B refers to the structure service life at design and operation phases, taking into account exceptional conditions, and Criterion C determines the possibility of efficient and effective construction of the structure. Under criterion D, the total investment project cost was assessed at the stage of design, construction and operation of the structure. Within criterion A, 4 sub-criteria were distinguished, covering consumption of materials (A1), reduction of energy intensity of technological processes to minimum (A2), recycling of non-renewable materials (A3) and environmental impact of the maintenance and repair work (A4). Criterion B has been divided into 3 sub-criteria. Criterion B1 – design – it considers possible use of geometry of components favourable for structure durability; ranking of alternatives according to B1 results from a strong impact of the design phase on durability of the structure. Criterion B2 refers to safety (resilience) of the structure to disruptive events like an impact into the structure, e.g. by a vehicle. Criterion B3, referring to structure durability, was used to assess the alternatives, e.g. in terms of complex nature of the maintenance and repair work required. For criteria B1 and B3, identical environmental conditions were assumed for all alternatives. Sub-criteria assumed under criterion C included: potential of maximum mechanisation of work processes (C1), universal character of erection technology (C2), possibility to execute erection work in variable weather conditions (C3) and a degree of complexity during execution (C4). Sub-criteria D included: the cost of the investment project (D1), its duration (D2) as well as frequency and cost of maintenance and repair work (D3).

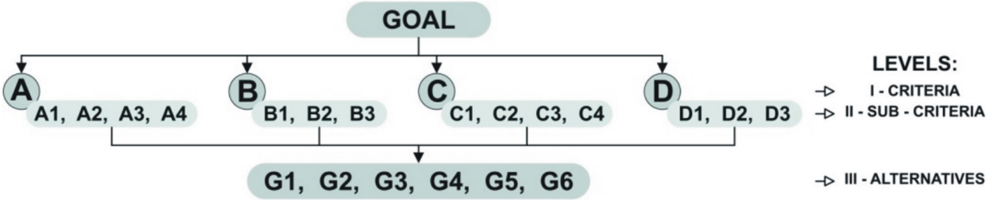

Fig. 4. Graphic interpretation of the hierarchical control structure

In the absence of a universally applicable model to define sustainability, the social aspect has been considered indirectly, as inextricably linked to environmental and economic criteria (e.g. minimising consumption of materials and their possible reuse, reduction of a risk of failure, favourable to safety of use).

4. Numerical example and discussion

Based on the algorithm given in Section 3, a numerical procedure was developed in the MATLAB software. In order to increase reliability of the results obtained, three DM teams were appointed, consisting of experts in engineering, environmental protection, process engineers, managers of road infrastructure and experts in civil engineering (15 persons in total). Ratings were generated by means of aggregation of individual judgements, subject to reconciliation by the group [37] (step 1, Fig. 3). It is justified by the complex character of the issue, as well as a wide range of criteria of an interdisciplinary nature, affecting the substantive scope of judgements.

The impact assessment obtained by means of the FDEMATEL method did not raise any major doubts in the opinion of teams. Differences appeared only in relation to 11 judgments, which when referred to their total number of 144 amounted to 7.6% (with 48 judgments per one DM team). Slight differences in judgments between teams may indicate stable influence between criteria/subcriteria. Table 2 shows a sample comparison of judgments for main criteria and for subcriteria B1–B3. In the case of the EA FAHP method, differences appeared in 96 judgments, which accounted for 13.7% out of 702 judgements (with 234 judgments per one DM team). To sum up, the greatest variation in judgement was for G6 alternative. That was mainly due to relatively little experience in the use of that type of beams, as well as the lack of uniform guidelines for the design and execution of composite girders.

Table 2. Comparison of ratings for main criteria and sub-criteria B1–B3 (FDEMATEL)

Main criteria																
Goal	**A**				**B**				**C**				**D**			
DM:	1	2	3	FN	1	2	3	FN	1	2	3	FN	1	2	3	FN
A					0	0	0	0	0.25	0.5	0.25	0.25	0.5	0.5	0.25	0.5
B	0.25	0.25	0.5	0.25					0.5	0.5	0.5	0.5	1	1	1	1
C	0.25	0.5	0.25	0.25	0	0	0	0					0.75	0.75	0.5	0.75
D	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.5	0.25	0.5	0.5				

Subcriteria B												
B	**B1**				**B2**				**B3**			
B1					0.5	0.75	0.5	0.5	0.75	0.75	0.75	0.75
B2	0.25	0.5	0.25	0.25					0.25	0.25	0.25	0.25
B3	0.25	0.25	0.25	0.25	0.5	0.25	0.5	0.5				

Note: 🟦 – final rank; 🟨 – rank awarded by DM team different from the final rank adopted for calculation; ▨ – value 0 or 1 for FDEMATEL or EA FAHP method, respectively, – inverse rank symmetrical to the main diagonal of the assessment matrix. Modal values of judgments are given in the rows.

