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1. Introduction

In building production engineering, embracing building investments management and building maintenance, building company management, building processes control, and building materials engineering [1]:

- decision problems occur where various alternatives are assessed, taking into consideration a specific number of criteria;
- specific complications occur while those problems are solved;
- there is a need for accepting such calculation procedures, which would allow incorporating the decision-maker's preferences to a maximum extent;
- instances of inaccuracy, imprecision, and vagueness must be taken into account while analysing the decision problems.

The decision-makers feel the need for applying procedures allowing an extensive comparison and reliable assessment of the accepted alternatives.

Satisfying those needs is much easier thanks to the methodology and methods of multicriteria decision-aid (MCDA).

The article presents a situation whereby the decision-maker is confronted with a problem of multicriteria assessment and final ranking of the compared alternatives of solutions concerning the chosen structures and designs of a road surface feasible under specific Polish conditions.

Poland has recently begun the implementation of the Motorway Construction Programme. For years we have been hearing debates, whether the road surface of Polish motorways should be asphalt (yielding, partially rigid) or concrete (rigid) [2, 3]. In principle, it is impossible to give one good answer as to which road surface type is best. The choice of the construction type for a specific length of a motorway depends on a number of factors, such as the intensity of traffic, weather and climate, feasibility of using local building materials and so on.

2. A short characteristic of the MCDA methodology and methods of multicriteria analysis

Within the area of the MCDA methodology, a number of basic notions can be identified, such as:

- aiding decisions,
- participants of the decision process,
- types of problem statements of multicriteria decision-aiding,
- modelling preferences,
- aggregation of preferences.

All notions have been defined in [4].

Aiding decisions helps designing, building, and strengthening a conviction, but is not a means for pointing at the optimum character of a decision, or a way of dictating which decision should be taken.

The MCDA methodology clearly identifies the participants of the decision-aiding process, and defines their roles and share in this process. Most often, it is the decision-maker and the analyst who are participants in this process. The decision-maker's role is crucial here: he defines the targets, gives estimates on possibility and results, expresses preferences and makes attempts to adjust the process of surfacing the decision to best suit those preferences. The analyst, by nature external to the problem to be solved and to the decision process, handles the decision-aiding process. His role is, among other things, to present a model and use it in arriving at elements constituting the answer, to explain the consequences of that or other behaviour or moves to the decision-maker and, perhaps, to recommend an action or a series of actions, or even a specific methodology to the decision-maker.

Another important issue in the decision-aiding is situating the multicriteria decision problem in relation to one of the four basic problems statements of aiding decisions which facilitate the description of decisions as targets to be aimed at. The following problem areas have been named: aiding multicriteria choice, sorting, ordering, and description.

Other important elements constituting the decision-aiding process are: modelling preferences and formulation of a global model of preferences (preference aggregation).

Modelling preferences in decision-aiding extensively uses the possibility of occurrence of different decision related preferential situations. Therefore, the systems of relational preferences and relational structures of preferences that are their counterparts (much richer than those in the classic decision theory) and are more varied. A system based on binary outranking relation is the most typical example of a relational system of preferences, placing itself within the framework of the discussed methodology.

The MCDA methodology gave way to introducing new models of aggregating, for example, a procedure of aggregating preferences based on the binary outranking relation, a procedure of aggregating preferences based on the local dialogue type assessment.

Within the framework of methodology under discussion, two basic groups of methods can be identified. The division stems from the mode of aggregation: global aggregation is reflected by multicriteria analysis methods, whereas local aggregation is reflected by dialogue methods, sometimes called interactive. The same groups of methods can be identified from the point of view of the character of a set of alternatives.

Methods of multicriteria analysis are used in solving multicriteria decision problems when the set of alternatives is known and well defined at the very beginning of the decision process (the set of alternatives is discrete). The criteria are also directly defined. Additional characteristic notions, typical for methods of multicriteria analysis, are as follows:

- a potential alternative,
- a coherent family of criteria,
- criteria discriminating thresholds,
- a concept (a model) of pseudo-criterion,
- incomparability of alternatives.

All notions have been defined in [4].

