

Multicriteria analysis in planning roads – Part 1. Criteria in determining the alignment of regional roads

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Abstract. The article presents the criteria taken into account in determining the alignment of regional roads, with particular reference to bypasses of towns located along regional roads. To determine the criteria for the evaluation of variants and their hierarchy, the surveys were conducted using the Delphi method in two rounds, with electronic surveys (the CAWI method). Based on survey studies, an entry list of criteria was set up as a proposal for determining the alignment of regional roads.

Key words: criteria, Delphi method, CAWI method, entry list.

1. Introduction

The transport policy of each region is connected with the necessity of improving the internal and external accessibility, understood as a decisive factor in the attractiveness, from both economic and touristic viewpoint. Apart from connecting the province or region to the national transport network, there is a need for the improvement of the connections between the most important towns in the region and subregional towns.

The basic road network of each province comprises national and regional roads. Regional roads complement the national roads and usually connect county capitals or are linkages between national roads. The majority of regional roads transfer economic traffic, as well as tourist and recreational traffic.

Regional roads in many cases pass through towns, in the vicinity of housing. Terrain limitations and thick housing make it impossible to use efficient solutions in order to fulfil the environment conservation requirements. In such cases, bypasses of towns are constructed, and the first step in this process is the preparation of design documentation of such investments. The issue at this stage, similarly to national roads, is the comparison of variants of road alignment of the designed road and the selection of the most beneficial solution ensuring the transport of people and objects, which would at the same time fulfil the requirements of environment conservation and the protection of health and lives of the inhabitants.

In general, the variant assessment criteria can be divided into the following groups: transport, environmental, economic and social [1–5]. The division of the main criteria in planning the road alignment is very diversified and depends to a large extent on the location of the investment and the class of the analysed road.

In multicriteria analyses measurable criteria are taken into account (quantitative), as well as unmeasurable (qualitative) and those classified as two-stage (state of 0, 1). In the case of qualitative variables, quantification must be conducted first, followed by normalization [6–10]. Individual criteria in this decision process are assessed as maximising (stimulants), minimising (destimulants) and nominants. The criteria chosen for the analysis should fulfil the requirements of: assessment exhaustion, cohesion and non-redundancy [11].

The problem of selecting the most beneficial road alignment variant with the use of multicriteria analysis was presented in two articles. This paper (Part 1) discusses the entry criteria list as a proposal for variant assessment. Part 2 presents the methodology for assessing the analysed variants based on the aggregation of the marks obtained for the normalization and assessment methods.

2. Criteria for the assessment of variants

The shaping of road alignment is a multicriteria issue and requires taking into account transport, economic, environmental and social criteria. This article presents the criteria taken into account while determining the alignment of public roads, with special focus on bypasses of towns located in the path of regional roads. The choice of assessment criteria depends to a large extent on the location of the investment and the functional-technical class of the analysed road. In order to be able to determine the variant assessment criteria and their hierarchy in transport issues, surveys are often used. In literature, heuristic approaches are the most common, i.e. expert approaches.

Heuristic methods are often used in predicting and in decision-making processes. Heuristic methods use opinions of experts based on intuition and experience in order to form a proper prediction [12]. There are many heuristic methods, of which two are the most commonly used: brain-storming and the Delphi method [13–15].

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2.1. Survey research. Survey research was conducted using the Delphi method, in two rounds, using electronic surveys (the CAWI method). The most important advantages of this method are:

- automatic (using the system managing the research) verification of the logical correctness of the input data,
- automatic saving of survey results on the server, which makes the analysis process easier and more efficient,
- the possibility to conduct research in cases of respondent groups which are spread out over a large geographical area.

In the first round of the survey the designed criteria list was assessed on a Likert's 7 degree scale (weight scale from 1 to 7, where 1 – a group of criteria of low significance, and 7 – a highly significant group of criteria). Additionally, the respondents had the possibility to add and assess other criteria, not included in the survey list. This allowed to complete the criteria list and assess, in the second round, the criteria from the first round as well as the newly added criteria, which were chosen from the ones suggested in round one. The respondent assessed the criteria in round two, seeing the results of the assessment of the individual criteria obtained in round one.

The group of experts consisted of: representatives of scientific areas of construction and environment protection, representatives of environment conservation organisations, representatives of the management of national and regional roads, representatives of environment conservation government agencies, representatives of towns and counties, and representatives of designers.

Based on a literature study on the criteria of road alignment and the rules, which a family of criteria should fulfil, 58 sub-criteria were proposed to assess the regional roads (Table 1). The criteria were assigned to one of four groups: transport, environmental, economic and social. The survey with the list of criteria was sent electronically to the respondents.

