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TIMBER TRANSPORTATION NETWORKS: GIS TECHNOLOGIES FOR PARAMETER DETERMINATION

GIS technologies and CREDO software consist of several major independent systems and several additional tasks combined in an integrated information processing line. Each of software systems automates information processing in different areas (engineering geodesy, engineering geological surveys, design etc.), and adds its data to the integrated information space (models of relief, situation, geology) and to the design solutions for the object to be created.

Introduction. The forest fund of the logging enterprise includes forested areas, forest and non-forest lands, swamps, streams, rivers etc. The special Digital Terrain Model (DTM) has been developed for the purposes of keeping records describing the forest stand characteristics in terms of silviculture and forest inventory and the specific terrain characteristics affecting the location of transport routes. This model can be used to access and determine the forest inventory description parameters quickly. The layered graphical information representation concept was adopted from CAD; however, it underwent major development in GIS. For example, thematic layers in GIS can be made not only in vector form but also in raster form.

The designed software for the timber transportation network location forecasting is based on four principles: universality (real terrains of any shape and area with traceable timber transportation ways can be modeled), flexibility (software can be easily expanded by addition of new components and by modification of existing components, with the software remaining unchanged in its entirety), quick response and interactive mode.

Key provisions. To forecast the location of timber transportation networks on large areas (such as forestries), the initial DTM must be divided into smaller segments (forestry districts), the optimization problem must be solved for each segment (i.e. for each forestry district), and the segments must be merged to synthesize the rational version of the timber transportation network.

The software for the timber transportation way location long-term forecasting includes the timber transportation network alternative generation system and the optimal alternative selection system.

1. *Data analysis.* The data analysis and preparation procedures are based on geoinformation modeling technologies. V. Ya. Tsvetkov [1, 2] has defined the geoinformation modeling as the spatial and temporal data modeling class in which the data organization in GIS is used; in accordance with this organization, each graphical object is closely interrelated with the database table(s). Thus, geoinformation modeling is a modeling class for graphical objects interrelated with databases.

Within the scope of the special digital model design, with GIS directly applied, the layers (patterns) as follows were specified:

– natural and climatic conditions in the design area (climate, relief, hydrographical characteristics, vegetation and soils, geotechnical and hydrological conditions);

– timber transportation network in the gravitation area (motor roads, railroads);

– motor road network condition (years of construction, road category);

– condition of road surfaces, roadbeds, roadsides, bridges, overpasses;

– culverts, small bridges, surface drainage systems;

– road environment, accessories etc.;

– gravitation area economy (industry, agriculture, transport etc.);

– freight and passenger traffic, freight traffic intensity in the existing timber transportation network under the existing conditions;

– freight traffic structure in terms of freight types (freight for industry, agriculture, construction, forestry).

For the purposes of the timber transportation parameter determination based on GIS technologies, the important problem is to provide automatic harmonization of basic design solutions, such as route layout, profile and cross-section, roadbed and pavement parameters etc., in CREDO DOROGI (that means *CREDO ROADS*) software. In GIS, vector data are always object data, i.e. they carry information about the objects but not about their elements; thematic layers in GIS are the specific types of digital map models built by way of combining the spatial objects having total properties or functional features. The combination of thematic layers is an integrated basis for the graphical part of GIS, with the digital and electronic maps providing an integrating basis (the substrate) for GIS.

Operation of the timber transportation network design system can be roughly divided into two stages: data analysis and preparation; optimization.

First, we need to determine whether commercial forests (group II forests) exist in the forestry district of interest. As for this case, in Sloboda Forestry District, the part of Borisov Experimental Forestry, group I forests cover 22.1%, group II forests, 77.9% (with the total forested area 5711.5 hectares).

Then, the commercial forests are identified in which the timber transportation network must be constructed, in terms of their age (i.e. overmature and mature forests, and, if necessary, ripening forests).

The basic timber transportation network design includes: identification of several alternatives for the forest road network location, taking into consideration the forest stand characteristics (in terms of silviculture and forest inventory) and the existing terrain, such as rivers, swamps, existing road network etc; identification of stages in the forest road construction process (see Fig. 1).

The basic timber transportation network shall insure that the forest exploitation will be continuous and non-exhaustive within the felling cycle, taking into consideration the forest age distribution, mature forest stand availability, forest biodiversity preservation. Then, the reporting indicators are calculated for the designed timber transportation network. These indicators are based on two methods applied for determination of the forest exploitation stages. The indicators include the cost of construction of the timber transportation network (by the forest exploitation periods), timber removal amounts (for each plot), length of network sections etc.