3. The choice problem of an appropriate calculation methods, classified as one of multicriteria analysis methods

The selection of an appropriate calculation method, classified as one of the multicriteria analysis methods, can be based on the procedure of multicriteria decision-aiding process, proposed in [5]. The procedure in question facilitates the proper collaboration between the analyst and the decision-maker in the process of multicriteria decision-aiding, and helps overcome difficulties which may come up at the stage of the problem description, as well as select the right method and use it in solving the problem. The procedure has been developed for the type of context in which the process of aiding decisions is targeted at arriving at the final order of all alternatives under comparison (accepting the rank - problem statement of multicriteria aiding). The accepted rank - problem statement of multicriteria aiding is most often used in solving decision problems containing a well defined initial set of alternatives (the amount of alternatives is known). The majority of methods using different items of information on the preferences of a decision-maker have been initiated within this problems statements. Therefore, the selection of the right method in decision-aiding is complicated, the more so that, simultaneously, what needs to be accounted for, is the suggestions and possible recommendations of the analyst, the decision-maker's requirements, and the possibilities of describing his preferences. The procedure, which is proposed, consists of the following stages:

- first stage (I): initial briefing,
- second stage (II): description of the decision-aiding problem,
- third stage (III): selection of the method of multicriteria decision-aiding to solve the analysed problem,
- fourth stage (IV): using the method applied in solving the decision problem.

The most important stage is stage III, focusing on the selection of an appropriate calculation method. It is this stage that is largely decisive about the right solution of the problem, about arriving at the solution in the shortest possible time, and about the trust that the decision-maker places in the analyst, as well as about the acceptance of the final result by the decision-

-maker. The basis of selection of the most appropriate method is constituted by the decision scheme, designed with that purpose in mind, and by the rapport, based on that scheme, between the analyst and the decision-maker [5]. The analyst, at that stage, must help the decision-maker find the right manner of modelling and defining preferences. Furthermore, the selected method should meet certain expectations of the decision-maker related, for example, to the form of the final results, or to other factors which may come up during the rapport between the analyst and the decision-maker.

4. An example of solving multicriteria decision problem

The decision problem being solved refers to the multicriteria assessment and final ranking of the selected alternatives of possible road surface structures and designs which can be practically implemented in the course of construction of a particular section of a motorway under Polish conditions.

4.1. Description of the decision problem

Types of road surface construction

Four alternatives of the designed road surface structures have been used in the analysis. Alternative I and II use asphalt concrete in the top layer (the flexible and semi-rigid construction), and alternatives III and IV - use a cement concrete construction (the rigid construction).

The following is a description of layers in the road surface alternatives:

Alternative I – a flexible construction:

- 0/20 asphaltic concrete abrasive layer, 5 cm thick,
- 0/25 asphaltic concrete binding layer, 9 cm thick,
- 0/31,5 asphaltic concrete base, 12 cm thick,
- 0/31,5 mechanically stabilised crushed aggregate bed, 37 cm thick (laid and condensed in two layers),
- technological layer (working platform), cement stabilised soil, R_m = 2,5 MPa 10 cm thick.

Alternative II – a semi-rigid construction with an anti-crack layer:

- 0/20 asphaltic concrete abrasive layer, 5 cm thick,
- 0/25 asphaltic concrete binding layer, 8 cm thick,
- 0/31,5 asphaltic concrete base 5, 12 cm thick,
- 0/31,5 mechanically stabilised crushed aggregate anti-crack layer, 12 cm thick,
- R_m = 5,0 MPa cement stabilised aggregate bed, 18 cm thick,
- technological layer (working platform), cement stabilised soil, R_m = 2,5 MPa 10 cm thick.

Alternative III – a rigid construction:

- B40 cement concrete slab, 24 cm thick,
- lean concrete layer, 15 cm thick,
- R_m = 2,5 MPa cement stabilised aggregate bed, 15 cm thick,
- technological layer (working platform), cement stabilised soil, R_m = 2,5 MPa 10 cm thick.

Alternative IV – rigid construction, continuous reinforcement:

- B40 concrete slab, continuously reinforced, (reinforcement percentage: μ = 0,67%), 20 cm thick,
- lean concrete layer, 15 cm thick,
- R_m = 5,0 MPa cement stabilised aggregate bed, 15 cm thick,
- technological layer (working platform), cement stabilised soil, R_m = 2,5 MPa 10 cm thick.

