Application of information systems in road-climatic zoning

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Abstract. The article is devoted to the problem of organization and integration of information streams when making territorial road-climatic zoning taking into account geocomplexes of zonal and intrazonal character. The scheme of data acquisition and processing at the stages of allocation of zones, subzones, and road districts is shown. The relevance of the article is due to insufficient consideration of peculiarities of climate conditions while designing of highways in newly reclaimed regions of Russia, for example, Siberia and the Far East.

1. Introduction

The regulatory documents of road industry provide insufficient consideration of climate conditions of the West Siberian region and other Russian regions. Therefore it leads to reduced reliability of highways while commissioning for operation. This also results in significant material and economic losses during their life cycle, associated with bringing of transport facilities to the required conditions.

Nowadays, the tasks of consideration of geographical complexes while designing and construction of roads are mainly solved based on the method of road-climatic zoning of territories. The "zone" was taken as a unit of road-climatic zoning already in the middle of the last century [1, 2]. The "zone" is usually defined as a broad strip of land characterized by a specific combination of heat and moisture, which determines the development of specific and interrelated types of soils and vegetation.

The results of research carried out by famous Russian specialists at Moscow and Leningrad road junctions, [3, 4] (beginning of the thirties of the last century) were taken as a basis when composing standards for designing transport infrastructure facilities. The standards are currently valid in Russia. The findings were extended to other areas, including Western Siberia, and documented in the form of requirements and recommendations. However, the qualitative verification of these results is not always possible on the newly reclaimed areas.

In some regions of Russia, current research is aimed at specification of the boundaries of road-climatic zones. Zoning of separate areas includes overlapping of distribution schemes of zonal, azonal, intrazonal, and regional nature geocomplexes, as well as applying novel solutions – mathematical methods in particular. Considering foreign practice of territorial zoning one should note the experience of scientists from the USA [5]. The effective application of new solutions for road construction industry cannot be implemented due to insufficient development of homogeneity and integrity criteria of the allocated areas, the rules for selection of observation elements, designation of geographical boundaries, as well as the diversity of methods for collecting and processing of initial data. Today, related research in Russian regions is of local nature. It relates only to particular administrative entities due to complexity of the executive organization of work and significant labor and financial costs at their implementation. As there are no unified requirements to work performance on road zoning, the results presented by different researchers are difficult to consider and apply. The aforementioned determines the relevance of the present work. Territorial distribution of boundaries of road-climatic zones considering peculiarities of geocomplexes of zonal, intrazonal, and regional nature should be performed because of absence of a unified methodology for performance of zoning works (within Russian Federation). The methodology should take into account peculiarities of the water-and-thermal regime of roadbeds formed under the influence of various climatic conditions.

2. Problem statement

The methodology of road-climatic zoning should consider additional structuring of territories [6, 7] occupied by zones with allocation of subzones and road districts, for example, on the basis of the taxonomic scheme: "zone – subzone – district" [8, 9].

In this system, the taxon "road district" corresponds to a genetically homogeneous territory characterized by geocomplexes (climate, geology, terrain and other conditions) typical and peculiar only to this territory. Within the territory of the road district, the same-type road structures, especially the roadbed and pavement, should be characterized by approximately same strength and resistance.

The main geocomplex feature of subzones is the terrain. According to the nature of the relief, the terrain is divided into flat, undulated, and mountainous. The guiding criterion at allocation of subzones is the morphostructure significantly affecting design, construction, and usage of auto roads.

The taxon "zone" combines subordinated terms "region" and "subzone" into a subsystem that characterizes the earth's surface with a uniform distribution of heat and moisture, determining the development of certain types of soils and vegetation.

2.1. Brief information on the problem area

The methodical scheme for specification of territorial dislocation of boundaries of road-climatic zones in the system "zone - subzone – district" includes three stages of research [7]. The first stage is aimed at building of information base of geocomplex indicators of zonal and intrazonal nature. Zonal features include climatic conditions that determine the flow of the water-and-thermal regime of roadbeds in the region (average, maximum, and minimum air temperatures, the amount and seasonal distribution of precipitations, evaporation from the land surface, snow height, the depth and the rate of roadbed freezing, the moisture content of the territory). Intrazonal natural factors can vary significantly within the limits of the territory of each zone. Such features can include: terrain, granulometric composition of soils, and other. Indicators considered at zoning can be assigned on the basis of field and laboratory research, consideration of peculiarities of the water-and-thermal regime of roadbeds [10], as well as on the basis of the reference source in relation to control points (settlements) located within the limits of the territorial distribution of zones near hydrometeorological stations.

The second stage of the research on road zoning of the Western Siberia territory consists in component-wise overlapping of geocomplex element distribution schemes, with the involvement of mathematical methods of characteristics processing included in the data base [11]. Features of the solution of the second stage of the work on specification of geographical location of the boundaries of road areas within territorial distribution of zones are discussed in detail in previous works [10].

The third stage of work focuses on positioning of boundaries of districts and zones located within the limits of adjacent administrative entities geographically situated in large regions, for example, in Western Siberia.