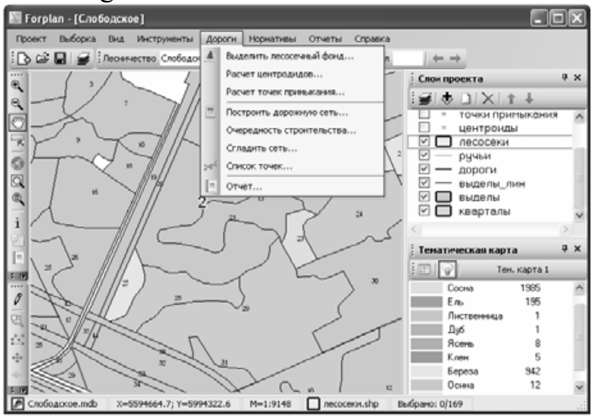
Timber transportation network indicators

Indicator	Construction period				Total
	I	II	III	IV	
Constructed forest roads (km)	4.52 2.65	4.26 3.77	2.79 4.91	6.44 6.68	18.0 18.0
Forest road construction cost (billion Belarusian Rubles)	0.62 0.34	0.62 0.52	0.43 0.83	1.06 1.04	2.73 2.73
Timber removal (thousand m^3)	21.4 21.2	22.8 21.0	21.7 19.0	22.0 23.7	87.9 87.9

Note. Numerator values are calculated by way of the procedure based on the maturity criterion; denominator values are calculated by way of the procedure based on the minimum cost criterion.

The report (see Table) demonstrates that the length of forest roads that must be built for complete exploitation of forests available in Sloboda Forestry District is 18.0 km. In total, the designed timber transportation network will be used to remove 87.9 thousand m^3 of timber; the total construction cost will be 2.73 billion Belarusian Rubles.

The software is capable to calculate great amount of important data, such as the average wood species composition throughout the territory, the total available wood amount, the average wood species composition for the strata of interest, the total available wood amount for these strata, age distribution, calculated growth, distribution in terms of growth.



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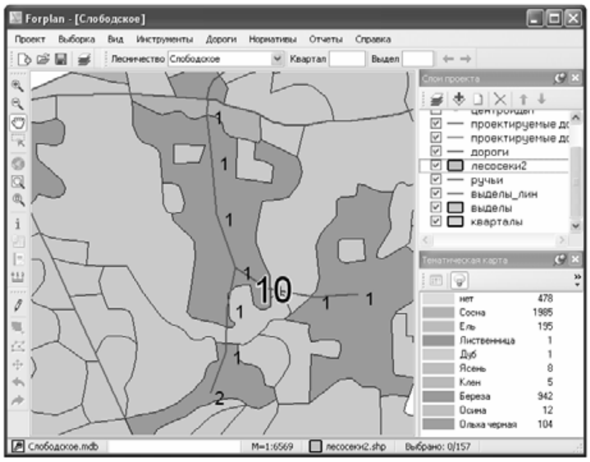

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Fig. 1. Software interface:
a – timber transportation network design procedure;
b – forest road design

Design technology in CREDO DOROGI. With CREDO DOROGI software applied, the forest motor road design process is the particular procedure to be carried out in accordance with the prescribed sequence, because the solutions resulting from a design stage are used as data for a subsequent stage [1].

The forest road route design procedure includes several stages as follows.

Maps preparation. TRANSFORM software is used to scan and transform the necessary parts of topographic maps with contour lines, to superimpose the visibility contours and to save the results for subsequent application as a substrate in CREDO DOROGI software.

Map-based digital relief model design. In CREDO DOROGI software, this model is described by the irregular triangulation (Delaunau triangulation) built in compliance with supplementary conditions imposed by the structural lines on the point field, with the points having spatial coordinates and height.

Digital situation mode design. This model includes areal objects (such as land plots, water bodies, settlements, separate buildings and facilities etc.), linear objects (such as roads, water streams, coasts, power transmission lines etc.) and point objects. In this particular case, the model describes the Forestry District's net of quarters, strata, existing forest road network, forest fund hydrology, contours of swamps, fire breaks.

Forest road route alignment design. Within the scope of the route alignment design, the basic requirements listed in SNB 2.05.07-91 Standard, *Industrial Transport*, were observed, such as minimum horizontal curve radii, maximum longitudinal gradients; natural conditions in the routing area; design area situational features; major watercourse crossing alternatives, passing place arrangement.

Forest motor road profile design, optimization method. In accordance with this method, software shall be used to check whether the designer's requirements are met in terms of minimum permissible radii, maximum permissible longitudinal gradient, and checkpoints.

In the project considered, the sketch line optimization method was applied to design the road profile in accordance with SNB 2.05.07-91. Irrespective of the design method, the basic principles for the profile grade line routing are as follows: compliance with technical design norms (maximum longitudinal gradient, minimum vertical curve radii); earthmoving minimization and reasonable earth mass distribution; grade line routing through the checkpoints (culverts, bridges, overpasses); minimum length of sections with maximum gradients; limitation for minimum lengths of same-sign vertical curves in order to avoid the grade line "instability", to make the route visually smooth and clear, and to ensure traffic convenience and safety (see Fig. 2).

