Parameterization of environmental components in the information-modeling context of roads

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Abstract. The design diagrams for the interaction of natural structures components at various stages of the linear-type facility information modeling have been introduced: territorial planning, pre-design, engineering and detailed design. To improve the reliability of design solutions, the need for more detailed road zoning based on the engineering surveys findings at the design stage has been justified. Bunch of methods for transforming indicators of primary materials in engineering surveys into summarized attributive characteristics of the environment has been proposed. The order of the three-dimensional configuration of linear facility (stations) elements the into the operational territorial units (OTU) for the implementation of the linear road zoning process based on the aggregate taxonomy algorithm has been specified.

Introduction

Current technologies of the information modeling (BIM, TIM) offer the possibility not only to take into account a host of factors that influence upon the elements of the designed structure in the life cycle, but also to control the facility parameters in automatic mode when the influence factors change [1, 2, 3, 4]. By the natural environments parameterization in the roads information modeling system (RIM), we mean the selection of the basic, essential characteristics of the environment, identification of their numerical values and interactions with the elements of the designed facility [5, 6].

The natural factors parameters for calculating the roadbed and road surfacing are defined in the effective standards, providing for the division of the Russian territory into 5 road building climatic zones (RBCZ), three subzones for the 1st road building climatic zone, topographic features and type of locality according to the moisture conditions [7]. Respective dependences are also included in the highways computer-aided-design (CAD-AD) systems to design the roadbed and road surfacing in an automated fashion [8].

Relying upon the recent studies, the need for further structuring of previously formed road-climatic zones is considered [9, 10, 11]. New methods suggest considering the general indicators of engineering and geological conditions as the decomposition factor of the territories into areas and districts.

Scientific developments in this regard are conducted throughout the world, predominantly in the states currently developing their road network. Many of them rely on the MEPDG manual [12, 13, 14, 15], involving software with a large number of the fixed meteorological stations. Automatic data processing for a series of years with creation of virtual meteorological stations for specific projects is provided. The MEPDG manual [16] provides a detailed listing of mechanical and physical parameters
to describe the state of varied geological structures at the groundwork base as well as a set of actions to solve routine design tasks. The structure reliability (R) is defined in this article as the probability (P) that during the service life its state does not exceed the threshold level with respect to the specified criterion and reaches the threshold level only at the end of its service life. At the same time, many foreign and national researchers note the inadequate reliability of roads in severe environmental conditions [17, 18, 19]. Analysis of the widespread defects and damages on the existing roads in Russia bears evidence of the insufficient spatial variability consideration of geological and hydrological conditions along the length of the road [20]. Increasing the level of the territories differentiation in the process of zoning does not solve the problem.

The current state of survey tools makes possible to increase the amount of data on the environment state along the road [21]. Meanwhile, existence of a large amount of unstructured information without the summarized, true-to-fact indicators concerning the natural constituents characteristics does not simplify but on the contrary complicates the possibility of making reasonable design solutions. This collision also appears when adjusting solutions in case of external conditions changing. That means the primary advantage of information modeling is lost: the parametric connection of the natural environment components with the design object elements.

Research objective: improvement of the information base structure on the multidimensional spatial characteristics of natural constituents along the length of the road in conjunction with the spatial modules of the designed linear-type facility in the RIM environment.

**Methods**

Within the system of the highways informational modeling, several levels of the design model distinguish to calculate the parameters of the facility with diverse accuracy and reliability degree. Several documents [22] defined the change in the information processing depth (LOG) from 100 to 350. The environment characteristics at these levels should be mutually causal and relevant to a certain modeling stage.

At the territorial planning level, when selecting options for a highway route, based on a preliminary economic appraisal, it is possible to use sufficiently enlarged characteristics of natural structures according to the road building climatic zones data. The natural complex elements, which define first the heat and moisture rate in the territory, form the basis of the zoning. At the preliminary planning stage for the selected route, the environmental parameters are specified following the differentiation of the selected zones according to the scheme: zone - subzone - district [10, 11]. The general pattern of the interaction of the structures design models with the parametric characteristics of the environment is shown in Table 1.

**Table 1.** The interaction of the road elements parameters with the attributive characteristics of the natural structures at different levels of the design model

| Design model level | Related elements presentation of the designed structure | Level of the geocomplexes parameters detalization |
|--------------------|----------------------------------------------------------|-----------------------------------------------|
| Territorial planning | Road category, route elements, transportation, aggregate estimated value | Road building climatic zones of the RF |
| Pre-design model | Preliminary dimensions, position and orientation of the major road elements: route, engineering structures, road bed, road surfacing, construction planning schedule | Geocomplexes of the territorial zoning: zone-subzone-district |
| Engineering and detailed design | Exact dimensions, position, orientation of all road elements, technological solutions, work execution design | Linear road zoning of the road layout |

For the sound design decision-making at the design stage, it was proposed to define the summarized design characteristics of the natural environmental components based on linear zoning. Bunch of methods of automatic zoning and geoinformatics was accepted as a theoretical background
for the linear geocomplexes forming [23, 24]. The principle method calculation element is the operational territorial unit (OTU). The procedure for the OTU of the linear-type facility creation is described below. The aggregate taxonomy algorithm is applied to combine the OTU into the grades with similar environment components characteristics. The structures obtained as a result of the OUT combination are called linear road complexes (LRC) and creation process of these structures is called linear road zoning (LRZ). The sequence of the LRZ stages is shown in Table 2.