2.2. Information systems in road-climatic zoning

Mathematical algorithms for specification of dislocation boundaries of zones, subzones, and road districts consider vector operations, therefore all the initial modelling data is represented in the form of information matrix [9, 12]:

$$\begin{pmatrix} I_1 \\ I_2 \\ \dots \\ I_i \\ \dots \\ I_n \end{pmatrix} = \begin{pmatrix} X_1 & X_2 & \dots & X_j & \dots & X_m \end{pmatrix} = \begin{pmatrix} x_{11} & x_{12} & \dots & x_{1j} & \dots & x_{1m} \\ x_{21} & x_{22} & \dots & x_{2j} & \dots & x_{2m} \\ \dots & \dots & \dots & \dots & \dots & \dots \\ x_{i1} & x_{i2} & \dots & x_{ij} & \dots & x_{im} \\ \dots & \dots & \dots & \dots & \dots & \dots \\ x_{n1} & x_{n2} & \dots & x_{nj} & \dots & x_{nm} \end{pmatrix} \quad (1)$$

The row of the matrix represents a uniform sequence of characteristics of analyzed attributes, the vertical column – a fixed sequence of considered controlled points. Where x_{ij} is the value of the j- th attribute in the controlled point with a number i; m is the number of attributes (the number of columns) characteristic to controlled points; n is the number of controlled points; X_j is the j- th column of the matrix; I_i is the i-th row of the matrix in which the information on the i-th controlled point is recorded. The initial data is standardized by presenting them in dimensionless random values with a zero mathematical expectation and a unit variance.

One major factor that describes the road-climatic zone in an integrated manner is found with the use of the method of principal components of the factor analysis. This factor is a linear combination of parameters and serves as a criterion for classifying the studied territory to a particular road-climatic zone.

Based on the known factor values a polynomial $f(x, y)$ is built for reference points, where for x, y are coordinates of the earth's surface point. The polynomial coefficients are determined by the least-squares method and lines of the polynomial level are built, which define the boundaries of the road and climatic zones, subzones, and districts by groups of intrazonal and regional parameters. Then, an imposition of the obtained results is carried out, and homogeneous territories are allocated by the accepted features.

Mapping of boundary positions for adjacently located zones, for example, administrative entities, as a rule, does not coincide at border segments. Therefore, for the obtained expressions $F1(x, y)$ and $F2(x, y)$ of two neighboring administrative entities, for connecting borders it is possible to use the following solution.

If there is an intersection point, then we shall assume that at this point one line merges into another. If the intersection point in regions is absent, then:

$$F3(x,y) = \frac{F1(x,y)(b-x)(d-y) + F2(x,y)(x-a)(y-c)}{(b-a)(d-c)}, \quad a \le x \le b, \quad c \le y \le d, \quad (2)$$

where (a, c) and (b, d) on lines F1(x, y)=C and F2(x, y)=C, respectively.
The points (a, c) and (b, d) can be assumed, for example, as intersection point of lines F1(x, y)=C and F2(x, y)=C with a common boundary of administrative entities, or points near this boundary point, if the lines do not cross the border.

Division of the studied territories into zones is carried out using the lines of the expression level F11 (x, y), F21(x, y), F31(x, y) (and so on for all administrative entities). Division of the studied territory into subzones is carried out using the lines of the expression level F12(x, y), F22(x, y), F32(x, y) (and so on) corresponding to the second principal factor. Overlaying of the obtained results together with the data on regional factors allows allocating homogeneous territories designated in accordance with the taxon system: road area - subzone - district [13].

3. Conclusion

Among the issues associated with the implementation of the proposed methodical scheme of structured execution of works on road-climatic zoning it is possible to distinguish:

- criterial substantiation of requirements to formation of an information base to prove the territorial distribution of boundaries of road areas, subzones and zones within regionally unified administrative entities;

- development of algorithms for determination of various types of regularities (uninformative, alternative, dependent, binding , pseudobinding, etc.);
- development of a logical-combinatorial optimizing of transformation in the space of optimal subset of attributes and the use of original means of cognitive graphics.

The essence of the latter position is that in accordance with existing representations [14] on the territory, for example Western Siberia, 4 road-climatic zones (RCM) are allocated: I - with distribution of permafrost soils; II - with overmoistened soils (Selyaninov hydrothermal moistening coefficient HTC>1,40); III - with significant moistening of soils in separate years (HTC = 1.00 - 1 40); and IV - with insufficient moistening of soils (HTC = 0.50 - 1.00). The considered territory is characterized by three subzones according to the terrain – flat, undulated, and mountainous. The preliminary analysis showed that within the limits of administrative entities on the territory I RCZ it is possible to allocate three road districts. Within the limits of administrative entities on the territory of II RCZ, according to terrain features and distribution of vegetation, it is expedient to allocate 5 road districts. On the territory III RCZ, according to the same features, it is expedient to conditionally allocate 5 road districts, and on the territory IV RCZ - 2 road districts.

The proposed methodological approach to specification of the boundaries of road-climatic zones in the vast territory of Russia can contribute to a better consideration of road-climatic conditions in the design, construction, repair, and maintenance of highways in regions with poorly developed road network and, therefore, to ensure a decrease in transport and production costs over their life cycle.

The work is supported by Russian Foundation for Basic Research grant (project № 14-07-00673 A).

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