MODERN TRENDS IN ROAD NETWORK DEVELOPMENT IN RURAL AREAS

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Abstract. Activities aimed at the improvement of instruments of rural development have been undertaken in Europe for many years. Those focusing on the changing the ownership structure, implemented through the traditional process of land consolidation, are gradually replaced by multifunctional activities for rural development, considering elements of environmental protection, agricultural landscape management, and solutions concerning soil and water protection. Such development must be accompanied by the application of new pro-ecological design and material-technological solutions regarding the construction of rural roads. The roads should be designed with possibly the fullest consideration of a rich resource of data on a given area, performance of many spatial analyses, and decision making in the scope of selection of the most appropriate solutions acceptable to all stakeholders (e.g. residents, farmers, local authorities, entrepreneurs, and investors). The article presents the concept of a model solution of the development of the rural road network based on the multiple-criteria model of spatial analyses with the application of the Analytic Hierarchy Process method. The research process was conducted in the geographic information systems environment. The importance of the proposed methodology was verified in actual conditions based on the example of the Harta village located in the southern part of Poland. The obtained results suggest that the process of development of rural roads with the application of the multiple-criteria model of spatial analyses is more accurate, more efficient than the traditional design method, and considers the requirements of the sustainable development of rural areas. Moreover, it permits presentation of solutions in the form of maps to the local community, almost in real time, and making excellent decisions with its active participation.

Keywords: Analytic Hierarchy Process, development, environment, multiple-criteria analysis, road, rural areas, sustainability.

1. Introduction

Rural areas are facing multiple challenges involving the development of efficient, competitive agriculture and forestry, strengthening areal structures as an independent living and economic space, and preservation of the cultural landscape and natural environment. Their implementation depends on the availability and quality of the local transport infrastructure, including rural roads.

Agricultural transport and the related roads are exceptional due to:
- uneven load of roads in time, or even only of their certain sections, particularly depending on the seasonality of cultivation works;
- development of the rural landscape and forms and sizes of agricultural parcels or forest areas located within the road networks;
- provision of convenient, possibly the shortest access to each cultivated part of the arable land in given terrain conditions.

For example, in Poland, rural roads constitute the weakest link in the road network, although they provide the most important connections for the proper development of rural areas, inhabited by 39.7% of the population, and occupying 93.1% of the total area of the country. In contrast to the ongoing fragmentation of arable land in Poland, the road network remains largely unchanged. The growing fragmentation usually results in the increasing scale of the phenomenon of no access of parcels to the public road network. In areas with high degree of fragmentation, the problem often concerns several tens percent of parcels. Access to such land is usually practically possible in the form of permanent informal roads and occasional transport through the adjacent land. This constitutes a serious obstacle in rational use of land owned by agricultural farms. In addition to the inconvenient road reallocation, the technical state of the roads is a serious problem. More than 50% of the length of roads in rural areas are unpaved surfaces, not adjusted to modern, currently used means of transport, agricultural machines, and devices. Almost all of them require modernisation or thorough renovation. Improvement of the situation is possible owing to the land consolidation process.

Land consolidation constitutes a part of the broadly defined process of rural development, stimulating the development of functions fulfilled by such areas in the economic, social, and environmental aspect through the improvement of the reallocation of parcels in farms. It involves a substantial reduction in the average number of parcels in farms, an increase in their area, and provision of access to a public road. An improvement in the reallocation, width, and surface of rural roads is also one of the effects of the implementation of the process.

Designing and delineating transport routes on the map is one of the first activities performed by the surveyor-designer in the scope of preparation of assumptions for a land consolidation project. At this stage, among others, the needs regarding changes in the transport network with consideration of pedestrian passages and crossings are specified. Proposals are presented concerning the arrangement of rural roads. The way of designing the new road system will affect the designed spatial reallocation of parcels and the agricultural landscape – its functionality and aesthetics. Moreover, this is the most expensive element of the entire investment project, the most rapidly subject to wear and tear, and therefore requiring further expenditures for repairs, modernisation, and maintenance. Design decisions taken at this stage must be preceded by a detailed inventory of the existing state and a thorough analysis of the local conditions occurring in the study area. The analyses and verification of design solutions cannot be unilateral, considering only the technical and economic aspects. Elements of environmental protection and landscape management, as well as solutions concerning soil and water protection, are also necessary and must be by the rules of sustainable development of rural areas.

The complexity of the process of development of the road network in rural areas requires the application of a research-information instrument for searching the most appropriate solutions acceptable for all stakeholders, including residents, farmers, local authorities, entrepreneurs, and investors. Such a solution can involve the multiple-criteria model of spatial analyses. The multiple-criteria character of analyses is necessary in the case of environmental solutions, distinguished by numerous correlations and mutual influences.

