Characteristics of the transport infrastructure of the Krasnoyarsk territory and its impact on the efficiency of the logging process

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Abstract. Forest infrastructure is an important element of economic development of territories. It is impossible to maintain sustainable forest management without forest infrastructure. Forest infrastructure is the basis of the production and non-production spheres. It creates favorable conditions for work and the life of the population. Forest infrastructure has an impact on the economic development of the timber industry connected regions of Russia. In the process of logging the use of forest infrastructure facilities is necessary. At the same time, the transport infrastructure, its condition, and development have a significant impact on the logging process and its effectiveness. The nature of this dependence is of practical interest. The purpose of this research is to evaluate the development of transport infrastructure and its impact on forest harvesting volumes in the forestries of the Krasnoyarsk Territory. The results of our studies allow to make the following conclusions: the structure and density of the forest transport infrastructure of the region is uneven. Its design lacks regularity and validity. The development of transport routes is chaotic. The dependence of the performance indicators of the harvesting process on the density or length of transport routes is ambiguous and it requires further investigation.

1. Introduction

About 45% of the territory of the Russian Federation is occupied by forests of various productivity and socioeconomic importance. Russia's share in the global forest area is 20%. However, in terms of timber harvesting, Russia lags behind the United States, China and Brazil. The share of Russia is about 6% of the global logging volume. The potential of the forest industry is not used to its full potential. There are many reasons for the unsatisfactory development of forest resources. One of the significant reasons is the underdeveloped forest infrastructure. Forest infrastructure is an important element of economic development of territories, without which it is impossible to maintain sustainable forest management regulated by forest legislation. The state of forest infrastructure has a direct impact on the level of economic development of forestry regions. Being the basis of the production and non-production spheres it creates favorable conditions for work and life of the population.

Forest infrastructure can be called a set of objects in the forest created for the use, preservation, protection, and land reproduction of forests. The objects of forest infrastructure associated with the possibility of moving equipment and people in the forest, storage and transportation of harvested wood
are parts of transport infrastructure [1]. When people talk about forest infrastructure, they mean its transport component, as the functioning, prospects and development of the forest complex depend on the state of the transport infrastructure.

In the process of timber harvesting, the use of forest infrastructure facilities is necessary. The logging industry cannot technologically function without logging roads, timber depots, loading areas, transshipment points, etc. Therefore, it is logical to conclude that the transport infrastructure, its condition and development have a significant impact on the progress of the harvesting process and its effectiveness. The identification of the nature of this dependence is of practical interest.

The influence of transport infrastructure on the efficiency of the logging process has been observed by many researchers [2-5]. Each forest region has its own climatic, economic and historical conditions, therefore the composition of the infrastructure for each of them differs [6-8]. Logging efficiency is evaluated according to many criteria: environmental, economic, technological, ergonomic. The impact of transport infrastructure can affect either all of these indicators or some of them.

The development of the transport infrastructure of one of the leading countries in the forest industry, Finland, was studied by Y.Y. Gerasimov, S. Karvinen, V.S. Syunyov, etc [9]. They concluded that even in market conditions, the government should participate in the planning and development of the transport infrastructure of the forest industry. The government subsidies and control lead to the effective development of forest infrastructure. Russian authors say that the government should be interested in the development of forest infrastructure, participate and subsidize it [7, 8].

The influence of road density on the felling volume and forestry activities was studied at Baikal State University [2]. It has been established that the road density in the region affects the amount of wood harvested from 1 ha, the yield of wood from 1 ha of forest per year is directly dependent on the degree of infrastructure development. When evaluating of the relation between the road density of forestries in the Irkutsk region and the volume of forestry operations (area of forest reproduction, improvement cutting, salvage cutting), it was revealed that there is no obvious connection between these indicators and the study needs some additional research.

In the study [3] researchers studied this issue on the basis of the mathematical model. They developed using the example of the Vologda Oblast. They concluded that the type of road and pavement affects the cost of transporting wood.

Other researchers [10, 11] tell that the development of the transport infrastructure of the region affects the development, stability and efficiency of production in the forest sector. The insufficient development of transport routes can slow down the volume of production. Whereas the presence of high density transport routes can ensure high efficiency of forest enterprises.

The purpose of this research is to evaluate the development of transport infrastructure and its impact on forest harvesting volumes in the forestries of the Krasnoyarsk Territory.

2. Methods and Materials

Krasnoyarsk Territory is one of the largest timber industry regions of Russia, a leader in the production of round timber and sawing products and it has great potential for further development of the forest industry. According to the forest plan, there are a lot of forest enterprises in the region. [12]. On the territory of the region there are several large enterprises of the forest industry, which are of great importance not only for the economy of the region, but also for the economy of the country.

Stable work of forest enterprises is determined by the transport accessibility of forests and uninterrupted supply of raw materials for production [13, 14]. The effectiveness of forestry production, the logging process, and the delivery of raw materials depends on the condition and development of transport infrastructure [15]. According to the forest plan, the main problem of the development of the forest complex of the region is low length of forest roads. This problem leads to transport inaccessibility of forests and a decrease in the profitability of products of the timber industry complex. It happens due to unfavorable pricing conditions with increasing production costs.
In accordance with the forest plan of the Krasnoyarsk Territory, the transport infrastructure of the Krasnoyarsk Territory includes [12]:

- Highways of federal and regional importance with a length of 28.7 thousand km (public roads).
- Specialized roads (logging and forestry) - 24.9 thousand km. The density of roads is on average 1.12 km per thousand ha. About (80.0%) of forest roads are winter roads, which significantly limit the work period of logging enterprises to 6-4 months a year.
- Railways. Railways with a total length of 874 km pass directly through the forest in a number of forestries in the Krasnoyarsk Territory.
- Navigable rivers: Yenisei (4092 km), Angara (1826 km), Kan (629 km) and their tributary streams. They make transport links with the Irkutsk region possible and provide access to the Arctic Ocean.