Determination of a coherent family of criteria

The assumed alternatives have certain characteristic attributes which, within the scope of the analysed problem, play directly the role of evaluation criteria. The following criteria have been taken into consideration:

- the cost of building 1 m^2 of a given type of road surface in PLN, criterion 1 – crit. 1,
- the cost of work involved in maintaining 1 m^2 of motorway surface in good technical condition over 20 years of service (the cost depends on the amount and kind of maintenance work carried out in this period of time) in PLN, criterion 2 - crit. 2,
- inconvenience for drivers and traffic delays in the phase of actual usage of the motorway related to periodical maintenance work and repair to the motorway surface, criterion 3 - crit. 3,
- calculated durability of the road surface construction expressed in years, criterion 4 – crit. 4,
- feasibility of using local material in the period of building the motorway, criterion 5 – crit. 5,

- road surface resistance to cracks and permanent deformations, criterion 6 – crit. 6,
- the time of building of 1 m² of a given type of motorway surface [machine-hour], criterion 7 – crit. 7,
- environmental impact when the motorway is under construction, criterion 8 – crit. 8,
- traffic noise [dB] (values assumed for a dry surface), criterion 9 – crit. 9.

A description of the motorway surface types, including all the assumed criteria, has been presented in Table 1.

There is an interesting aspect of the problem which has been analysed, namely – within the framework of the alternatives in question – accounting at the same time for the criteria related to the phase of actual building of the motorway surface, and the criteria related to the phase of service of the surface.

Due to the character of the criteria themselves, it is possible to make an evaluation of the road surface alternatives basing on some quantitative or qualitative scales assumed for those criteria.

Table 1. Data describing the types of compared road surfaces on the motorway

Criteria	Alternative I	Alternative II	Alternative III	Alternative IV
Criterion 1 (construction costs)	130 PLN/m²	110 PLN/m²	160 PLN/m²	160 PLN/m²
Criterion 2 (cost of maintenance work)	replacing the abrasive layer every 5 years (3×10 = 30 PLN/m²)	replacing the abrasive layer every 5 years (3×10=30 PLN /m²)	filling in the cracks every 5 years (3×13 = 39 PLN/m²) and surface retreating every 8 years (2×6 = 12 PLN/m²)	filling in the longitudinal cracks every 5 years (50%×3×13 = 19,5 PLN/m²) and surface retreating every 8 years (2×6 = 12 PLN/m²)
Criterion 3 (traffic delays caused by maintenance work)	temporary closure of 1 lane (3 times in 20 years)	temporary closure of 1 lane (3 times in 20 years)	temporary closure of 1 lane (3 times in 20 years) and temporary closure of 1 lane (2 times in 20 years)	temporary closure of 1 lane (3 times in 20 years) and temporary closure of 1 lane (2 times in 20 years)
Criterion 4 (calculated durability of road surface)	20 years	20 years	30 years	30 years
Criterion 5 (feasibility of using local building materials)	0 cm / 63 cm=0 (0%)	18 cm / 55 cm=0,33 (33%)	15 cm / 54 cm=0,28 (28%)	15 cm / 50 cm=0,30 (30%)
Criterion 6 (surface resistance to cracking and permanent deformation)	average resistance to permanent deformation, considerable resistance to cracking	average resistance to permanent deformation, considerable resistance to cracking	considerable resistance to permanent deformation, average resistance to cracking	considerable resistance to permanent deformation, considerable resistance to cracking
Criterion 7 (the time of building 100 m² of the road surface)	12,7 machine-hour	9,1 machine-hour	17,0 machine-hour	15,4 machine-hour
Criterion 8 (environmental impact during the actual building of the motorway surface)	occurrence of 3 harmful factors: dust, aromatic compounds filtering through to the air at high temperatures, soil and ground water pollution	occurrence of 3 harmful factors: dust, aromatic compounds filtering through to the air at high temperatures, soil and ground water pollution	occurrence of 1 harmful factor: dust	occurrence of 1 harmful factor: dust
Criterion 9 (traffic noise; mean values for dry surface)	77 dB(A)	77 dB(A)	82 dB(A)	82 dB(A)

Table 2. Evaluation table – an overview of alternatives of the motorway surface structur

Criteria / Type of road surface	crit. 1 [PLN/m²]	crit. 2 [PLN/m²]	crit. 3 [points]	crit. 4 [years]	crit. 5 [-]	crit. 6 [points]	crit. 7 [m-h]	crit. 8 [points]	crit. 9 [dB]
Alternative I	130	30	3	20	1	3	12,7	4	77
Alternative II	110	30	3	20	0,67	5	9,1	4	77
Alternative III	160	51	8	30	0,72	3	17,0	2	82
Alternative IV	160	31,5	5	30	0,70	1	15,4	2	82

The qualitative scales (discrete values) should be properly designed, on the assumption that the separated states may be equivalent to certain integers.

