Assessing the Transport Accessibility of Agricultural Lands According to Geospatial Data[1]

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Abstract—The objective of this work was to assess the transport accessibility of agricultural lands in the central and southern districts of Krasnoyarsk krai and Khakassia. An assessment technique based on using geospatial data is presented. The assessment was made based on the use of the Dijkstra's algorithm for searching state space and applying the model of obstacles that are specific to agrarian and agricultural landscapes in the given areas.

Keywords: geographic information systems; state space searching; transport accessibility.

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INTRODUCTION

In the Russian Federation, the problem of assessing the agroecological and economic potential of agricultural lands (ALs) arises when solving issues such as the cadastral valuation of ALs in order to optimize their taxation, assess the market value of lands as objects of economic turnover, assess their investment attractiveness as objects of potential development of agricultural production, etc. In this context, one should emphasize the problem of returning lands withdrawn from service in the years of the post-Soviet agricultural crisis, which is considered, e.g., in [4–5, 11]. In the case under consideration, assessment is a necessary stage of ranking of lands for their step-by-step remediation.

Under the conditions of undeveloped transport network and the remoteness of ALs from agricultural processing points in the vast areas of Siberia and the Far East, the assessment of the transport accessibility of these types of lands is one of the key parameters for solving the considered problems, along with the characteristics of soil fertility, climate, etc. [3–4, 6].

This article considers methods of determining the transport accessibility of agricultural lands in the agrarian and agroindustrial landscapes of the agricultural part of Krasnoyarsk krai and the Republic of Khakassia.

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STATEMENT OF THE PROBLEM

As a rule, the Euclidean metric or the metric of urban quarters are used for assessing the transport accessibility of geospatial objects (GSOs) in geographic information systems [2–3]. The metric of urban quarters has specific fields of application and cannot be directly used for the purposes in question. We apply the Euclidean metric for solving the problems under consideration. Thus, in work [3], it is used to calculate the distance from fallow lands to the open water. However, the direct application of this metric for solving the problem of assessing the transport accessibility of agricultural lands may lead to significant errors. Results of the cadastral valuation of agricultural lands in the central group of Krasnoyarsk krai districts in 2013 may serve as an example. According to them, in some cases, overestimated indicators of the land cadastral values were obtained due to the topographic features of the area and road network features that were not taken into account. This practice eventually leads to an artificial high cost prices on agricultural products.

To improve the accuracy of assessments, methods for determining the transport accessibility of agricultural lands should take into account both topographic factors and natural and technogenic aspects of the respective area. The area under consideration is characterized by factors such as underdeveloped transport system including roads with different types of coverage, the presence of wetlands, developed hydrographic network, wavy landscapes, foothills, and sub-taiga areas. The presented work proposes using assessments based on a functional distance model that takes into account the cost of movement over the rough terrain or over the road network as opposed to direct movement or movement with bypass of obstacles that obstruct the movement.

Formalization of the Problem

Based on assessment of the transport accessibility of ALs, we intend to find the integral numerical parameter that characterizes the degree of complexity of tangible goods from the respective agricultural contour to a target object for economic business management. This assessment is based on analyzing possible movement routes and the algorithm for the optimal route search.

The initial data for solving the task are formed using digital vector topographic base maps. In practice, these maps can be obtained based on the soil maps of the Soviet (post-Soviet) period with the topographic overlay, which were updated according to the space survey data.

For the convenience of data operation, let us turn from the vector image to the raster image, where a separate raster element corresponds to a certain area of the land surface. In turn, the terrain area is a square with side d, which is correctly oriented along the coordinate axes. Let us present the search space in the form of two-dimensional matrix R: $M \times N$. The dimension of matrix is determined by the size of the analyzed area and the quality of initial data, which defines the possible discretization of land surface elements in the model.

Let us match a mark for each matrix element according to the object dictionary (AL, forest, road, ravine, etc.). According to the fraction surface model, the mark of a raster element determines the numerical evaluation of difficulty in traversing the respective area. Another important feature is the mean altitude of the area above sea level.

Let us conventionally divide the sections of the terrain that slow down the movement and increase time for reaching the set point compared to the surface without resistance into three types, i.e., absolute barriers, meaning areas that stop or deflect movement, including rocks, lakes, and rivers; relative barriers, meaning objects that involve high costs to traverse, such as ravines, railway lines, and highways; and conventional barriers, meaning objects traversed without significant difficulties, such as hills and lowlands.

The route is defined as a route laid from point A with coordinates (x_A and y_A) to point B with coordinates (x_B and y_B), where (x_A and y_A) and (x_B and y_B) are the coordinates of the initial and finishing points. Points A and B for the matrix will correspond to elements r_{xy} and r_{kl}, respectively, and $x, k \in [1..N]$ and $y, l \in [1..M]$. Movement is possible both along the coordinate axes and in the diagonal direction. Assume that costs are $\sqrt{2}$ times higher in the diagonal movement than in the movement along axes. In the case of transfer from one raster element to an adjacent one, we assume that the transfer is made from the center of the first element to the center of the other one. The costs of the transfer are the mean value of costs of the movement along two adjacent elements $z_{12} = (z_1 + z_2)/2$.