Analysing the results obtained in case of the EA FAHP method, a value of the Consistency Ratio (CR) fluctuated between 0.026 and 0.098 for the pairwise comparisons matrix of variants against the C2 and C4 criteria, respectively (step 2, Fig. 3). Table 3 shows sample values of relation and prominence indicators obtained for the main criteria using the FDEMATEL method. Columns 6 and 7 show indicators standardized using the ZUM method S_i^+ and S_i^- (Fig. 3).

The DEMATEL cause and effect diagrams of criteria and subcriteria analysed are presented in Fig. 5. The nodes reflect components of the model and the arcs correspond to the direct impact relations with a determined direction and intensity. Their interpretation consists in correlating the indicator with the source of impact. The higher values of s^+ prominence indicator, the larger significance of the given criterion (*the cause group*). The s^- relation indicator is to a higher degree a source of impact on other criteria (*the effect group*). For example, if we analyse a diagram showing the main criteria (red), criterion B has the greatest

Table 3. Values of prominence and relation indicators obtained for the main criteria acc. to FDEMATE

Criterion	R_i	C_i	s_i^+ $(R_i + C_i)$	s_i^- $(R_i - C_i)$	S_i^+	S_i^-
A	0.758	0.749	1.507	0.009	0	0.453
B	1.264	0.512	1.777	0.752	0.301	1
C	0.907	1.063	1.970	–0.157	0.518	0.330
D	0.898	1.503	2.401	–0.605	1	0
		min	1.507	–0.605		
		max	2.401	0.752		

impact on cause (safety and durability of the structure) and economic criterion D has the least impact (it is equated with effect), while criterion A is neutral. Taking into account the s^+ indicator, criterion D is the most important.

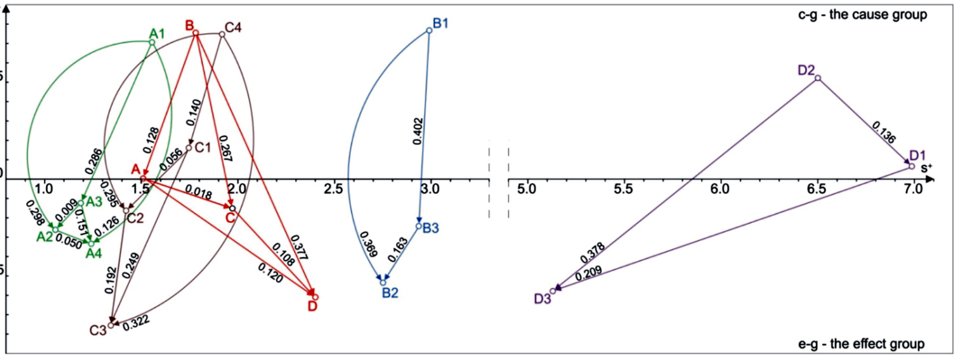

Fig. 5. The cause and effect diagrams of the main criteria and subcriteria

Examples of aggregated weights for the main criteria obtained as a result of the hybrid algorithm application are presented in Table 4.

Table 4. Example of aggregated weights for the main criteria

Main criteria	w_i **(EA FAHP)**	s^+ **(Fuzzy DEMATEL + ZUM)**	**Aggregated weights** w_i^{fin} **after standardization**
A	0.198	1.507	0.163
B	0.578	1.777	0.562
C	0.083	1.970	0.089
D	0.141	2.401	0.186

Figure 6 shows differences between the weights obtained by means of the compared methods (stage IV, Fig. 3). They result from consideration of interactions between the criteria obtained using the FDEMATEL method. This results in a more favourable representation of the relationship compared to the EA FAHP, provides more accurate judgements and takes into account the long-term effect, allowing more effective modelling of the decision problem. Based on interpretation of the criteria weights, criterion B (safety and durability of the structure) along with its B1 sub-criterion (design criterion) is decisive for ranking of alternatives, while criterion C (design for manufacturability) is the least important.