**Table 2.** Implementation of the linear zoning stages based on the findings of the engineering and geological research at the CAD-model level

| Stage | Linear-type facility and decompositio element | Multidimensional signs of the natural environment components | Mathematical method of forming a connection between the environment and facility components | Display format of the natural environment and structural elements of the facility parametric connection | Facility decomposition within boundaries of zone –subzone–district |
|-------|-----------------------------------------------|-------------------------------------------------------------|----------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|------------------------------------------------------------------|
| 1     | Within boundaries of the facility and the RBCZ crossing Station | Physical and climate characteristics | Information analysis, data presentation with breakdown by route stations | Facility decomposition within boundaries of zone –subzone–district | GIS-AD longitude section |
| 2     | Station | Multidimensional vector GIS spatial data | Statistical analysis of information on engineering geological elements (EGE) | Road axis landscape profile | |
| 3     | Station | Summarized data on geostuctures bodies | Statistical series processing when combining the stations in the OTU | Matrix: environment component indicator - OTU | |
| 4     | Operational territorial unit (OTU) | Average probabilistic characteristics of the environment in the OTU | Nuclear taxonomy. Statistical series processing when combining the stations in the OTU | Multidimensional characteristics visualization of natural factors in taxon space | |
| 5     | LRC based on the OTU group | Calculated parameters for the LRC | Aggregative hierarchical geoinformatics algorithm (taxonomy) | | |

The initial data in the road geographic information system at the 2nd stage (refer with Table 2) is represented as multidimensional spatial data. The term “multidimensional” refers to the attributive indicators (numerical or rank) of various environmental indicators; the term “spatial” refers to the data location with vertical positioning to the stations along the road axis. The station is the primary element of road decomposition. To compress the geological information within the station boundaries, the averaged indicators of the soil section are presented in the form of 2 bodies: the first is the mollisol thickness; the second below this mark to the wells base. Mechanical and physical characteristics of the soils (deformation modulus, consistency, adhesion, drained angle of internal friction, degree of heaving, conditional shear resistance, porosity, etc.) are taken as weighted average of engineering geological elements (EGE) depending on the thickness of the EGE layer within bodies boundaries at every station.
Quantitative estimate of soil moisture content due to different boundary conditions for cohesive, granular and dispersed frozen soils is provided in the form of a rank (discrete) scale in grades depending on the type of the soil [14].

Groundwater level data is interpolated with respect to the stations between the wells. Other indicators are distributed by the stations depending on the survey results. These include, for example, the rhythm and depth of the relief dismemberment, orientation of the slopes, etc., converting the data into the rank attributive indicators. Under the perpetually frozen soil conditions (RBCZ I) additional factors are introduced that characterize the natural conditions of this zone.

At the fourth stage, adjacent stations are united into the operational territorial units (OTU) according to the nuclear taxonomy principle (supplement to the previous station). The algorithm for the OTU forming is presented in Fig. 1.

**Figure 1.** The OTU forming algorithm

The OTU basic data is presented in the form of the adjacency matrix “the OTU is an indicator of the environmental component”. As a result of the standard classification algorithm implementation [23, 24] at the fifth stage (refer with Table 2) the OTU are combined into geographically dispersed classes (taxons). Aggregative taxonomy algorithm for the formation of linear road complexes (LRC) is shown in the work [25, 26].

**Results and discussion**

The linear taxonomy result is to obtain summarized natural components parameters for the road structures design as well as a reduction of the natural factors dispersion within the LRC. Variation coefficients comparison for several indicators for the separate LRC with similar values throughout the road is shown as an example in Figure 2.
If the road structure reliability is considered as a function of combination of many factors, including ones of natural character then according to the error propagation formula, the variance of the function (reliability) decreases while reducing the acting factors variance of sum:

$$\sigma_F^2 = \sum_{i=1}^{n} \left( \frac{\partial F}{\partial x_i} \right)^2 \cdot \sigma_{x_i}^2,$$

where $F$ is the function of interest which variance $\sigma_F^2$ is present; $x_i$, $\sigma_{x_i}^2$ function parameter (argument) and its variance.

Thus, the design of the same types of road structures in a more homogeneous environment within the LDC dispersed along the road will help increase the design solutions reliability.

The proposed method has been tested when designing the facilities in severe environmental conditions in Siberian regions. Linear road zoning was carried out when developing projects for 3 facilities with a total length of about 50 km.