2.2. Analysis of survey results. As a result of the first round of surveys the respondents listed many additional criteria. The largest number of criteria was suggested in the transport group (33 criteria) and environmental (43 criteria). 17 additional criteria were listed in the economic group and 22 in the social one. After conducting a detailed analysis of the suggested additional criteria and taking into account the rules which those criteria should fulfil, the second round of surveys included only the following new criteria:

- in the transport group:
 - participation of heavy vehicles in traffic,
 - length of segments passing through urban areas,
- in the environment group:
 - size of areas in which noise pollution limits are exceeded,
 - length of segments passing through difficult terrain (peatlands, wetlands, flood plains).

The survey appended with the new criteria was sent to the respondents who completed the first round of surveys.

In the first survey, 2355 persons received the survey and 340 of them replied (14.44%). In the second round the survey was completed by 226 respondents (66.47%).

Table 1
Criteria for selecting a road alignment variant
– first round of surveys

No.	Criteria groups	Sub-criteria
1	Transport (17)	road length, road tortuosity, level of service, transport performance, journey time, accessibility, alignment of the road with the directions of main traffic weights, interstitial distances, degree of usage of existing transport routes, traffic safety, accordance with planning documentation, influence on local development, collisions with technical infrastructure, number of planned engineering structures, geological-engineering conditions, possibility for staging of works, investment fulfilment period
2	Environmental (20)	passing through forest areas, influence on surface waters – collisions with watercourses, influence on groundwaters – collisions with groundwater reservoirs etc., crossing of migration corridors of mammals and amphibians, influence on monuments, collisions with archeological sites, collisions with Nature 2000 areas, collisions with national parks, collisions with landscape parks, collisions with nature reserves, collisions with landscape protection areas, collisions with natural monuments, collisions with documentation sites, collisions with ecological sites, collisions with nature-landscape complexes, distance from protected areas, number of lost sites of protected species, influence on landscape, occupation of new terrain, air pollution
3	Economic (12)	construction costs, buy-out costs of ground, objects and compensations, demolition costs, costs of environment conservation equipment, maintenance costs, vehicle usage costs, time costs in passenger transport and freight, cost of traffic incidents, costs of toxic components of fumes emission, economic net present value (ENPV), economic internal rate of return (EIRR), benefit index (B/C)
4	Social (9)	social conflicts, area of land or number of lots to expropriate, inhabited or non-inhabited buildings for demolition, number of inhabited buildings within 0–100 m from the road axis, length of noise barriers, number of persons exposed to excessive noise levels, health threat – risk of road incidents with dangerous materials, number of lost connections between areas located on both sides of the planned road, tremors and vibrations

The characteristic of the respondents in the second round of survey is presented in Figs. 1–4.

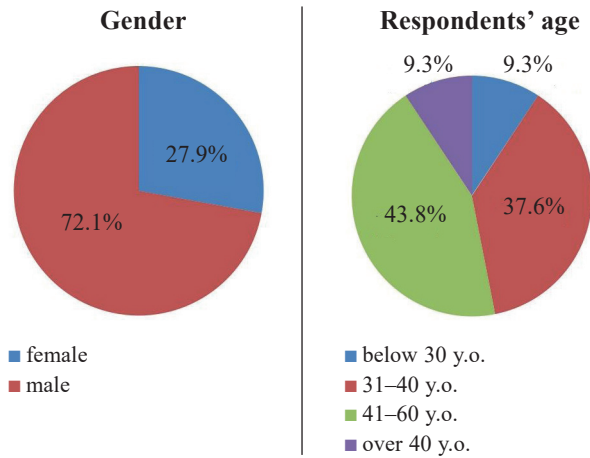


Fig. 1. Respondent structure by gender and age

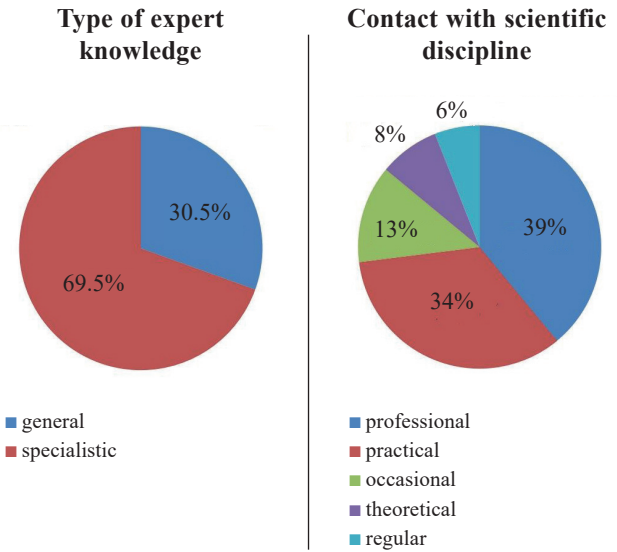


Fig. 4. Respondent structure by type of knowledge and contact with the scientific discipline

