Assessment of road density in logging areas using geographical information systems

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Abstract. In Russia, the density of forest roads is significantly lower than in countries with a developed forest industry. This negatively affects the logging efficiency and the yield of wood per unit area. There are different opinions on the normative and actual values of the density of forest roads in the forest regions of Russia. Today, it is possible to assess the density of forest roads and analyze its development using modern geographic information systems (GIS). In these studies, the density of forest roads is determined using the ArcGIS software package on the territory of two forest districts of the Krasnoyarsk region. Roads located on the investigated areas territory are digitized and divided by types: year-round highway, branch, and logging road. Using the tools of the software package, the lengths and densities of roads are determined by their types. The obtained values are consistent with the indicators of other researchers from different regions of Russia. The results of this task are necessary for planning logging production when searching for wood delivery optimal routes, taking into account natural and climatic conditions.

1. Introduction

Continuous and sustainable forest management depends directly on the availability of forest resources. To date, the issue of wood resources availability has been highlighted in the works of many domestic and foreign scientists, various algorithms for comparing forest fund plots are proposed, as well as, methods for calculating rent and the cost of reforestation, formulas for determining the planned profitability of the site, etc. [1–5]. There are differences of opinion on accessibility, but almost all researchers come to the conclusion that the main problem is the underdevelopment of transport development of forest areas. This problem is especially acute in the northern forestry regions.

There are various opinions of scientists about what should be the normative density of forest roads for high-quality performance of forest management works. Researchers of the St. Petersburg State Forest Technical University determined that a minimum of 10-15 km of forest roads per 1 thousand hectares of forest fund is needed to fully cover plantations by forestry operations [1]. According to other researchers [2], the optimal density of forest roads is 6 km / thousand ha. It is not clear what is the basis for calculating the density of forest roads - the values determined for the optimal level of this indicator differ by 2.5 times. Perhaps the calculation was made for different categories of roads. But even the lower limit of the standard is already impracticable for most forest users. At the same time, the yield of wood from 1 ha of forest per year is directly dependent on the degree of infrastructure development [2].
Countries with the most intensive forestry (Sweden, Finland) are usually characterized by the highest density and better quality of forest roads. The high level of forest accessibility makes it possible and profitable to conduct intense forest care in these countries, which as a result can significantly increase their productivity. In Central Europe and the United States, legislative restrictions are imposed on the maximum density of forest roads in order to preserve the ecosystem, while in developing countries, they are actively being built to increase the volume of forest harvesting, which is often devoid of proper ecological and economic foundations.

For example, in Finland, there is a special method for determining the optimal density of the forest road network. This is achieved by minimizing the cost of constructing and operating the road, as well as the cost of timber transporting by reducing transportation distances: the farther from the forest road is a cutting area, the more expensive is wood harvesting; the denser the road network, the higher the costs of construction and operation. Thus, optimizing the density of the road network comes down to the task of comparing the timber transportation costs with the construction costs [3].

In Russia, the average density of forest roads is 1.2 km / thousand ha, which is less than in other countries [4]. According to S V Pochinkov, comparing the density of forest roads in Russia with other countries of the world is incorrect, since it depends on two parameters: the maximum distance of wood skidding on the logging portages and the concentration of economically available forest resources. The first parameter is approximately the same for all countries, so the density of logging roads is the same everywhere per the developed forest area. There is a significant difference in the specific length of roads per 1 m³ of logging: it depends on the productivity of plantings. If to take the entire area, then the more economically inaccessible resources and the more forests not involved in exploitation, the lower the density of roads. Today, the share of economically inaccessible resources in Russia due to weak demand and poorly developed transport infrastructure is significant and varies depending on the region and forestry at the level of 20-80 % (low forest sites productivity and plantations with a high proportion of hardwoods). In addition, there are still a lot of "untouched" forests. Therefore, without taking into account all these factors, any international comparisons are incorrect [5]. However, one can disagree with S V Pochinkov’s point of view. First, the low yield of wood from 1 ha of forest area in Russia is primarily due to the insufficient density of forest roads; second, the productivity of plantings (quality) also depends on the transport accessibility of forests; third, the low density of the transport network is the reason for the unavailability of significant areas of the forest fund for industrial use, inefficient protection of forests from fires and unsatisfactory amount of reforestation [6].

2. Methods and Materials
Within the scope of these studies, the objects will be the Khrebtovskoye and Gremuchinskoye forestries of the Krasnoyarsk region (figure 1). The total area of forest fund lands of Gremuchinsky forestry is 1 209 495 hectares, Khrebtovsky - 824 918 ha. Logging has been active in this area for several decades. The area of developed territories is 1 383 400 ha. The main part of the harvested wood is transported by road to the Angara river. Then it is transported by water in rafts to the city of Lesosibirsk. The territory is characterized by flat and hilly terrain. Year-round highways connecting the Angara river and the Northern territories of the forest area are laid through the forestries. Branches and winter timber logging roads fork from these roads.
The ArcGIS software package is used for territory analysis and road density calculation. Creating a digital database is performed using modern technical software tools ArcGIS [7-9].