The article presents the concept of a methodology supporting the surveyor-designer in the decision-making process in the scope of the location of new elements of the road network in rural areas and adjustments of the course of its existing elements by the rules of sustainable development of rural areas. The proposed methodology is based on the multiple-criteria model of spatial analyses with the application of the Analytic Hierarchy Process method (AHP). The practical implementation of the proposed solutions was based on the geographic information systems (GISs) environment. This permitted ordering in a logical structure as well as verification and updating of source reference data and thematic data necessary for the complex analysis of the existing technical state of the surface of rural roads, followed by the visualisation of the results

in the form of maps. Due to the differences in local environmental conditions of rural areas forcing considerable flexibility, the model constitutes a proposal for an approach to the discussed problem. The proposed model can be extended by material-technological solutions for rural road construction which change with time.

2. Literature review

According to the rule of sustainable development, all the elements of the human life environment are interconnected, and it is impossible to develop a concept of permanent economic growth without taking care of the natural environment and society. In rural areas, the idea of sustainable development assumed the improvement of life conditions of residents and conducting the economic activity with simultaneous maintenance of untouched specific resources of rural areas, including the natural environment, rural landscape, traditions, and cultural heritage. The supporting activities, including construction and modernisation of local roads, are implemented within the framework of the European Union policy of rural development.

The characteristic feature of the construction or transformation of rural roads is their specific effect on the state of the natural environment and rural landscape. The interference of such works into the vegetation and landforms is clearly visible. Improperly introduced, it causes damage and losses very difficult to overcome in a short period. According to the modern European approach to transformations of rural areas based on sustainable development, every such unfavourable change introduced in the natural environment should be counteracted by some pro-ecological undertakings. One of such undertakings is the application of ecological, so-called "sustainable" structures of the pavement of rural roads. Such pavement should most importantly be distinguished by environmentally-friendly structure, low energetic investment, and low emission of pollutants. It should be safe, efficient, and meet the current transport needs, without restricting meeting such needs in the future (Radziszewski *et al.* 2014).

Although the primary approach remains the same, the applied solutions of construction of local transport infrastructure differ from country to country, depending on the occurring environmental conditions, design standards, local building practices, and actual availability of local resources. Certain good practices exist, however, applied in road construction, which corresponds with the idea of the sustainable development of rural areas. They include among others (Kowalski *et al.* 2016; Nazarko *et al.* 2015; Radziszewski *et al.* 2016):
- structures of roads with unbound pavement;
- roads with the application of binding agents of natural origin;
- asphalt pavement – road pavement with bitumen material for binding;
- cement concrete pavement – road pavement with cement for binding;
- pavement with recycled materials – road pavement with demolition waste, material form road

reconstruction and other post-industrial material used in structural layers;

– long lasting (so-called perpetual) pavement – special road pavement designed and constructed to achieve at least 50 years of durability;

– quiet pavement – special road pavement designed and constructed to mitigate traffic noise.

In European countries, and particularly in Germany, surfaces with pro-ecological properties include among others concrete pavements or pavements made of small-sized concrete products, i.e. cobblestones, or cellular concrete slabs with grass sown in the spaces.

Surfaces with pro-ecological properties also include grassy surfaces minimising the risk of occurrence of erosion on rural roads running through terrain with varied relief, unstable climate, and soils prone to washing. Soil erosion is the dominant factor damaging roads in rural areas all over the world. Results of field research conducted by Chinese scientists (Cao *et al.* 2005) in the period from 1996 to 2001 in the loess areas of province Shaanxi showed that the rate of soil erosion is 3.09 times higher on dirt roads than on roads with mixed grass turf. It was also estimated that the costs of construction and maintenance of grassy roads are incomparably lower than those for unbound surface roads (more than 50%). This evidences that grassy roads can fill the technological gap between paved and unpaved roads in highland areas with soils prone to washing and low traffic, and simultaneously minimise the level of soil erosion, landscape degradation, and other environmental damage. Despite some described advantages,

however, they also have drawbacks. In the case of application of heavy agricultural machinery, particularly in the period of early spring when roads show considerably weakened structure, they are prone to damage, and the possibilities of their regeneration in the period are limited.

The selection of the surface of rural road is a decision taken for years. It should consider all important technological, economic, and environmental-landscape factors. For this purpose, a comparative analysis was performed concerning three types of pavements of rural roads commonly applied in Europe (Budzyński *et al.* 2015). The analysis was performed in cooperation with scientific employees from the Division of Road Materials and Technology from the Faculty of Civil Engineering of the Warsaw University of Technology.

The analysis presented in Table 1 shows that asphalt roads are after all the most environmentally-friendly. Construction of asphalt roads requires less energetic expenditure and involves considerably lower emission of greenhouse gases than that of cement concrete technology. In aesthetic terms, asphalt roads were assessed substantially lower than concrete roads. Regarding technological and economic factors, asphalt roads were assessed the best. Cellular concrete slabs also received a high rating in this classification.