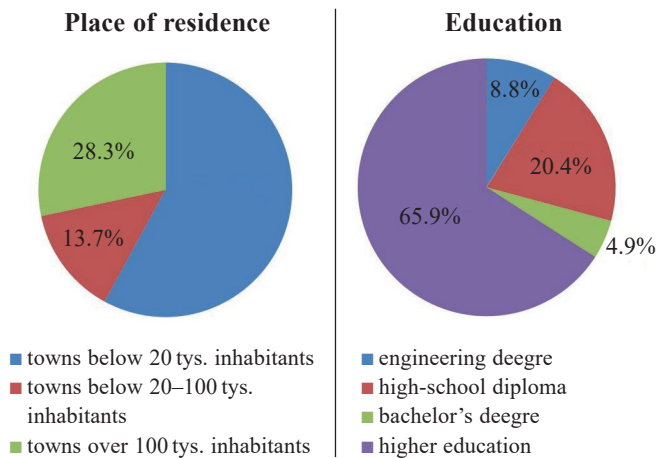


Fig. 2. Respondent structure by education and place of residence

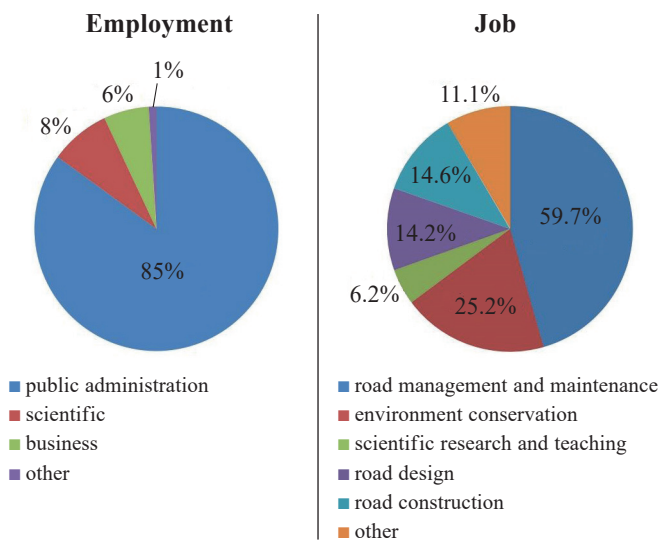


Fig. 3. Respondent structure by employment and performed job

At the first stage of the surveys, the respondents assessed the importance of the main criteria groups in the context of planning the road alignment of regional roads. The level of importance was assessed according to a 7-degree Likert's scale. The basic description statistics for each degree of criteria group importance are presented in Table 2.

Table 2
Description statistics for criteria group importance degrees

No.	Criteria group	Arithmetic mean	Standard deviation	Coefficient of variation [%]
1	Transport	5.77	1.13	19.6
2	Environmental	5.38	1.21	22.5
3	Economic	5.35	1.17	21.8
4	Social	4.96	1.38	27.8

The highest average value (5.77) was noted for transport criteria. Expert assessments in this area were the least diversified (coefficient of variation at 19.6%). Environmental criteria were placed at 5.38, and the individual assessment values varied from the average one by ± 1.21 (standard deviation). A similar average assessment value could be seen for economic criteria (5.35), with the lowest assessment value noted for social criteria (4.96). It is worth noting that in the case of this group of criteria, expert assessments were the most diversified (coefficient of variation at 27.8%).

The next step of the analysis was to conduct a classification of the importance of all 62 assessed criteria. In the group of transport criteria, the experts assessed the importance of 17 criteria and two additional criteria suggested in the first survey round: participation of heavy vehicles in traffic and the length of segments passing through urban areas (Fig. 5).