The grades in the assumed scales (both quantitative and qualitative) constitute a total order reflecting the character of preferences (where the preferences grow with the increase in value), we call the scale an increasing scale – a „profit" type criterion. And where, on the other hand, preferences diminish alongside with the increase of value, we call the scale decreasing one – a „cost" type criterion. It has been assumed that the criteria are monotonous, non-decreasing functions. A function, as defined for the qualitative scales, is a more arbitrary concept.

Regarding the criteria: the cost of building 1 m² of road surface expressed in PLN – crit. 1, the cost of work involved in maintaining 1 m² of motorway surface in good technical condition expressed in PLN – crit. 2, the calculated durability of the road surface construction expressed in years – crit. 4, feasibility of using local material in the motorway building period – a quantity without denomination – crit. 5, the time of building 1 m² of the road surface, expressed by the machine/hour rate (calculated on the basis of the Catalogue of Work Loads KNR 2-31 [6]) – crit. 7, traffic noise [dB] (values for a dry surface have been taken directly from [3]) – crit. 9, the evaluation of alternatives is made on the basis of quantitative scales (the scale of money, of time and of volume – a coefficient of the percentage share of local building materials with regard to the total amount of building materials in the total vertical cross-section of the layers of road surface, the noise level). This is why the values have been taken directly from Table 1 and transferred to the evaluation table (Table 2), with the only exception being criterion 5, whose values quoted in Table 2 were calculated by the formula of: $1 - U_{mm}$ (a quantity without denomination), where U_{mm} signifies a % share of local building material used in the motorway construction.

A basis for evaluation of the remaining criteria shall be the properly defined qualitative scales, which are described in [7].

Designing an evaluation table

Basing on the assumed solutions regarding the structure of the motorway surface (selected alternatives), and the criteria (all criteria have been taken into account), an evaluation table has been compiled (Table 2) which includes the values available for the criteria in the compared alternatives. The values for the qualitative criteria have been arrived at on the basis of Table 1, and on the data in [7]. The following criteria: crit. 1, crit. 2, crit. 3, crit. 5, crit. 6, crit. 7, crit. 8 and crit. 9 are the „cost" type criteria, whereas criterion 4 (crit. 4) is a „profit" type criterion. The evaluation table represents the conclusion of the problem and is a starting point for further analysis related to the full spectrum evaluation of the compared alternatives of the motorway surface structure, accounting for the criteria which have been originally assumed.

4.2. Selection of the most appropriate multicriteria decision-aid method

Justification of the feasibility of using the MCDA methodology in solving the analysed problem

It was only possible to describe the problem, the way it was done in paragraph 4.1. due to a close cooperation between the analyst and a decision-maker. They both are crucial players in the decision-aid process. Pointing at their individual roles is part of the MCDA methodology. What should be stressed is that a decision-maker was a technology specialist representing a prospective investor. There is a set of potential alternatives within the problem [4]. Each alternative is described by means of values associated with individual criteria. The assumed family of criteria is coherent [4]. From the mathematical standpoint, the problem is poorly defined. Only on the basis of: additional information about the preferences of the decision-maker, assuming a manner of modelling the said preferences, and application of a calculation procedure which enables one to carry out a thorough comparison and a final evaluation of all the alternatives, it is possible to solve the problem. It has been assumed that a target of the comparative analysis in question shall be arriving at the final ordering of the alternatives, from the most to the least favourite. The data used to define the values of the criteria for the alternatives are not absolutely accurate, and this fact is significant in modelling the decision-maker's preferences. The values of a number of criteria are not exactly precise, and this is a result of lack of precision and arbitrariness of the assumed qualitative scales that describe the criteria. That is why, during the comparison of any two alternatives, the decision-maker may want to refrain from expressing an opinion regarding preferences solely on the basis of the fact that, regarding certain alternatives, the values for a criterion may be different (preference) or equal (equality). The decision-maker may, on the other hand, want to stress that the compared alternatives are not equal, and neither of the alternatives is preferred (a situation of weak preference). In such circumstances, a concept of a pseudo-criterion may be used [4]. It facilitates modelling the following situations: equality, weak preference, and ordinary preference by means of introducing indifference and preference thresholds.

