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Intelligent evaluation of implementation road infrastructure development program

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Abstract

The problem of development of transport infrastructure of settlements is considered. The application of a target-oriented approach for solving the problem is associated with the necessity to monitor and evaluate the implementation of individual stages of the program implemented within the framework of a public-private partnership, which requires specialized information and analytical support. In this paper, an approach to the development of intellectual tools for linguistic analysis of programs for the development of road and street infrastructure of settlements is proposed. The approach allows taking into account a high level of uncertainty in assessing the technical, economic, social and environmental aspects during the implementation of the program stages. Taking into account these aspects, a hierarchy of typical target indicators is constructed in the form of a system of linguistic variables. The relationships between the indicators of neighboring tiers reflect knowledge about the subject area and are described by fuzzy production rules. The transition from one tier to another is implemented as a procedure based on Mamdani's fuzzy inference algorithm. Using the proposed tools allows you to assess the degree of implementation of individual stages of the program and, if necessary, change the scenario of its implementation.

Keywords: Road; infrastructure; development.

1. Introduction

Developed transport and road infrastructure is an indispensable condition for ensuring sustainable development of settlements and a high level of quality of life of the population (Blewitt, J., 2017). The necessity to improve the road infrastructure is due to both the development of settlements and the increase in technical, economic, social and

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environmental requirements for the organization of transportation of people and goods within settlements, which determines the high practical significance of scientific research aimed at studying various aspects of road infrastructure. An effective mechanism for improving urban road infrastructure is state municipal programs funded on the basis of public-private partnership (Arata, M. et al, 2016) or jointly by local government and central government (Hammes, J. & Mandell, S., 2019).

As part of a comprehensive scientific analysis of programs, recent studies have shown the importance of ensuring transport security (Kaundinya, I. et al, 2016), as well as social (Margorínová, M. & Trojanová, M., 2019; Kim, J., 2019), economic (Leendertse, W., et al, 2016) and environmental (Karlson, M. et al, 2014) requirements, including compliance with restrictions related to energy conservation and carbon footprint reduction at all stages of public transport services (Fontaras, G. et al, 2017). The application of a program-targeted approach to solving the problems of urban street and road infrastructure development is based on the definition of program targets. However, as a rule, the numerical representation used to assess the targets (Graham, D. J. & Gibbons, 2019) does not fully reflect the high level of uncertainty characteristic of the implementation of long-term socio-economic programs in conditions of instability caused by various factors (pandemic restrictions, asynchronous processes of transition to green energy, fluctuations in supply/demand in the transport services market (Ivanyuk, V., 2021), etc.).

The objective of the current study was development of an approach to the elaboration of intellectual tools for linguistic analysis of programs for improving the road and street infrastructure of settlements, which allows taking into account a high level of uncertainty in the assessment of technical, economic, social and environmental aspects during the implementation of the program stages.

2. Materials and Methods

To present the estimated indicators of program performance, we will use the tools of L. Zadeh's theory of linguistic variables. According to (Monte-Serrat, D. M. & Cattani, C., 2020) the linguistic indicator variable (denoted by Ind) takes the form of a tuple:

$$< Ind, D_{Ind}, ITB_{Ind}, SintR_{Ind}, SemR_{Ind} >$$

where Ind – name of the indicative linguistic variable; DInd – the range of numerical values of the considered indicator (taking into account the normalization, it can be assumed that DInd=[0, 1]); ITBIInd – a basic set of indicative terms (we will assume ITBInd = {low, medium, high}); SintRInd – a syntactic rule that allows generating the names of indicative terms from the names of elements ITBInd through the use of linguistic constructions denoting the strengthening/weakening of the property and logical connectives «and» (∧), «or» (∨), «not» (¬); SemRInd – a semantic rule establishing a correspondence between temporal terms and fuzzy subsets DInd. Further, it is assumed that the membership functions of the base terms μ(x) are trapezoidal, as shown in Fig. 1.