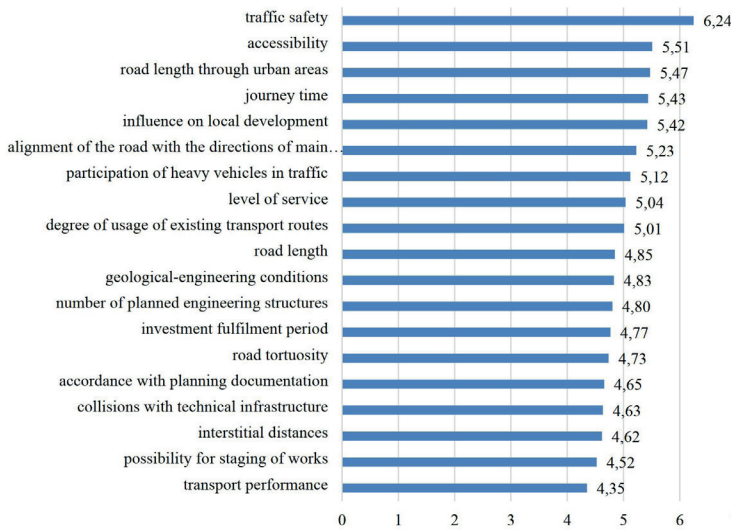


Fig. 5. Average assessment values of the importance of sub-criteria in the transport criteria group

In the group of environmental criteria the experts assessed the importance of 18 criteria and two additional criteria suggested in the first survey stage: the length of segments passing through difficult terrain (peatlands, wetlands, flood plains) and the size of areas in which noise pollution limits are exceeded (Fig. 6).

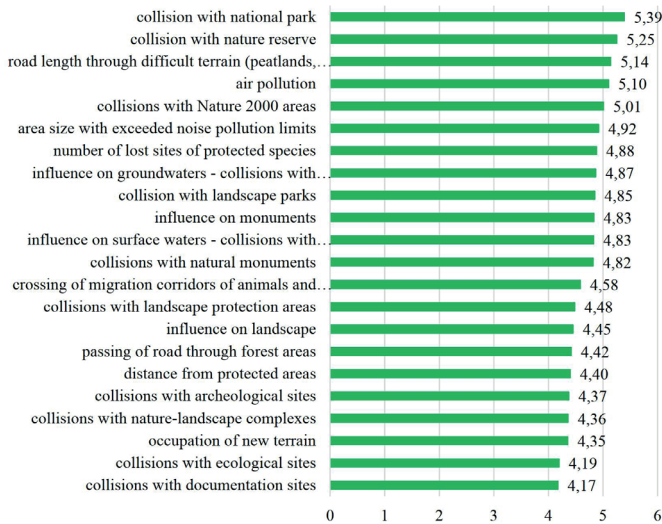


Fig. 6. Average assessment values of the importance of sub-criteria in the environmental criteria group

In the group of economic criteria, the experts assessed 12 criteria (Fig. 7).

In the group of social criteria the experts assessed 9 criteria (Fig. 8).

In the next step of the analysis a classification of the importance of all the assessed criteria was conducted. The division scope was determined based on the mean aver-

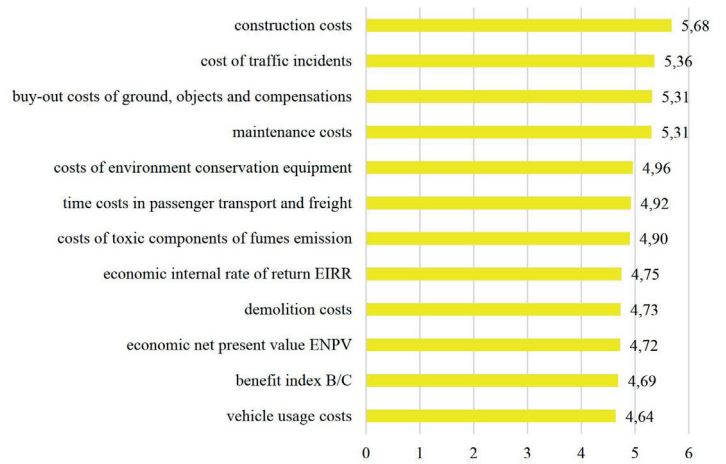


Fig. 7. Average assessment values for the importance of sub-criteria in the economic criteria group

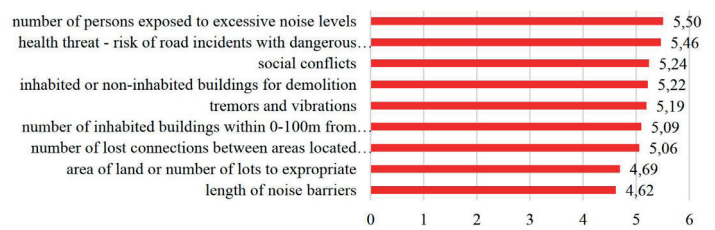


Fig. 8. Average assessment values for the importance of sub-criteria in the social criteria group

age of assessment values and standard deviation, thus creating a ranking of criteria importance. Next, these criteria were divided into four groups as in the rule presented in Table 3.