All the issues discussed above are characteristic of the methodology of multicriteria decision-aid. The fact that those issues were present in the problem in question, influenced the decision to assume the methodology and to select an appropriate calculation and computation methods which also constitute a part of multicriteria analysis.

Selecting an appropriate calculation method

Using the procedure proposed in [5], and basing on the dialogue with the decision-maker (which in itself is part of the procedure), the ELECTRE III method was chosen. This method:

- accounts for the lack of precision and accuracy of the values describing the criteria;
- gives a decision-maker a degree of freedom in submitting information on preferences regarding individual criteria in the form of indifference and preference thresholds, using the pseudo-criterion model and the veto threshold, as well as information regarding relative significance of individual criteria;
- allows the presentation of the final result in the form of an outranking final graph, defining the outranking levels and placing the compared versions on specific levels.

Description of the selected MCDA method

The ELECTRE III method is based on the binary outranking relation [8]. In this method, the basic set of data consists of the following: a finite set of alternatives, a family of criteria, and information submitted by the decision-maker. This information constitutes indifference thresholds, preference thresholds, and veto thresholds for individual criteria (the thresholds may be constant or take the form of a linear function [8]), as well as the relative significance of the defined criteria. The veto threshold facilitates accounting for the situation of the so-called strong opposition regarding a given criterion. The result of going above the threshold is that, while the first of the compared alternatives is better than the other from the point of view of many criteria, it is impossible to assume a hypothesis that the first option outranks the second. The outranking relation in the ELECTRE III method is built on the basis of the so-called concordance and discordance tests. The values of outranking relations, arrived at as a result of a computation procedure, inform the user about the degree of credibility of occurrence of those relations for all pairs of compared alternatives. The final result, in this method, is an outranking graph which stems from a cross between two preliminary total orders built by means of the so-called distillation procedure [8]. Basing on the interpretation of the final result, the decision-maker may accept the form of the outranking graph, or modify the initial information about preferences.

4.3. Using ELECTRE III in solving the problem

Input data assumed for the calculation constitutes the basic values displayed in Table 2 (the evaluation table). All compared alternatives and criteria have been accounted for during the computation. The information about the decision-maker's preferences – the provided threshold values (threshold functions) and the values of relative significance of criteria have been compared in Table 3.

The decision-maker's experience was a basis for evaluating the alternatives at hand, and it was implemented by providing the information about the decision-maker's preferences, obligatory in the chosen computation method.

It has been assumed that the threshold values shall be constant for all criteria. Regarding the criteria described by qualitative scales, it has been assumed that the indifference threshold shall be zero (the decision stems from the arbitrariness of the assumed grades on the scale). The values of relative significance of the criteria indicate that what is most important for the decision-maker: the cost of building 1 m² of motorway surface, the calculated durability of the motorway surface, and surface resistance to cracking and permanent deformations.

The computation has been made, basing on the input data (Table 2), and on the information about preferences of the decision-maker (Table 3), using the „ELECTRE III" software.

4.4. The analysis of the final ranking

An outranking final graph was a basis for comparison of the debated alternatives of chosen types of construction of the motorway surface. The graph presented in Fig 1 constitutes a final ordering tool in the ELECTRE III method. The first (top) outranking level in the graph is taken by the semi-rigid tape of road surface, with roadway surfaces made from asphaltic concrete (Alternative II). This alternative outranks all other alternatives. The second outranking level in the graph is occupied by the rigid construction, with continuous reinforcement (Alternative IV), outranked by the first level solution, and outranks the remaining two alternatives. The last (bottom) second outranking level in the graph is occupied by the cement concrete construction (Alternative III), outranked by the remaining alternatives. The semi-rigid alternative was so highly rated because it is inexpensive to build, and economical to maintain in good technical condition, while the percentage of usage local building material at the time of actual construction of the motorway is high, and the