The ArcGIS system is a scalable environment for creating a complete GIS. ArcGIS Desktop is a set of different software applications for creating, editing, deep analysis, and distributing geographic information. ArcGIS has toolsets and geographic data that can be used to model various processes and predict the development of the situation based on the results obtained.

The Line Density tool calculates the density of linear objects in the vicinity of each cell in the output raster. Density is calculated in units of length per unit area. Conceptually, a circle with a radius equal to the search radius is built around the center of each raster cell. The length of each part of the line that falls inside the circle is multiplied by the value of the Population field. These numbers are added up and the result is divided by the area of the circle.

The existing network is analyzed with respect to terrain slopes. For this purpose, the received SRTM data is processed using the "Slope" geoprocessing tool from the "Spatial Analyst" toolset. SRTM (Shuttle radar topographic mission) is a radar topographic survey covering most of the Earth's territory. The exceptions are the northernmost (>60) and southernmost (>54) latitudes and oceans. For this reason, slopes are not defined on the part of the northern territory of the analyzed forestries.

3. Results and Discussion
Roads of various categories have been digitized and added to the ArcGIS system. Figure 2 shows the roads on the slope map of the analyzed forest areas.

![Figure 1. Location of the studied forestries in the Krasnoyarsk region.](image-url)
As can be seen from figure 2, logging and, accordingly, the transport network is developing in the northeast direction with predominant slopes in the territory of less than $7^\circ$.

According to the methodology, using the ArcGIS tools, the density of roads was calculated relative to the entire area and the area developed by logging. The results are presented in table 1.

**Figure 2.** Transport network and slopes of the analyzed forest areas.

| Characteristic                                      | Indicator by territory |
|-----------------------------------------------------|------------------------|
|                                                    | entire | developed |
| Length of all roads, km                             | 3911.9 |           |
| Length of year-round highways, km                   | 770.7  |           |
| Length of the logging branches, km                  | 1740.1 |           |
| Length of temporary logging roads, km               | 1401.1 |           |
| Density of all roads, km / thousand ha              | 1.923  | 2.82      |
| Density of year-round highways, km / thousand ha    | 0.379  | 0.557     |
| Density of logging branches, km / thousand ha       | 0.855  | 1.26      |
| Density of year-round logging roads and branches, km / thousand ha | 1.234  | 1.817    |
| Density of temporary logging roads, km / thousand ha| 0.689  | 1.01      |
According to the data obtained, most of the exploited roads account for logging branches (figure 3). Enterprises prefer not to invest in an expensive year-round highway. The construction of branches allows them to develop the territory without large investments for 5-10 years. Year-round highways have the smallest length, which negatively affects transport costs. In general, the density of forest roads (highways and branches) in the territory under consideration is within the average indicator in Russia. However, the main part of roads accounts for 68% of the developed part of the forest fund. This suggests that the density distribution is uneven, which affects the availability of forest resources and the efficiency of their transportation.

![Figure 3. Distribution of road types in the considered territory.](image)

Assessing the territorial distribution of road density (figure 4), several sections with the highest density can be distinguished. In the main part of the territory, this indicator is extremely low.

According to the authors, this approach to solving the problem determines the density of logging roads most accurately and quickly. This indicator characterizes the developed infrastructure in the forest area.

The results obtained are consistent with the known representations [10, 11] about the density of logging roads. The density of roads in the considered forestries is much lower than in countries with a developed forest industry.

The results of this task are necessary for planning logging production when searching for optimal routes for wood delivery, taking into account natural and climatic conditions [12]. For this purpose, it is necessary to analyze the existing or projected road network, taking into account the terrain slopes, encountered obstacles in the form of rivers and streams. First of all, a graph is built on the road network. Also, these studies can be used to determine the availability of forest resources in the development programs of regions and timber enterprises [13].
Figure 4. The territorial distribution of road density.

4. Conclusion
As a result of the research, it was found that logging and, accordingly, the transport network of the studied territories are developing mainly in the North-Eastern direction. This fact is primarily due to the natural and climatic features of the region, as well as less potential in the development of alternative directions. As practice shows, the entire logging industry of the Krasnoyarsk region is developing in the northeast direction, where the largest reserves of intact forest stands are preserved.

The use of ArcGIS tools made it possible to automate a significant number of calculations in the study and, in particular, to calculate the density of roads, visualize the data obtained, and form a base for further researches. The key direction of the latter is to assess the availability of wood resources in the Krasnoyarsk region, including its northern regions. Another important aspect, for which modern information technologies are extremely necessary, is the correlation of the current and future functioning with the life activity of the indigenous small-numbered peoples of the North, with whom conflict and disputable situations that arise here quite often [14].

The result of the ongoing researches should be a long-term plan for the development of the forest infrastructure of the Krasnoyarsk region, taking into account the complex of mutually affecting factors and the need to increase the availability of wood resources.

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