Route costs are determined by the sum of expenses on all transfers between the points of the route $[Q] = \sum_{i=1}^{N-1} z_{i,i+1}$, where N is the number of points of the route.

To make the search algorithm work in the matrix under consideration, one should make correlations in the graph representation, according to which each element of the matrix is correlated with the respective graph junction, and its arcs form the ratio of adjacency 8 between the adjacent elements of the matrix. To accelerate the operation of the algorithm, junctions that are absolute are removed. Simultaneously, incoming arcs are also removed. This makes it possible to significantly reduce the number of roads to be investigated. In addition, rules based on the distance norm are applied during the search to remove roads with an a priori overestimated length.

Dijkstra's algorithm was used as a search algorithm [7]. The physical significance of assessing the movement cost is to estimate time spent on the movement. The movement cost is calculated by the formula

$$g(v) = (l_e/2)(1/v_1 + 1/v_2), \quad (1)$$

where l_e is the movement distance and v_1 and v_2 are the estimates of speed with which the vehicle moves over the respective types of terrain taking into account possible altitude differences.

TECHNIQUE DESCRIPTION

Let us consider the sequential scheme of implementation of the technique.

1. Collection of Initial Data

According to [1], the collection of geospatial objects (GSOs) is divided into two substages, 1.1 and 1.2.

1.1. Preparation of vector cartographic documents. The initial cartographic material (topographic maps) are selected for the analyzed area. If there are no electronic maps, a series of measures on selection, digitization, geographical reference, and vectorization of hard copy map objects is performed. Mapinfo data formats are used.

1.2. Collection and preprocessing of satellite images with a medium spatial resolution for the analyzed area. This stage includes the use of archival image and current observation data that are publicly available (Landsat 5 and Landsat 7).

1.2.2. Updating geospatial information according to the results of interpretation of satellite images. Depending on the availability/absence of up-to-date data on target objects (ALs including their typification, hydrographic network elements, electric lines, and human settlements), certain vector layers are updated. The technique described in [4] is used to separate fallow lands.

1.2.3. The transformation of data into a form that is convenient for manipulating. A set of digital matrices is formed according to the number of estimated agricultural contours. Each GIS matrices has a rectangular test area that corresponds to it with sides that are parallel to the north–south and east–west directions, and the respective contour within this area. A separate matrix is constructed so that the distance from the westernmost, northernmost, easternmost, and southernmost contour point to the respective rectangle side is equal to distance L (empirical constant determined on the terrain). One of the predetermined types of geospatial objects is established for each corresponding matrix element (pixel). The dimension of the matrix is determined by the size of the estimated contour, parameter L, and the scale of the initial map.

1.2.4. The parameters of the operation of the route search algorithm are set in the dialog with the user (represented by an expert in assessing agricultural lands). Types of friction surfaces and the respective weight coefficients are determined. In addition, parameters for the task of assessing the transport accessibility are specified. Thus, for facilities of types, such as human settlement and ALs, we may choose the facility coordinates which the search should be started from. The variants are the geometric center, the nearest point, or a point chosen by the user. Parameters provided by the algorithm are determined. Thus, for single-type GSOs, we may calculate the distance to the nearest GSO or the collection of distances to all GSOs of this type.

1.2.5. Using Dijkstra's algorithm, a route is calculated for all target GSO pairs within the above-formed constraints.

1.2.6. The user is given a visual route pattern (for visual estimation and control) and the collection of calculation results, which are exported into the MS Excel spreadsheet format for further analysis.

APPROBATION

The software that provides and implements the technique [8–9] was developed using open software development technologies. This is based on the following set of open-source projects and technologies: GDAL open-source library (preparation of geodata for publication), GeoServer open source java project (control of the web-publication of cartographic infor-
1 mation), and open source javascript project OpenLayers (user's cartographic web interface).

The technique was tested on solving the task of making recommendations on the conversion of fallow lands in Mansk raion of Krasnoyarsk krai into agricultural use. Fallow lands with a total area of 31
2 154 ha (plow-land covered with hayfields (14 354 ha) and with forest (16 800 ha)) were identified. Assessments of transport accessibility were obtained for each of the identified agricultural contours with respect to such objects as human settlements, electric lines, and roads.

Currently, the following stage of the technique approbation is being carried out in the area of Sukhobuzimskii raion in Krasnoyarsk krai, which serves as one of the elements of the system of the integrated evaluation of agricultural lands, which is being created in Krasnoyarsk krai.

CONCLUSIONS

A technique for assessing the transport accessibility of agricultural lands based on using geospatial information has been developed. This technique applies the model of obstacles, that has been developed for the conditions of sub-taiga landscapes in the south of Krasnoyarsk krai. It has been tested on solving the problems of remediation of fallow lands in Mansk raion of Krasnoyarsk krai [10]; at the present time, the test site is expanded by the lands of Sukhobuzimsk raion of the krai. The technique can be modified for application under the conditions of agrarian and agroindustrial landscapes in other areas through the adaptation of the model of obstacles with respect to mesorelief features and anthropogenic factors of a specific terrain.

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SPELL: 1. javascript, 2. hayfields