One of the specific features of agricultural production is its spatial character, largely dependent on the density and quality of the road network. In conditions of improper reallocation in the relief and choice of the technology of their construction inaccurate for the soil and hypsometric conditions, roads are prone to degradation. Effects of such processes are not only limited to the reduction of the

Table 1. Assessment of selected pavements of rural roads regarding technological, economic, and environmental-landscape factors

Properties	Asphalt pavement	Pavement of cellular concrete slabs	Cement concrete pavement
TECHNOLOGICAL: Technology of constructing the pavement	+	+	–
Durability	+	+	+
Resistance to permanent deformation	+/–	+	+
Availability of materials for production	+	+	+
Ease of performing repairs and renovations	+	+	–
Ease of draining	+/–	+	+/–
ECONOMIC: Investment costs	+	–	–
Recyclability	+	–	+/–
Operating costs	+/–	+	+
Maintenance in winter	+	+/–	+/–
ENVIRONMENTAL-LANDSCAPE: Landscape aspects	+/–	+	+/–
Environmentally-friendly	+	+	+
Ecological costs of production of binding material (binders, adhesives)	+	– (emission of greenhouse gases)	– (emission of greenhouse gases)
Driving comfort	+	+/–	+
Noise	+	–	+/–

Note: + positive effect; – negative effect.

transport usability of roads. They also lead to the intensification of erosion processes, and deterioration of the conditions of water management. According to a study conducted by Polish scientific from the Institute of Soil Science and Plant Cultivation in Puławy (Józefaciuk; Józefaciuk 1999; Nowocień 2003), at a longitudinal slope exceeding 4%, roads should be paved with the application of specially strengthened facilities for removing water from surface runoff. Such unpaved roads are transformed into road gullies, becoming deeper by 4.5 cm/year on average, and max by 9.0 cm/year. The growing intensity of the phenomenon justifies the need to apply relevant rules of road location in eroded areas. Proposals for the location of rural roads in an area with diverse land relief are presented in Fig. 1.

Depending on the location of rural roads in land relief, the literature on the subject (Wawer 2004) mentions the following types of roads:
- roads in river valleys and on flat plateaus;
- across-slope roads – with an angle between the road section and land contour of 0°−10°;
- roads diagonal to the slope – with an angle between the road section and land contour of 11°−80°;
- along-slope roads – with an angle between the road section and land contour of 81°−90°.

From anti-erosion protection, the recommended location of rural roads is perpendicular to the direction of the slope. In the case of inclinations of 6−14%, rural roads should be located at the top of the slope, on the local watershed with the lowest concentration of surface waters. In the case of slopes with an inclination exceeding 14%, roads should be designed diagonally to the slope, or in curvilinear fashion for the purpose of reduction of their longitudinal inclination (preferably to 6%) and increasing the aesthetic values of the rural landscape. Roads with such location, however, have large catchment areas, and periodical waters are flowing through them cause substantial erosion. Therefore, if possible, it is best to locate them in valleys between slopes, on the condition that the valley floor is permanently sown with grass, and the road belt is out of reach of concentrated flow of surface waters.

Along- and diagonal to the slope roads are the most prone to washing. Such roads are admissible when roads are located in valleys and on plateaus and provide access to the adjacent fields. They should always be paved, however, and the boundaries of parcels should be perpendicular to the road axis.

The current scope of provisions concerning the development of the network of rural roads in the aspect of environmental and landscape protection is too general to perform relevant analyses and forecasts without additional interpretations and methodological materials, or to apply necessary facilities and methods of environmental protection against the adverse effect of roads and road traffic.

3. Research methodology

The methodology supporting the decision making process regarding the transformation of the transport system in rural areas during consolidation works, proposed in this article, was developed with the application of the multiple-criteria model of spatial analyses. It was prepared based on the GIS technology. The proposed method differs from typical design solutions implemented e.g. in Poland for land consolidations because it involves environmental-landscape aspects. The diagram of the course of the research process is presented in Fig. 2.

The concept of the model is by the assumptions of the AHP method, the stages and mathematical basics of which are presented in numerous publications by Saaty (1994, 2000, 2008). The AHP method is based on the assumption that the majority of complex decision making problems can be broken down and presented in the form of a hierarchical tree (hierarchical structure). This permits avoiding difficulties mentioned by Benjamin Franklin in his famous letter addressed in 1772 to the well-known English chemist philosopher Joseph Priestley: "when these difficult cases occur, they are difficult chiefly because while we have them under consideration all the reasons pro and con are not present to the mind at the same time" (ProCon.org).