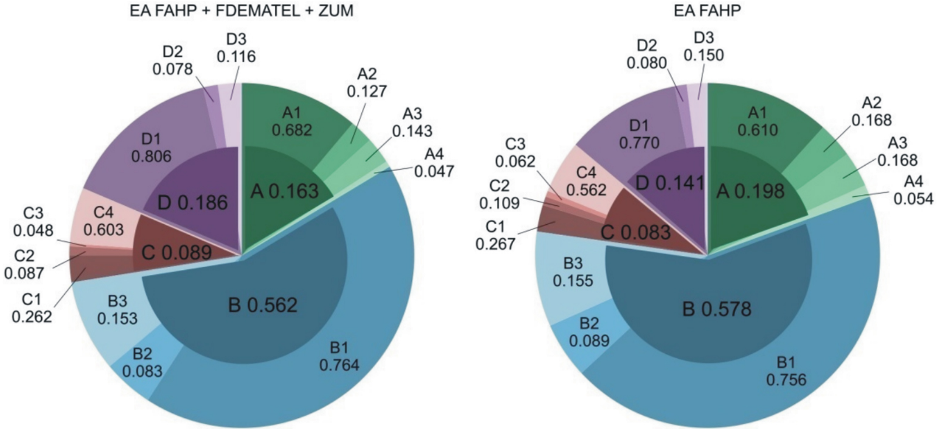

Fig. 6. Graphic comparison of the criteria weights obtained by means of methods: EA FAHP only and hybrid AE FAHP + FDEMATEL + ZUM

The final ranking of alternatives for selected design solutions of main girders is presented in Fig. 7. The G4 alternative received the highest score i.e. 0.255, while G6 received the lowest score i.e. 0.071. These are solutions of composite girders where the deck is a reinforced

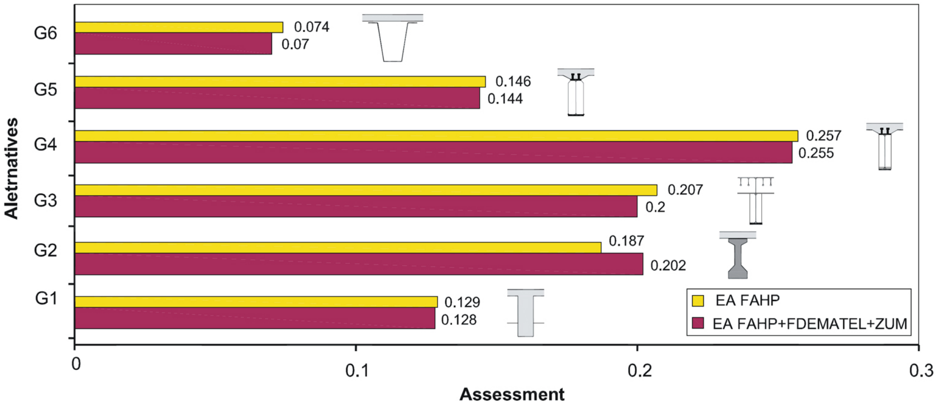

Fig. 7. Comparison of the final assessments of alternatives according hybrid method and EA FAHP

concrete slab and girders are of a steel and a composite type, respectively. The resulting significant difference in ranking for outermost alternatives clearly demonstrates the benefits of G4 implementation. It was also found that, apart from the one indicated, the highest ratings correspond to the prestressed concrete girder (G2) and the welded steel girder with a steel deck (G3) alternatives. The G6 alternative initially appeared to be more competitive with the others in terms of sustainability, but the cause-effect analysis carried out with FDEMATEL allowed identification of fundamental reasons preventing its implementation on a larger scale at the moment. That was affected by assessment criteria regarding recyclability, design life and resilience to disruptive events, as well as prefabrication, level of complexity and investment costs (criteria: A3, B1, B2, C1, C4 and D1). This is due to the implementation of a relatively new technology for which the manufacturers of such structures are not yet prepared, but also to the lack of qualitative and quantitative testing of such girders to confirm their suitability for use over the expected service life of at least 100 years.