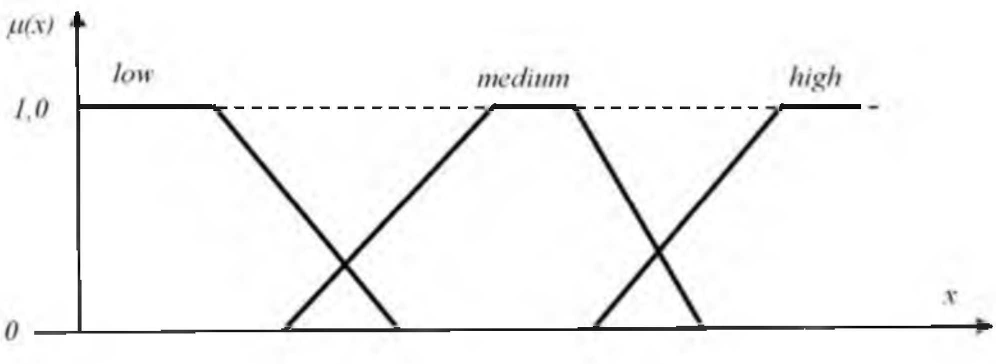

Fig. 1. Graphical representation of the membership functions of the base terms low, medium, high of the indicative linguistic variable Ind corresponding to the estimated indicator.

The semantics of syntactic generated terms is given by membership functions calculated by formulas:

μTerm1«and» Term2 (x)=min{μ Term1 (x), μ Term2 (x)},

μ Term1«or» Term2 (x)=max{μ Term1 (x), μ Term2 (x)},

μ«not» Term (x)=1– μ Term (x),

μ«very» Term (x)=(μ Term (x))2,

μ«not very» Term (x)=(μ Term (x))1/2.

3. Results

Evaluation of the implementation of road and street infrastructure development programs involves not only a direct comparison of the achieved values of indicators with their planned values, but also an understanding of the significance of the degree of achievement of planned values based on knowledge about the subject area. Let's build a hierarchy (tree) of typical indicators of the program for the development of the road infrastructure of a settlement (Fig. 2.), within which the indicators of the lower tier can be directly measured, and the indicators of higher tiers are obtained by generalizing the corresponding indicators of the underlying tier. At the top most tier there is one indicator (Ind0) - a generalized indicator that characterizes the degree of program implementation.

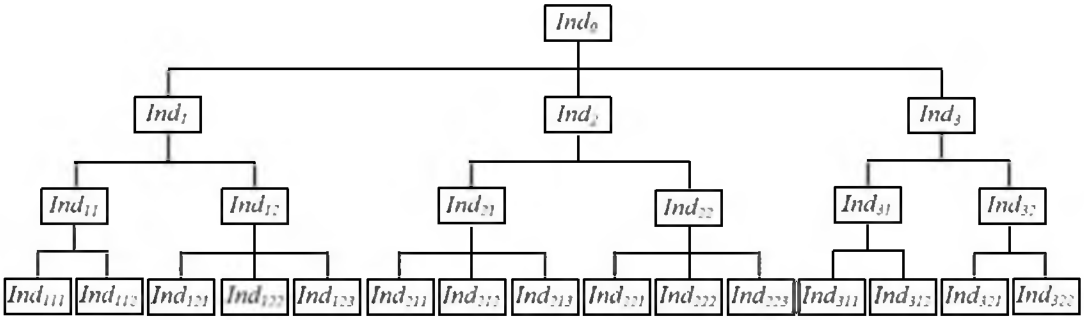

Fig. 2. Hierarchy of indicators for the implementation of the program for the development of the street and road infrastructure of the settlement.

The left branch (subtree) of the program performance indicators tree contains technical and economic indicators:

- Ind1 – generalized indicator of the technical and economic aspect of the implementation of the program;
- Ind11 – indicator of an increase in cargo traffic on the road network;
- Ind111 – number of filling stations and service points;
- Ind112 – share of transport equipped with automated transportation management systems;
- Ind12 – increasing the length of roads that meet regulatory requirements;
- Ind121 – reduction in the proportion of roads in need of major repairs (reconstruction);
- Ind122 – increasing the length of roadsides;
- Ind123 – increase in the length of roads provided with storm sewers.