The structure of the AHP model includes several levels. The highest level represents the primary goal of the decision making process. The implementation of the goal is determined by criteria located on the lower level. These, in turn, depend on the corresponding sub-criteria (factors). The bottom level represents decision variants. This relatively simple hierarchy can be expanded. Intermediary stages can be introduced, such as auxiliary (subordinate) goals, or groups of decision-makers with different preferences – this
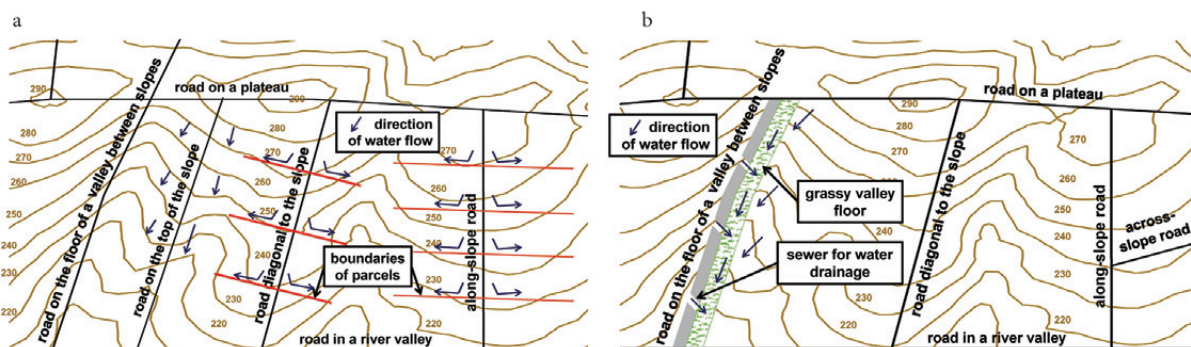

Fig. 1. Proposals for the location of rural roads in an area with diverse land relief: a – roads along and diagonal to the slope; b – road in the valley between slopes

way, the obtained result will also depend on the value of judgements involved in the decision making process.

The ready structure of the hierarchical model should be subject to analysis by pair-wise comparison of its particular elements using a square pair-wise comparison matrix with dimensions ($n \times n$), where "n" is the number of compared criteria. Comparisons are conducted based on so-called Saaty nine-grade scale. According to the scale, the importance of one element as compared to another varies from "equal importance" (1) through "moderate importance" (3), "strong importance" (5), "very strong importance" (7) to "extreme importance" (9). In addition to odd values, intermediate values can be applied – 2, 4, 6, 8.

The next stage of the AHP procedure involves the determination of weights of the analysed criteria. Four methods of estimation of the value of weight coefficients are distinguished, applying: specialist software (e.g. Super Decisions), matrix calculation, geometric mean, and arithmetic mean. The application of the arithmetic mean is the simplest, and the most frequently applied manual way of determination of values of weight coefficients (e.g. using the Microsoft Excel spreadsheet), based on two steps:

– normalisation of expressions of the pair-wise comparison matrix through the calculation of the total of each column, and then division of all the values of a given column by a relevant total:

$$PCM = \begin{bmatrix} 1 & a_{12} & a_{1n} \\ a_{21} = 1/a_{12} & 1 & a_{2n} \\ a_{n1} = 1/a_{1n} & a_{n2} = 1/a_{2n} & 1 \end{bmatrix}, \quad (1)$$

$$NVM = \begin{bmatrix} 1/\Sigma_1 & a_{12}/\Sigma_2 & a_{13}/\Sigma_3 \\ (1/a_{12})/\Sigma_1 & 1/\Sigma_2 & a_{23}/\Sigma_3 \\ (1/a_{13})/\Sigma_1 & (1/a_{23})/\Sigma_2 & 1/\Sigma_3 \end{bmatrix}, \quad (2)$$

– calculation of the arithmetic mean of each row of normalised data:

$$\omega = \begin{bmatrix} \left[1/\Sigma_1 + a_{12}/\Sigma_2 + a_{13}/\Sigma_3 \right]/3 \\ \left[(1/a_{12})/\Sigma_1 + 1/\Sigma_2 + a_{23}/\Sigma_3 \right]/3 \\ \left[(1/a_{13})/\Sigma_1 + (1/a_{23})/\Sigma_2 + 1/\Sigma_3 \right]/3 \end{bmatrix}, \quad (3)$$

where PCM – pair-wise comparison matrix; n – number of compared criteria; NVM – matrix of normalised values; Σ_i – total of column i of matrix PCM; ω – weights.

In a simple approach, weights can also be determined based on the knowledge and experience of the person conducting the analysis or based on the preferences of the stakeholders (i.e. local community, landscape architects, experts in environmental protection, transport engineering, etc.).

This way, decision variants are ordered from the optimal to the least desirable one, facilitating making the decision involving the selection of one of them.

The AHP method applied together with GIS software has an evident spatial aspect, manifested both in the defined goal (related to spatial planning) and in the set of criteria (referring to various aspects of space) and spatial data for the implementation of criteria. In this version, it can be included in procedures of spatial analyses constituting a GIS functionality (Malczewski 1999). Then it covers tasks in the scope of usefulness of land for a particular purpose, including the designation of optimum location (Carr, Zwick 2007), and tasks involving comparison of particular solution variants for the purpose of selection of the best one, e.g. concerning the course of a road (Geneletti 2005).