Results obtained with the hybrid and the EA FAHP methods show that they converge in terms of ranking. The difference lies in the change of places of the highly ranked G2 and G3 alternatives to second and third place (Fig. 7). These results only partly correspond to the trend prevailing e.g. in Poland, for the construction of medium span bridges, i.e. in the 15–25 m range. This is affected by a number of factors, including the ongoing, early stage of implementation of environmentally friendly solutions, etc. At the same time, it should be borne mind that some of the parameters assessed in the example analysed (e.g. disposal of non-renewable materials, conditions of use, etc.) may change over time. At the same time, this confirms a need to carry out such analyses for a similar set of parameters in order to observe trends in the changes taking place.

5. Conclusions

In order to solve complex decision problems concerning the selection of optimal bridge material and structural alternatives, a tool to assist designers has been proposed in a form of aggregated MCDA algorithm based on EA FAHP + FDEMATEL + ZUM methods. Ranking in a form of triangular fuzzy numbers have been applied which allows to consider uncertainty, group judgements and the correct interpretation of linguistic judgements, often used in this type of issues. An analysis has been made for selection of main girders in a sample span of a road bridge, taking into account factors affecting the sustainability of the structure construction process.

The main features of the proposed model include:

- transparent control of the variability of the cause-effect relation judgement over time;
- HCS that allows quick adaptation of the algorithm to changes in technical requirements and market conditions;
- ability to incorporate non-standard solutions, e.g. composite girders, into the design process;
- versatility in application for other types of building structures.

In addition, the use of systematic evaluation measures that take into account variable aspects in the proposed hybrid method allows to define a so-called utility function, leading to identification of constraints and the analysis of their intensity. The most significant contribution of this research is consideration of interactions between the criteria. They demonstrate invariance over time, achieved as a long-term effect through aggregation of judgements. This has been demonstrated by comparing the hybrid and single EA FAHP methods.

Based on the case study for the selected road bridge structure, the composite girder with rolled steel beams (G4), has been found to be the most advantageous. That was affected by rating obtained from the following criteria: environmental (A) – rank 1, safety and sustainability (B) – rank 2, technological (C) – rank 2 and economic (D) – rank 3.

Implementation of the model in question may result in economic benefits in terms of construction and maintenance costs. Disadvantages of the method include, among others, a need for the DM teams to generate a large number of judgements of criteria and alternatives, obtain their weights. It is therefore proposed to focus on the creation of a database that will allow the refinement of the evaluation measures with a larger team of experts and improvement of the criteria evaluation methods.

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Analiza wybranych konstrukcji mostowych z zastosowaniem hybrydowej metody decyzyjnej

Słowa kluczowe: dźwigar, model hybrydowy, most, optymalizacja wielokryterialna, przęsło

Streszczenie:

Celem artykułu jest opracowanie oryginalnej metody MCDA, jako narzędzia wspierającego proces podejmowania decyzji przy wyborze wariantów materiałowo-konstrukcyjnych mostowych dźwigarów głównych. W związku z tym stworzono zaawansowany algorytm hybrydowy, składający się z metod EA FAHP + FDEMATEL + MUZ (Metoda Unitaryzacji Zerowanej), stosowany na etapie projektowania konstrukcji. Rozpoznanie literatury z przedmiotowego zagadnienia wskazuje na brak publikacji .Wybrane do celów analizy, uprzednio zwymiarowane warianty zostały następnie poddawane procesowi oceny na podstawie złożonego zbioru kryteriów, transponowanych na sterującą strukturę hierarchiczną (HCS). Aplikację algorytmu wykonano na przykładzie mostu płytowo-belkowego o średniej rozpiętości przęsła, przyjmując 6 alternatywnych koncepcji dźwigarów. Uzyskane wyniki analizy, porównane z metodą EA FAHP wskazują na efektywność proponowanego algorytmu oraz jego aspekt praktyczny, mogący się przyczynić do podniesienia jakości i bezpieczeństwa konstrukcji mostowych. Do głównych cech proponowanego modelu należy zaliczyć: strukturę sterującą HCS, umożliwiającą szybkie dostosowanie algorytmu do zmian wymogów technicznych i uwarunkowań rynkowych, możliwość uwzględnienia w procesie projektowania nietypowych rozwiązań, np. dźwigarów kompozytowych, uniwersalność w zastosowaniu dla innych rodzajów konstrukcji budowlanych. Za najbardziej znaczący wkład niniejszych badań uznano uwzględnienie interakcji pomiędzy kryteriami. Charakteryzuje je niezmienność w funkcji czasu, osiągana jako efekt długoterminowy dzięki agregacji ocen.

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