The central branch (subtree) of the program performance indicators tree contains socio-economic indicators:

- Ind2 – a generalized indicator of the socio-economic aspect of the implementation of the program;
- Ind221 – number of public transport stop complexes;
- Ind222 – length of footpaths;

- Ind223 – length of bike paths;
- Ind23 – improving road safety;
- Ind231 – reduction in the number of road accidents;
- Ind232 – reduction of the number of victims in road accidents.

The right branch (subtree) of the program performance indicators tree contains environmental indicators:

- Ind3 – generalized indicator of the environmental aspect of program implementation;
- Ind31 – reduction of negative impact on the environment;
- Ind313 – increasing the length of roads provided with electric transport infrastructure;
- Ind314 – increasing the length of roadside plantations;
- Ind32 – reduction of direct negative impact on public health;
- Ind321 – reducing the level of pollution of the roadside zone of settlements;
- Ind322 – reduction of the noise level of the roadside zone of settlements.

The constructed standard hierarchy of indicators is not exhaustive. For a specific program (taking into account the specifics of the settlement), individual indicators of the proposed hierarchy may be excluded from consideration and some additional indicators may be included. The proposed hierarchy is an example and can serve as a basis for the development of a hierarchy of indicators for the implementation of a specific program.

One of the central issues in calculating the values of indicators included in the hierarchy is the method of generalization (transition from indicators of one tier to indicators of the next tier). With the numerical type of indicators, the value of the generahzed indicator is found as a weighted sum of the values of the generalized indicators. However, the determination of the weighting coefficients of particular indicators based on expert judgments (for example, by the method of paired comparisons (Saaty, T. L., 2008)) is often quite inaccurate, and changes in expert assessments can significantly affect the solution of the problem (Dmitriev, M. & Lomazov, V., 2014). Within the framework of the approach proposed in the paper, the values of indicators are set by linguistic terms indicating the degree of compliance with these terms. Therefore, it is natural to generalize indicators (transition to a higher level of hierarchy) using the procedure of fuzzy logical inference (Ekel, P. et al, 2019) based on fuzzy production rules describing the specifics of the subject area. Let us give as an example, a system of fuzzy products summarizing the indicators of reducing the total number of road accidents (Ind231) and the number of victims (Ind232) to a more general road safety indicators (Ind23):

if ((Ind231–low $\vee$ medium)) $\wedge$ (Ind232– low) then (Ind23–high);

if (((Ind231–low) $\wedge$ (Ind232–medium $\vee$ high)) $\vee$ ((Ind231–medium) $\wedge$ (Ind232–medium)) $\vee$ ((Ind231–high))$\wedge$ (Ind232–low)) then (Ind23 –medium);

if ((Ind231 – high) $\wedge$ (Ind232– medium $\vee$ high)) $\vee$ ((Ind231– medium) $\wedge$ (Ind232– high) then (Ind23 – low).

The transition from one tier to another is implemented as a procedure based on Mamdani's fuzzy inference algorithm. The choice of the Mamdani algorithm is due to a high level of interpretability compared to other fuzzy inference algorithms (Sugeno, T), which is significant within the framework of the problem being solved. At the same time, the last two stages of the Mamdani algorithm (accumulation of conclusions and defuzzification) are performed only when it is necessary to determine the numerical value of the generahzed indicator, which is not mandatory to obtain the values of the generalized indicators of intermediate tiers. As an example, we give the procedure for determining the numerical value of the generahzed environmental indicator Ind3 (Fig. 3).