The practical implementation of solutions applied in the proposed methodology was based on the GIS environment. A significant advantage of the GIS technology involves its analytical possibilities which can be formalised in the form of developed models of spatial analyses – creating groups of new, ready for use tools supporting the decision making process regarding functional division of space. This requires feeding the system with high quality valid data. It is important for the data to be ordered in a logical structure and subject to relevant verification and updating to enable their integration followed by a comprehensive analysis and presentation of results. Presentation is defined as a system of maps – from analytic maps showing particular criteria to synthetic maps showing analysis results, permitting accurate perception and understanding of the proposed solutions by the stakeholders.

4. Study results and discussion

The importance of the adopted solutions applied in the proposed methodology of development for the road network in rural areas was verified in actual conditions based on the example of the Harta village located in the southern part of Poland. The research process was based on the diagram presented in Fig. 2.

4.1. Identification of the decision making problem

The decision making process begins with the identification and defining the decision making problem, followed by its presentation in the form of a hierarchical structure by the assumptions of the AHP method. For the conducted research, the decision making process is defined as the classification of the usability of land for the assessment of the correctness of location of the existing rural roads with particular consideration of technical-economic and environmental-landscape aspects, including the determination of needs for adjustments of their course and modernisation.

4.2. Obtaining and organisation of data

The broad thematic scope of the development of the network of rural roads in the process of land consolidation forces the use of a rich resource of various input data concerning the land, objects creating the rural space, and the road network. Provision of full integration of data, i.e. their unification regarding the degree of detail, validity, and manner of disclosure is currently a serious problem. The structure and organisation of the data base must be coherent and cover all aspects related to the characteristics

of the area and analyses of the natural environment. It should also allow for adding new elements at any moment.

The set of input data necessary for solving the discussed decision making problem is composed of: cadastral data base, base of data on topographic objects, digital terrain model, soil-agricultural map, detailed geological map of Poland, geoenvironmental map of Poland, hydrogeological map of Poland, flood map, ortophotomap, planning documentation, photographic documentation from the performed inventory, and audio documentation from conducted social consultations. It is an open set of data which can be extended by descriptive data, and studies prepared by expert institutions concerning among others environmental-landscape issues, directly related to the study area.

4.3. Assessment of the reallocation and technical state of the surface of rural roads

The determination of needs and urgency of improvement of the rural road network in the study area was based on its assessment of the following points of view:

- quantitative: whether they are not excessively expansive in comparison to their function, i.e. whether their road density index is not too high, whether they do not occupy an excessively high percentage of arable land, and whether they are rationally reallocated in the agricultural production space;
- qualitative: whether the width, type of surface and minimum radius of the curves are the requirements of the prospective traffic;
- particular farms: whether they provide convenient access in given terrain conditions from the homestead to all the cultivated fields.

4.4. Selection of criteria and determination of barriers – excluding criteria

Due to the adopted primary goal of the project, relevant criteria of its assessment were selected. Two groups of criteria were distinguished, concerning (Table 2):

A. technical-economic conditions;
B. environmental-landscape conditions.

The group of criteria for the discussed decision making problem was determined based on: literature study, analysis of legal regulations, own research, and opinions collected from employees of Polish surveying and rural development units, residents of the study area, and experts on transport engineering and technology of road materials and surfaces. The criteria included a special group, namely barriers defining areas excluded from the analysis. These are: legal forms of environmental and landscape protection, legally protected soils of arable land, forests, areas of direct protection of surface water and groundwater intakes, areas of surface inland waters, areas of direct flood threat, landslides and areas threatened by mass movements, objects of protection of the cultural heritage and historical sites, and developed and urbanised land. They result from legal regulations. They constitute an obligatory requirement of common law, or a requirement of other legal acts, particularly including acts of local law.

4.5. AHP method – determination of the values of weight coefficients

The weights of the discussed criteria were determined based on their pair-wise comparison in accordance with the procedure presented in Chapter 3. The obtained values are given in Table 2.

4.6. Development of a multiple-criteria model of spatial analyses in the GIS environment

The next stage of the process was conducted in the GIS environment. The development of the decision making model included the following stages:

- development of a map of criteria (raster map of single layers of values of criteria);
- standardisation (normalisation) of values of criteria;
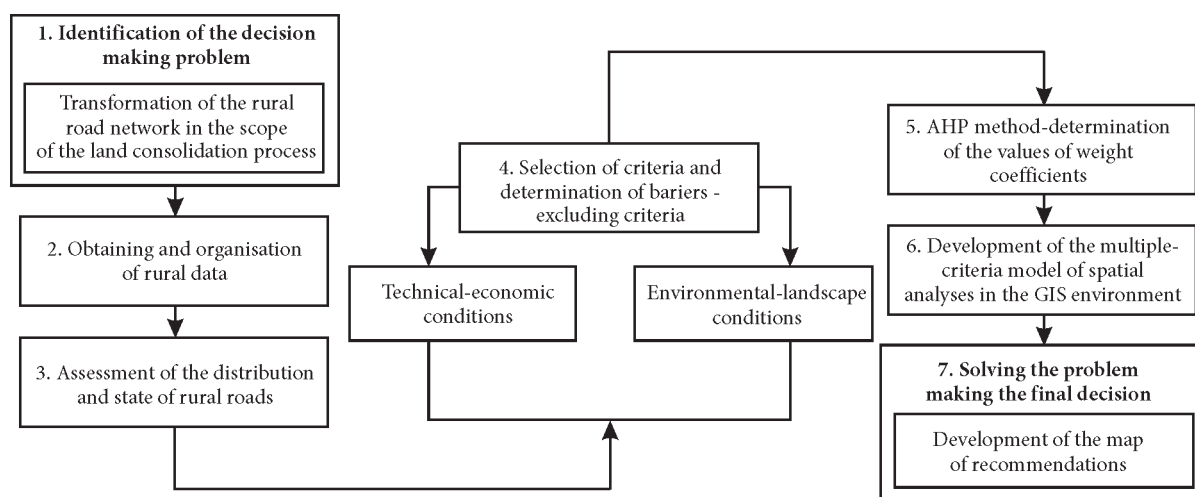- development of normalised maps of values of criteria;