Table 3. Information about decision-maker's preferences required by the ELECTRE III method

Information about decision-maker's preferences Criterion	indifference threshold	preference threshold	veto threshold	relative significance of a criterion
the cost of building 1 m² of the road surface [PLN/m²]	5	15	60	10
the cost of maintenance within 20 years of usage of the road surface [PLN/m²]	5	10	30	6
assessment of traffic delays during the time of usage due to periodical repair work done to the motorway surface [points]	0	1	–	4
the calculated durability of the road surface construction [years]	5	10	20	8
the feasibility of using local materials in the phase of motorway construction (no denomination)	0.05	0.15	0.60	3
surface resistance to cracking and permanent deformation [points]	0	1	7	7
the time of building 1 m² of the road surface [m-h]	1	2	10	3
environmental impact in the phase of building the motorway surface [points]	0	1	–	4
traffic noise [dB]	1	3	9	5

traffic delays at the stage of service of the motorway related to maintenance are the shortest, and it is the quickest to build. On the other hand, the low score given to the cement slab surface resulted mainly from the high cost of building such a motorway surface, high maintenance costs, long traffic delays while the motorway is in use, it would take the longest to build, and the traffic on such a motorway would be extremely noisy.

FINAL GRAPH

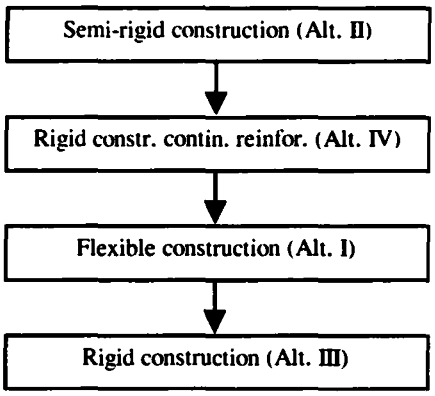

Fig 1. The final ordering of the compared solutions of motorway surface in ELECTRE III method - an outranking graph

Basing on the evaluation table, the credibility matrix, the outranking graph, and information about the decision-maker's preferences, the best solution has been selected, namely the semi-rigid asphaltic concrete construction, as well as the second best, namely the reinforced concrete road surface alternative, and the satisfactory alternative, namely asphaltic concrete flexible road surface alternative and, finally, the worst alternative has been named, ie the cement concrete surface.

4.5. Sensitivity analysis of the final result

Sensitivity analysis is understood to be the influence of the change of values quoted with regard to parameters which include the information about the decision-maker's preferences on the form of the final result (various methods use different parameters reflecting the decision-maker's preferences). It is quite useful in interpreting the results, which have been arrived at, in the course of modifying the values of the appropriate parameters reflecting the decision-maker's preferences, and in estimating the influence of the modifications on the final result.

Within the framework of the analysed problem, the analyst suggested a sensitivity analysis of the final outranking graph that had been arrived at. The decision-maker has quoted some changes in values, which he accepted, with relation to the chosen parameters reflecting his preferences (minimum and maximum values for a specific parameter). In the course of the sensitivity analysis, the decision-maker was not interested in taking into consideration simultaneously the influence of changes in values of relative significance for a single criterion, or for a number of criteria and the changes in threshold values, ie the indifference thresholds (q), preference thresholds (p), and veto preference thresholds (v) for a single criterion or for a number of criteria. What follows is the result of the sensitivity analysis performed depending on the range of changes of the selected parameters reflecting the decision-maker's preferences (the arrangement of the initially assumed preliminary values for all parameters is illustrated in Table 3). Only selected examples of those changes have been presented for individual ranges of change, and the final ranking form.

1. The influence of the change in value of the relative significance introduced only for individual criteria in the initially assumed arrangement of values which had been accepted by the decision-maker – see Table 3 (values of threshold functions: the q, p, and v thresholds remain unchanged – compare Table 3):
   - changes of values of relative significance for the criterion of feasibility of utilising local materials (crit. 5), reducing the significance from 3 to 2 or, regarding crit. 6, the increase in significance from 7 to 8 influenced the form of the final graph of outranking. The same form of final ordering arrived at in that way in all cases has been presented in Fig 2.