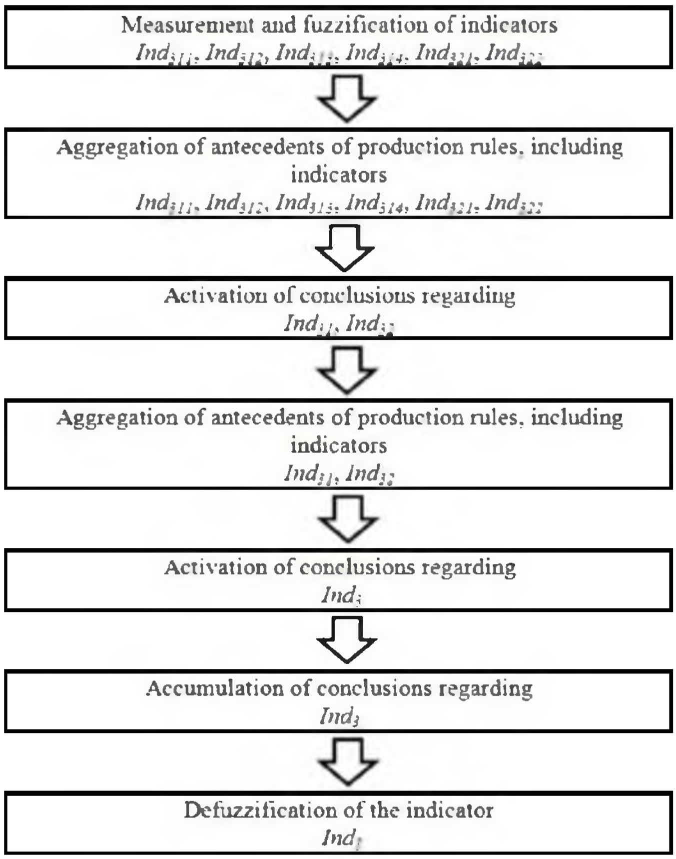

Fig. 3. Scheme of the procedure for determining the numerical value of the generalized environmental indicator of the program for the development of the street and road infrastructure of the settlement.

The procedures for determining the generalized indicators of the techno-economic (Ind1) and socio-economic (Ind2) aspects of the implementation of the program are constructed in a similar way. The value of the overall program performance indicator (in accordance with the proposed approach) is found using the fuzzy inference procedure based on previously defined Ind1, Ind2 and Ind3.

4. Discussion

The approach proposed in the paper to assessing the implementation of programs for the development of the street and road infrastructure of the settlement is focused on the human perception of the results of the programs. To evaluate programs with a high level of uncertainty characteristic of modern (political, social, economic, technological, environmental, etc.) conditions for the implementation of the program, it is advisable to involve experts. Within the framework of the proposed approach, the semantics of terms of linguistic variables (concepts corresponding to program indicators) and the structure of fuzzy production rules (corresponding to the relationships between indicators) are set by experts (specialists in the field of road infrastructure) based on their experience and intuition. The linguistic description of the progress of the program is more convenient for experts than a numerical description. The linguistic description, which operates with the concepts of natural language, is also convenient for users of the road infrastructure (residents of the locality), for whom the program is implemented. Thus, it is advisable to use a linguistic approach for assessing the implementation of road infrastructure development programs, despite some cumbersome data presentation and processing procedures (at least in addition to traditional approaches).

5. Conclusions

In this paper, to evaluate the implementation of programs for the development of transport infrastructure of settlements, a linguistic approach is proposed, within which a hierarchy of indicators (described by linguistic variables) is constructed, a model of knowledge about the subject area is developed (in the form of links between indicators represented by a system of fuzzy production rules) and procedures for fuzzy logical inference of the values of generalized indicators based on the primary measured indicators of the program are constructed.

Estimates of the values of indicators at individual stages of the program can be used to make scientifically sound management decisions on making changes to the program scenario. A set of estimation algorithms supplemented by a system of decision rules can serve as a basis for the synthesis of a multi-scenario program for the development of transport infrastructure (for example, by methods of evolutionary synthesis (Petrosov, D. A. et al, 2018).

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