Fig. 2. Diagram of the proposed methodology of development of the network of rural roads in the process of land consolidation with the application of the multiple-criteria model of spatial analyses

Table 2. Values of weights of criteria and sub-criteria considered in the analysis

$\omega_L = \omega_G$	Criteria	ω_L	ω_G	Sub-criteria	ω_L	ω_G
			TECHNICAL-ECONOMIC GROUP OF CRITERIA			
0.7500	Longitudinal inclination of the road	0.0420	0.0315	up to 4°	0.5254	0.0166
				4–8°	0.3009	0.0095
				8–12°	0.1104	0.0035
				more than 12°	0.0634	0.0020
	Soil-water conditions of the substrate of the surface structure	0.5683	0.4262	good	0.8333	0.3552
				bad	0.1667	0.0710
	Type of surface	0.1446	0.1085	paved surface improved	0.6689	0.0726
				paved surface unimproved	0.2674	0.0290
				unpaved surface	0.0637	0.0069
	Location of rural roads in land relief	0.2450	0.1838	roads in river valleys and on flat plateaus	0.4122	0.0758
				across-slope roads	0.4122	0.0758
				roads diagonal to the slope	0.1114	0.0205
				along-slope roads	0.0643	0.0118
			ENVIRONMENTAL-LANDSCAPE GROUP OF CRITERIA			
0.2500	Soil quality	0.2066	0.0517	class IVa	0.0659	0.0667
				class IVb	0.0870	0.0667
				class IV	0.1188	0.2000
				class V	0.2470	0.2667
				class VI	0.4812	0.4000
	Resistance of soils to transport pollutants	0.0517	0.0129	very good	0.4346	0.0056
				good	0.2860	0.0037
				moderate	0.1556	0.0020
				weak	0.0825	0.0011
				very weak	0.0413	0.0005
	Threat of surface water erosion of soils	0.6578	0.1644	does not occur	0.4133	0.0680
				low	0.2581	0.0424
				moderate	0.1716	0.0282
				average	0.0835	0.0137
				strong	0.0441	0.0073
				very strong	0.0294	0.0048
	Distance from the edge of forest complexes	0.0839	0.0210	up to 10 m	1.0000	0.1644
				more than 10 m	0.0000	0.0000

Note: ω_L – values of local weight coefficients (they define mutual importance of a given element towards an element located a level higher in the hierarchical model; they are obtained directly from the pair-wise comparison matrix); ω_G – values of global weight coefficients (they define the contribution of each element in the implementation of the general goal; they are obtained by means of multiplication of the local priority of a given element by the weight coefficient of the relevant element located a level higher in the hierarchy).

– development of maps of the usefulness of land for particular groups of criteria (combined criteria in the mixed approach – Weighted Linear Combination method);
– development of a map of recommendations presenting a classification of land by the degree of its usability for the construction and transformation of the road network in rural areas;

– sensitivity analysis (determination of solidity, the reliability of the model).

4.7. Solving the problem, making the final decision

The Harta village (Fig. 3) is an exceptionally difficult area from the implementation of this type of works. It is characterised by diverse land relief, intensive soil erosion processes, a dense network of access roads to fields, and

excessive fragmentation of arable land. The correlations and interactions between the discussed elements determine the recommended multidimensional development based on the multiple-criteria analysis.

The solution to the decision making problem was based on the resulting map of recommendations presenting the following classification:

- degree 1 – land with unlimited usability, change of location of the existing roads not required;
- degree 2 – moderately useful land, change of location of the existing roads moderately urgent, recommended paving of dirt roads and strengthening of surface drainage facilities;
- degree 3 – land of low usability, change of location of the existing roads recommended, the urgent need for paving unbound surface roads and strengthening surface drainage facilities;
- degree 4 – useless land, change in location of the existing roads very urgent.

The ranges (classes) defining particular degrees of usability were determined based on the analysis of the distribution of the studied variable. For this purpose, the Natural breaks classification method was applied in the GIS environment. It permitted the determination of the thresholds of classes, allowing for similar grouping values, and maximisation of differences between classes.