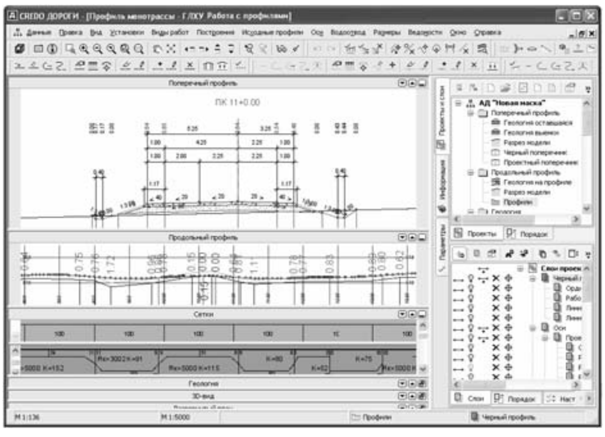

Fig. 2. Forest road profile

Roadbed design. The roadbed is the most variable component of the forest motor road in terms of its design. It must be designed in a way ensuring its durability and stability under repeated stresses exerted by vehicles and natural factors. In accordance with the requirements for roadbeds applicable in various climatic zones, the standard design of roadbed components has been developed. The tailored roadbed design cases, including the roadbed stability analysis, are described in SNB 2.05.07-91, *Industrial Transport*.

Within the scope of the roadbed design for the forest road, the parameters of the carriageway (the single-lane road with passing places), the roadsides (soil part of the roadside) and the roadbed slope were identified, and the amounts of earthmoving were calculated (see Fig. 3).

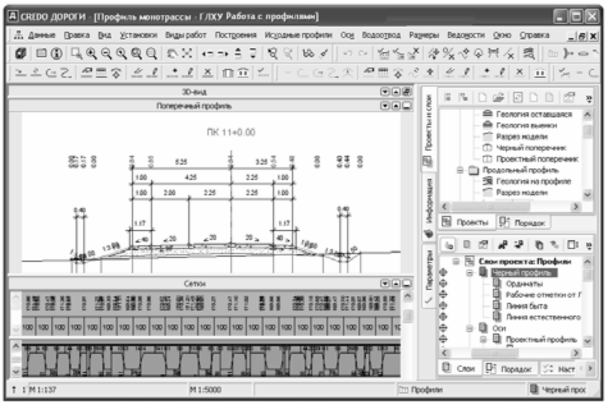

Fig. 3. Single-lane road with a passing place: the cross-section

Drawings and reports preparation and output. This is a final stage of the timber transportation network for Khutor Forestry District, Cherven Forestry. Within the scope of this stage, the forest road route alignment drawing, the road profile drawing and the road cross-section drawing shall be prepared and printed. Also, the work amount reports shall be output.

Conclusion. The developed procedures and data sets involving GIS technologies can be used to implement the new continuous forest management technology, including current updates keeping the forest fund information in line with its real condition, and annual extraction of updated forest fund information in order to keep records describing the forests and to plan the forestry activities. For these purposes, the GIS is used as the primary environment for the timber transportation network design and analysis.

The key functions implemented by the map interface as the GIS component:

– use the information from the map database and factual database to build the map image, i.e. to visualize the information spatially;

– provide access to the objects in these databases, i.e. implement the spatial queries. In these queries, a user can directly manipulate the graphical images on the display to identify, select and access the data.

To make it possible for an expert user to develop an own mapping language freely as a system of symbols, the map data imaging methods are implemented in a way making them independent from spatial data. As a result, the same spatial data contents can be used repeatedly to design timber transportation networks in accordance with the specified tasks.

The key requirements are as follows: the models must use, for their operation, the standard information collected in forestry; the models must be easily configurable for the existing physical and geographical environment; the interface of models must be user-friendly. The basic information in forestry is delivered by the forest management enterprises decoding the aerial photos, field observation data, geodetic survey data and topographic maps to make plane tables and other forest maps and to fill the forest inventory databases [1, 2, 3].

A forest management enterprise applies the basic information technologies to implement the new forest management, and develops the forestry organization and maintenance plan. All data shall be input, processed and stored in special databases, such as a strata-oriented forest inventory database, a cartographical planning material database (geodetic materials, plane tables and other forest maps) or a GIS.

Logging and forestry enterprises implement all scheduled activities, such as various types of fellings, reforestation etc., resulting in changing the forest fund characteristics; for these activities, the designed timber transportation network is used.

For practical implementation of the forestry activity at this level, the system is necessary that would make it possible, first, to make various queries, including their visualization, in order to retrieve maps and other documents necessary for logging and other related works; second, to update the GIS information; third, to use both attribute and map data to prepare the reporting documents.

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