2. The influence of changes in values of relative significance introduced simultaneously for a larger number of criteria in the initially assumed and accepted arrangement of values of the relative significance of criteria – see Table 3 (values of threshold functions: the q, p, and v thresholds remain unchanged – compare Table 3):

- changes in values of relative significance introduced for a number of criteria simultaneously, for example, for criterion 1 decreasing the significance from 10 to 9, for criterion 2 increasing the significance from 6 to 7, and for criterion 3 increasing the significance from 4 to 5. Those changes have not influenced the form of the final graph of outranking. The form of the final ranking, arrived at in this case, has been presented in Fig 2.

FINAL GRAPH

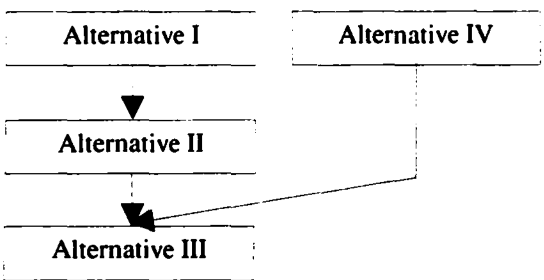

Fig 2. The form of the outranking graph, part of ELECTRE III method, derived from sensitivity analysis within ranges 1 and 2 of changes in values of chosen parameters regarding information on the decision-maker's preferences

3. The influence of changes in threshold functions (for q, p, and v thresholds), introduced for a single criterion only, in the arrangement of values of threshold functions, defined separately for each criterion, initially assumed and accepted by the decision-maker, see Table 3 (the values of the relative significance for all criteria remain unchanged – compare Table 3):

- changes in values of threshold functions – for criterion 1 increasing the value for threshold q from 5 to 8, for threshold p from 15 to 18, for threshold v from 60 to 80, have resulted in the form of the final graph of outranking, as presented in Fig 3.

4. The influence of changes in threshold functions (for q, p, and v thresholds), introduced for a number of criteria simultaneously, in the arrangement of values of threshold functions, defined separately for each criterion, initially assumed and accepted by the decision-maker, see Table 3 (the values of the relative significance for all criteria remain unchanged – compare Table 3):

- changes in threshold (for q, p, and v thresholds) introduced for a number of criteria simultaneously, for example, for criterion 1 increasing the value for threshold q from 5 to 8, for threshold p from 15 to 18, and for threshold v from 60 to 80, for criterion 2, reducing the value for threshold q from 5 to 3, for threshold p from 10 to 6, and for threshold v from 20 to 18, whereas there was only one change for criterion 5, namely increasing the value of threshold p from 0.15 to 0.20, for criterion 6 increasing the value of threshold q from 0 to 1, for threshold p from 1 to 2 (with threshold v remaining unchanged), for criterion 7, increasing the value of threshold q from 1 to 15, for threshold p from 2 to 2.5, and reducing the value of threshold v from 10 to 9, for criterion 9, reducing the value of threshold q from 1 to 0, for threshold p, reducing the value from 3 to 2, and for threshold v, from 9 to 8, resulted in the form of the final graph of outranking, as presented in Fig 3.

FINAL GRAPH

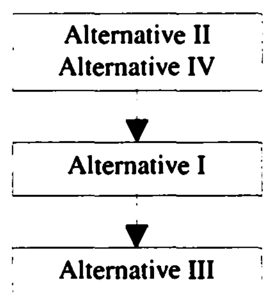

Fig 3. The form of the outranking graph, part of ELECTRE III method, derived from a sensitivity analysis within ranges 3 and 4 of changes in values of chosen parameters regarding information on the decision-maker's preferences

After performing sensitivity analysis the decision-maker relates to obtained results.