The resulting map in a single calculation process (Fig. 3) was applied in both cases: for the analysis of the location of new roads, and for making the decision on the fate of the existing roads.

The verification of the methodology involved comparisons of results of the performed multiple-criteria analysis with the provisions of the land consolidation project for the Harta village in the extent of implemented changes in the transport network. Combining the content of the map of recommendations with the map of the new road network provided the following results:

- degree 1 – 9.330 km, which constitutes 12.31% of the total length of roads in the study area;
- degree 2 – 0.920 km, which constitutes 1.21% of the total length of roads in the study area;
- degree 3 – 57.525 km, which constitutes 75.88% of the total length of roads in the study area;
- degree 4 – 8.040 km, which constitutes 10.60% of the total length of roads in the study area.

The study area is dominated by roads (with a total length of 57.525 km) for which urgent surface paving and strengthening of surface drainage facilities is recommended. They are roads with a diagonal orientation towards the slope, established on very expansive soils for which it is recommended to design roads on an embankment and strengthen or technologically enhance the ground together with the construction of a relevant drainage system. In such a situation, their proper use and maintenance require the construction of a road with surface paved with asphalt concrete and aggregate, as planned in the project. The provisions of the consolidation project are similar to the obtained analysis results.
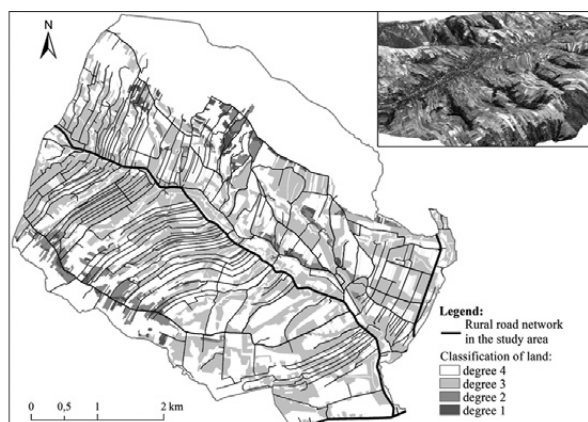

Fig. 3. The resulting map of recommendations

A length of 8.040 km represents roads for which an urgent need of a change of location was determined (degree 4). They are roads running through high quality arable and forest land which should not be allocated for road construction. It should be emphasised, however, that the land use structure is not uniform, but of mosaic character, and in many places despite respecting the rules of rational land management, a certain amount of soils with high production value is still excluded from use for the implementation of public use investments.

Only 9.330 km of roads were included in degree 1. They are roads running in the uppermost parts of slopes. Therefore, a change of the location is not necessary. Also, here the project is coherent with the results of the analysis.

The greatest differences between the content of the land consolidation project and results of the conducted analysis concern the existing rural roads not subject to modernisation work through the land consolidation process. Approximately 66% of the area of land occupied by them was assessed as the land of low usability, where a change in the location of the existing roads is recommended, and an urgent need for paving dirt roads and strengthening surface drainage facilities occurs (degree 3).

Importantly, the local community has a considerable impact on the introduced changes in the transport system in the framework of the land consolidation process. Their expectations concerning the location of roads or properties of the road surface are of high importance because each of the decision-makers shows different preferences as to which criterion is more important and what consequences of decisions are better. Therefore, the decision making process regarding the construction and transformation of the network of rural roads in the land consolidation process should be supported by geographic information systems which through their analytic possibilities permit the development of multiple-variant solutions to a given problem in accordance with the intention of the designer, and selection of the single most appropriate proposal with active participation of the local community. In such a context, the decision making model presented in the article is applicable when one decision-maker occurs, but a number of

ways exist to expand the model and consider many decision-makers or groups in the proposed methodology.

5. Conclusions

The conducted research and analysis allow drawing some preliminary findings regarding the future development of the road network in rural areas:

1. Given limited financial resources for the improvement of local road infrastructure in rural areas, and in consideration of the idea of sustainable development and environmental protection, the arrangement of rural roads should consider the proper choice of road materials and technologies. They include among others: pavements made of recyclable materials, local materials, and grassy surfaces.

2. The application of the multiple-criteria model of spatial analyses in the land consolidation process can support the surveyor-designer in locating new elements of the road network in rural areas, and adjustments of the course of its existing elements. Its advantages include:

- consideration of some criteria in the decision making process, and assessment of the importance of each criterion in comparison to other criteria;
- consideration of the preferences of the surveyor-designer of the consolidation (and other decision-makers) concerning particular groups of criteria – the obtained result does not only depend on the spatial distribution of values of particular criteria, but also on the values of judgements included in the decision making process;
- ordering in a logical structure, verification, and updating of data necessary for the assessment of the existing state and improvement of the transport system;
- presentation to the stakeholders of the obtained solutions in the form of maps, almost in real time, and possibilities of making excellent decisions with their active participation;
- consideration of the requirements of the sustainable development of rural areas, and the possibility of their implementation in the scope of surveying works – land consolidations.