The calculations were performed using the “Excel” program. Comparison of the natural factors parameters for the LDC obtained using the taxonomic analysis method, with the data of engineering surveys at the stations was estimated by the linear correlation coefficient, which is theoretically justified measure of the correlation ratio between two rows of indicators. The values of the linear correlation coefficients for the key indicators varied from 0.78 to 0.96. The testing of the correlation coefficients significance was performed using the null hypothesis and Fisher $Z$-transformation. The testing using two methods confirmed the significance of the correlation coefficients and therefore the possibility of applying the taxonomic analysis algorithm to solve the task of linear road zoning.

Summary

The present approach in contrast with other zoning methods reflects the peculiarities of the spatial variability of engineering geological conditions along the road. The experience of this method use in roads design under severe natural conditions demonstrated the method efficiency and appropriateness. In the future, it is intended to use standard geoinformatics programs for the taxonomic analysis and situation modeling on change in environmental characteristics [24]. Statistical information processing at the preparatory stage can be automated as a part of GIS-AD.

Analysis study of the initial information according to the engineering surveys results will permit to assess the conditions of the construction area more accurately, to increase justification of design and
organizational and technological solutions and to use information technologies more widely in the process of technical documentation development for the design and construction of the highways.

References
[1] Information on http://hdl.handle.net/1903/13063
[2] Information on https://iopscience.iop.org/article/10.1088/1757-899X/497/1/012020/meta
[3] Information on http://www.witpress.com/journals
[4] Sarychev D S, Skvorcov A V 2017 Draft BIM standards and regulations for highways (CAD and GIS roads) 1 (8) 9-12.
[5] Construction Rules 333.1325800.2017, Information modeling in construction. Formation rules of the information objects model at different stages of the life cycle. Ministry of Construction of the Russian Federation, Moscow, 2017.
[6] Information on https://sapr.ru/article/15603
[7] Construction Rules 34.13330.2012. Car roads. Ministry of Regional Development of the Russian Federation, Moscow, 2012.
[8] Skvorcov A V 2014 Regulatory and technical support for BIM roads (CAD and GIS roads) 2 (3) 22-32.
[9] Bobrova T V, Efimenko S V 2013 Evaluation of the economic efficiency of accounting for the variability of geocomplexes in the road pavements design (The Russian Automobile and Highway Industry Journal) 4 (32) 136-140.
[10] Efimenko V, Efimenko S, Sukhorukov A, Yankovskaya A 2015 IOP Conf. Series: Materials Science and Engineering 71 (1) (012049).
[11] Efimenko V, Efimenko S, Sukhorukov A 2018 MATEC Web of Conferences 143 (01012).
[12] Information on https://trid.trb.org/view/1131916
[13] Saha J 2011 Evaluation of Climatic Effects on Pavement Performance using MEPD (LAP LAMBERT Academic Publishing).
[14] Information on http://www.iosrjen.org/Papers/vol4_issue4%20(part-2)/C04421326.pdf
[15] Information on http://pubs.sciepub.com/ajcea/2/3/4/
[16] Information on https://fenix.tecnico.ulisboa.pt/downloadFile/563568428712666/AASHTO08.pdf
[17] Kondratev V G, Soboleva S V 2010 The system concept of engineering and geocryological monitoring of the Amur highway Chita – Khabarovsky (Zabtrans, Chita).
[18] Information on https://www.piarc.org/ressources/documents/actes-seminaires0102/c12-mongolie029167.2-4a.pdf
[19] Zhadanova S M 2007 Principles for ensuring the stabilization of the subgrade in the southern permafrost zone (Extended Abstract of Doctoral (Technical) Dissertation. Moscow).
[20] Bedrin E A, Dubenkov A A 2014 Analysis of the causes of excessive deformations on the roads in conditions of high-temperature permafrost (according to the results of monitoring of the Amur highway) (The Russian Automobile and Highway Industry Journal) 3 (37) 48-52.
[21] https://elibrary.ru/download/elibrary_18103289_24953439.pdf
[22] Register of corporate standard, the State Company Russian Highways Avtodor 8.6 2016. Organizational and technological support of the generation of information models for highways at all life cycle stages 2016 (Avtodor, Moscow).
[23] Chaban L N 2004 Theory and algorithms of pattern recognition (Moscow).
[24] Zavarzin A V 2003 Automatic zoning of multidimensional data in vector GIS, Extended Abstract of Candidate of Sciences (Technical) Dissertation (Moscow State University, Moscow).
[25] Bobrova T V, Dubenkov A A 2013 Mathematical model of linear zoning of the road in the zone of permafrost (JOURNAL of Construction and Architecture) 2 362-370.
[26] Kodenceva Yu V 2007 Justification of the resource intensity of the winter maintenance of the road network on the basis of regionalization of territories by adverse climatic factors, Candidate of Sciences (Technical) Dissertation (the Siberian State automobile and highway University, Omsk).