Regarding the case of introducing the change of value of the relative significance only for individual criteria and in case of change in values of the relative significance of criteria introduced simultaneously for a larger number of criteria, in the initially assumed and accepted arrangement of values of relative significance of the criteria (see Table 3) which influenced the form of the final graph of outranking (see Fig 2), the decision-maker, basing on the analysis of the evaluation table and the table containing information on his preferences, did not accept this particular form of the final result. As to cases of introducing changes in values of threshold functions, both for a single criterion and for a number of criteria at the same time (in the arrangement of values of threshold functions defined separately for each criterion, initially assumed and accepted by the decision-maker – see Table 3) (compare the ranges 3 and 4 of changes in the sensitivity analysis) which influenced the final form of the graph of outranking (the graph which has been arrived at is presented in Fig 3), the decision-maker, having taken into consideration the values from the evaluation table and the table containing information about his preferences, has finally accepted the form of the final result. He agreed with the fact that, in both cases, the alternatives of solutions of the design and structure of semi-rigid road surface with an anti-crack layer, and a rigid surface with continuous reinforcement may be considered as the best and equal. Nonetheless, the choice of either of those will always be a compromise. If alternative II of the road surface were accepted, economic criteria would support the choice (crit. 1 and crit. 3), ie the criteria of time and of noise pollution. On the other hand, if alternative IV of the road surface were accepted, such a choice would be supported by the practical usage criteria (related to the usage of the motorway), ie the criterion of calculated durability and road surface resistance to cracking and permanent deformation, and the natural environment related criterion, valid during the construction stage of the selected section of the motorway.

Basing on the sensitivity analysis, it is possible to formulate a following conclusion: the decision-maker is able to accept also a different form of the final ranking. It is, nonetheless, possible when the influence of the introduced changes on the final result can be justified, and when the form of this result changes only slightly, compared to the final ranking accepted by the decision-maker before the sensitivity analysis has been performed (see Figs 1 and 3)

The sensitivity analysis of the final result has shown that it is very important for the decision-maker to make sure that his conviction is strong as to the values provided by him for particular parameters which include information about his preferences (see Table 3) and, consequently, that the final result form is credible.

Within the framework of the method accepted, the decision-maker has made a judgement that the interpretation of the final result, the coherence of the result with his preferences, the easy availability of identifying information which may influence the final result, and the way of modifying this information fully reflected his expectations. The decision-maker was not interested in defining the "distances" between alternatives within the final ranking.

This was the end of the procedure of incorporating ELECTRE III and using this method for solving of the analysed decision problem, and the whole the decision-aiding process.

5. Final conclusions

1. Decision-makers tend to fully accept incorporating multicriteria analysis methodology into the process of solving decision problems, notwithstanding the fact that such methods are not fully formalised from the mathematical point of view. Nevertheless, they make room for a variety of information regarding the decision-makers' preferences.

2. Thanks to the ELECTRE III method of multicriteria decision-aid it was possible to make a full spectrum assessment of the assumed alternatives of motorway surface layers, simultaneously taking into consideration certain technological, economical, and practical usage aspects of the problem, and to point at the alternatives which may be regarded as the best.

3. The practical usage result is in keeping with the preferences of the decision-maker. The form of the final result - an outranking graph - and intermediate results is comprehensible and clear for the decision-maker.

4. The solution of the analysed problem is a basis for the statement that the methods of multicriteria decision-aid should be widely applied in the phase of investment planning and construction projects in the building production industry, as well in the phase of initial design (feasibility study).

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DAUGIATIKSLIŲ SPRENDIMŲ METODŲ TAIKYMAS PROJEKTUOJANT STATINIUS

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Santrauka

Glaustai pateikiamos pagrindinės daugiatikslės sprendimų teorijos taikymo problemos ir klausimai, susiję su tam tikrais daugiakriterinės analizės metodais. Aptarta sprendimų priėmimo, vadovaujantis nagrinėjamų sprendimų (kelio dangos projektiniai pasiūlymai) alternatyvų eiliškumu (nuo geriausios iki blogiausios), problema. Analizei pasirinktos sprendimų alternatyvos gali būti pritaikytos, atsižvelgiant į Lenkijos ypatybes. Skaičiavimams buvo pasirinktas daugiakriterinės analizės metodas ELECTRE III, kurį taikant galima nustatyti alternatyvų eiliškumą. Lyginamų alternatyvų galutinė prioritetiškumo eilė nustatoma, atsižvelgiant į jautrumo analizės rezultatus, pasirinkto skaičiavimo metodo rezultatus ir sprendėjo nuomonę. Siūlomas problemos sprendimo būdas rodo, kad daugiatikslė sprendimų teorija ir daugiakriterinės analizės metodai gali būti taikomi investicijų planavimo ir projektinių pasiūlymų etapais.

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