The model is made of modules. This facilitates its expansion by additional criteria and material-technological solutions of rural road construction which change with time.

References

Budzyński, T.; Wrzosek, M.; Wasilewicz-Pszczółkowska, M.; Szczepańska, A.; Krupowicz, W.; Gwiaździńska-Goraj, M.; Goraj, S. 2015. *Changes in Rural Areas in Poland. Spatial and Technical Aspects*. Croatian Information Technology Society. GIS Forum. 88 p.

Cao, C. S.; Chen, L.; Gao, W.; Chen, Y.; Yan, M. 2005. Impact of Planting Grass on Terrene Roads to Avoid Soil Erosion, *Landscape and Urban Planning* 78(3): 205–216. https://doi.org/10.1016/j.landurbplan.2005.07.007

Carr, M. H.; Zwick, P. D. 2007. *Smart Land-Use Analysis: The LU-CIS Model Land Use Identification Strategy*. ESRI Press. 277 p.

Geneletti, D. 2005. Multicriteria Analysis to Compare the Impact of Alternative Road Corridors: a Case Study in Northern Italy, *Impact Assessment and Project Appraisal* 23(2): 135–146. https://doi.org/10.3152/147154605781765661

Józefaciuk, A.; Józefaciuk, Cz. 1999. *Ochrona gruntów przed erozją*. Wydawnictwo IUNG – Puławy. 109 p. (in Polish).

Kowalski, K. J.; Król, J. B.; Radziszewski, P.; Casado, R.; Blanco, V.; Pérez, D.; Viñas, V. M.; Brijsse, Y.; Frosch, M.; Le, D. M.; Wayman, M. 2016. Eco-Friendly Materials for a New Concept of Asphalt Pavement, *Transportation Research Procedia* 14: 3582–3591. https://doi.org/10.1016/j.trpro.2016.05.426

Malczewski, J. 1999. *GIS and Multicriteria Decision Analysis*. Wiley. 408 p.

Nazarko, J.; Radziszewski, P.; Dębkowska, K.; Ejdys, J.; Gudanowska, A.; Halicka, K.; Kilon, J.; Kononiuk, A.; Kowalski, K. J.; Król, J. B.; Nazarko, Ł.; Sarnowski, M.; Vilutienėc, T. 2015. Foresight Study of Road Pavement Technologies, *Procedia Engineering* 122: 129–136. https://doi.org/10.1016/j.proeng.2015.10.016

Nowocień, E. 2003. The Study of Planning and Designing Some Elements of Agricultural Roads Located within Upland Protected Areas, *Electronic Journal of Polish Agricultural Universities* 6(2). Available from Internet: http://www.ejpau.media.pl/volume6/issue2/civil/art-03.html

ProCon.org. *Benjamin Franklin's 1772 Letter to Joseph Priestley*. Available from Internet: http://www.procon.org/view.background-resource.php?resourceID=1474

Radziszewski, P.; Piłat, J.; Kowalski, K.; Bohatkiewicz. J. 2014. *Perspektywy i kierunki rozwoju konstrukcji oraz nowych rozwiązań materiałowo-technologicznych nawierzchni drogowych w aspekcie ochrony środowiska i zrównoważonego rozwoju*. Research Report. Warsaw: Warsaw University of Technology (for the Polish General Directorate for National Roads and Motorways – GDDKiA). 399 p. (in Polish).

Radziszewski, P.; Nazarko, J.; Vilutiene, T.; Dębkowska, K.; Ejdys, J.; Gudanowska, A.; Halicka, K.; Kilon, J.; Kononiuk, A.; Kowalski, K. J.; Król, J. B.; Nazarko, Ł.; Sarnowski, M. 2016. Future Trends in Road Pavement Technologies Development in the Context of Environmental Protection, *The Baltic Journal of Road and Bridge Engineering* 11(2): 160–168. https://doi.org/10.3846/bjrbe.2016.19

Saaty, T. L. 1994. How to Make a Decision: the Analytic Hierarchy Process, *European Journal of Operational Research* 48(1): 9–26. https://doi.org/10.1016/0377-2217(90)90057-I

Saaty, T. L. 2000. *Fundamentals of Decision Making and Priority Theory with the Analytic Hierarchy Process*. Vol. 6 of the AHP Series. RWS Publications. 477 p.

Saaty, T. L. 2008. Decision Making with the Analytic Hierarchy Process, *International Journal of Services Sciences* 1(1): 83–98. https://doi.org/10.1504/IJSSCI.2008.017590

Wawer, R. 2004. An Indicator for Estimating Arrangement of Rural Roads in Terrains Relief and Its Digital Implementation in GIS on the Example of Grodarz Stream Watershed, *Electronic Journal of Polish Agricultural Universities* 7(2). Available from Internet: http://www.ejpau.media.pl/volume7/issue2/civil/art-01.html