Table 3
Criteria division

No.	Division	Division name	Value scope
1	$\langle x_{\min}; \bar{x} - S_x \rangle$	least important criteria	$\langle 4.17; 4.52 \rangle$
2	$\langle \bar{x} - S_x; \bar{x} \rangle$	less important criteria	$\langle 4.52; 4.92 \rangle$
3	$\langle \bar{x}; \bar{x} + S_x \rangle$	important criteria	$\langle 4.92; 5.32 \rangle$
4	$\langle \bar{x} + S_x; x_{\max} \rangle$	most important criteria	$\langle 5.32; 6.24 \rangle$

The symbols used in Table 3 are explained below:

- x_{\min} – minimum criteria assessment value,
- \bar{x} – average assessment value for all criteria,
- S_x – standard deviation of the assessment values of all criteria,
- x_{\max} – maximum criteria assessment value.

3. Entry criteria list and their weights

Based on the results of the survey, an entry list of criteria was created as a suggestion to be taken into account in the variant assessment of road alignment for regional roads. An assumption

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was made that they would be criteria with the highest assessment values, and their number should be the same. The number of criteria in each group was set at 7, which is an approach widely known in literature. Table 4 shows the entry list of criteria designed for the selection of the most beneficial road alignment variant.

Table 4
Entry list of criteria and their weights

No.	Transport (0.2609)	Environmental (0.2422)	Economic (0.2474)	Social (0.2495)
1	traffic safety (0.0424)	collision with national park (0.0366)	construction costs (0.0386)	number of persons exposed to excessive noise levels (0.0373)
2	accessibility (0.0374)	collision with nature reserve (0.0356)	cost of traffic incidents 0.0364)	health threat – risk of road incidents with dangerous materials (0.0371)
3	road length through urban areas (0.0371)	road length through difficult terrain (peatlands, wetlands, flood plains) (0.0349)	buy-out costs of ground, objects and compensations (0.0360)	social conflicts (0.0356)
4	journey time (0.0369)	air pollution (0.0346)	maintenance costs (0.0360)	inhabited or non-inhabited buildings for demolition (0.0354)
5	influence on local development (0.0368)	collisions with Nature 2000 areas (0.0340)	costs of environment conservation equipment (0.0337)	tremors and vibrations (0.0352)
6	alignment of the road with the directions of main traffic weights (0.0355)	area size with exceeded noise pollution limits (0.0334)	time costs in passenger transport and freight (0.0334)	number of inhabited buildings within 0–100m from the road axis (0.0346)
7	participation of heavy vehicles in traffic (0.0348)	number of lost sites of protected species (0.0331)	costs of toxic components of fumes emission (0.0322)	number of lost connections between areas located on both sides of the planned road (0.0343)

In Table 4, the group of transport criteria were rated the highest, and the group of environmental criteria were rated the lowest. It should be noted that the weight of the social criteria group is almost the same as the weight of the economic criteria group. The value of individual groups of criteria results from the value of individual criteria received in the survey.

In the case of the lack of one of the listed criteria for analysis, the next criteria should be selected for analysis according to the importance rating. In special cases (e.g. road passing through mountainous terrain, or through mining damage areas), the criteria and their weights need to be determined individually.

The weights of individual criteria were suggested based on the assessment values obtained through surveys according to the following equation (1):

$$\omega_{jk} = \frac{\omega_{jsred}}{\sum_{j=1}^m \omega_{jsred}} \quad (1)$$

where:

ω_{jk} – weight of a given criterion,

ω_{jsred} – mean average of the weights of a given criterion,

$\sum_{j=1}^m \omega_{jsred}$ – the sum of the values of all mean averages of criteria taken into account in the analysis.

4. Conclusions

Determining a list of criteria for variant evaluations is one of the basic tasks within the framework of multicriteria analysis.

An entry list of criteria for selecting the most beneficial variant of regional road has been proposed.

The criteria were assessed using the Delphi method, CAWI technique.

Based on the surveys studies, an entry list of criteria has been developed, divided into four groups: transport, environmental, economical and social.

The classification of the importance of all assessed criteria was determined on the basis of the arithmetic mean of grades and standard deviation, and then they were divided into four groups: least important criteria, less important criteria, important criteria, most important criteria.

Seven sub-criteria with the highest scores were assigned to each main group. A method for determining the weight of a given criterion has been proposed, as the quotient of the values of the assessed criterion to the sum of all the criteria included in the analysis.

In special cases (e.g. road passing through mountainous terrain, or through mining damage areas), the criteria and their weights need to be determined individually.

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