The transport infrastructure of the region has an uneven structure and degree of development. Some forestries of the region have a high density of roads - Ilanskoye (52.4 km per thousand ha), Manzenskoye (42.8 km per thousand ha), Daurskoye (31.1 km per thousand ha), Rybinskoye (21.8 km per thousand ha), Gremuchinskoye (14.9 km per thousand ha). A high degree of transport accessibility with an optimal road density from 6 to 15 km per thousand ha according to various sources [4, 6] is explained by the fact that the forests of these forest districts have been in forest management for a long time. The transport infrastructure was formed in the past when those forestries had been developed. However, the condition of these roads may not be satisfactory now.

Some forestries of the region practically do not have land transport routes - Baykitskoye, Bolsheuluyskoye, Krasnoturanskoye, Taimyrskoye, Turukhanskoye, Tungusko-Chunskoye, Sharypovskoye. These forestries are located in the northern regions of the Krasnoyarsk Territory, the development of which is difficult or is not planned.

The information on the development of transport infrastructure and the forest harvesting volumes in the Krasnoyarsk Territory in 2018 according to the Forest Plan of the Krasnoyarsk Territory were under study. Initial data are the length of different types of the roads (railroads, paved, year-round, winter roads), their density, the felling volume and the volume of improvement cutting. It should be mentioned that not all roads were taken into account in that source, and the method used for evaluating the transport routes was not defined. Obviously, only logging and forestry roads were not taken into account, which distorts the information.

Analysis and processing of the source data was carried out in Excel and Statistica.

3. Results and Discussion

Figure 1 shows that all year-round roads predominate to a large extent in the region. The uneven structure and density of the transport network indicate that there is practically no planned design and development of the transport infrastructure. The roads were built randomly, with the development of forests for timber harvesting purposes. Roads are designed and built by loggers, the government does not participate in this process.

Within the framework of the studies, the volumes of actually harvested wood and improvement cutting in the forestry of the Krasnoyarsk Territory were analyzed [12]. The analysis of the dependence between the annual felling volume and the volume of improvement cutting with the density of roads showed a relation statistically evaluated as very weak. As it is shown in figure 2 the point scattering diagram is random.
Figure 1. The structure of land transport routes of the Krasnoyarsk Territory.

Figure 2. Dependence of the annual felling volume and the improvement cutting on the road density of forestries in the Krasnoyarsk Territory.

The results of a correlation analysis of the dependence of the annual felling volume and the volume of improvement cutting on transport routes of various types are in table 1.
Table 1. The relation between the actual annual felling and improvement cutting in Krasnoyarsk Territory forestry and the length of transport routes.

| Correlation coefficient with different types of roads |
|-------------------------------------------------------|
| Roads length, km                                      | Road density, km/1000ha |
| railroads hard surface roads all year-round roads winter roads total |                           |
| Actual annual felling                                 | 0.17 | 0.047 | 0.033 | 0.043 | 0.014 | 0.006 |
| Actual annual improvement cutting                     | 0.065| 0.095 | 0.15  | 0.51  | 0.25  | 0.22  |

When evaluating the relation between the annual felling and transport routes, a dependence is obtained, which is estimated as very weak or practically absent. The highest connection strength is in the dependence of the felling volume and the length of the railways. In order to get an adequate dependence, one should take into account not only land types of timber transportation, but also water transport routes.

Correlation analysis showed a strong relation between the volume of improvement cutting with the length of transport routes and their density. In this case, the relation has a scatter, estimated from a very weak dependence to a weak one. The highest correlation coefficient is in the dependence of improvement cutting on the length of winter roads.

The lack of dependence between the considered indicators may be due to the fact that the road density in the forest plan is determined taking into account all transport routes, including public roads. It is calculated per 1000 hectares of the total forestry area. When we talk about the effectiveness of the logging process and forest management in the forest, it is advisable to correlate the density of transport infrastructure with the area involved in forest management. Indeed, the total area of forestry includes areas in which forestry is not conducted or is not planned in the near future (reserve forests, land not covered with forest, not suitable for reforestation, etc.). This hypothesis is based on previous studies. We studied the density of forest transport routes using the example of Khrebtovsky and Gremuchinsky forestry. The research revealed that the main part of the roads is 68% of the developed part of the forest fund (figure 3). Most of the roads are used as logging branches. Enterprises do not want to invest in an expensive all year-round highway. The construction of branches allows them to develop the territory without large investments for 5-10 years.
Figure 3. Road density in Gremuchinsky and Khrebtovskiy forestries.

The total road density is 1.93 km/thousand ha. In the developed area of 2.82 km/thousand ha, which means that the difference is significant. Therefore, determining the dependence of logging efficiency on the road density, one should recalculate the road density in relation to the area involved in forest use, and determining the dependence of the effectiveness of forestry measures on the road density. The road density in relation to the area involved in forestry according to regulatory requirements should be recalculated.

In the study the dependence of the specific gravity of timber harvesting of the periodic yield on the road density was also analyzed. Based on the data of the Forest Plan of the Krasnoyarsk Territory in 2009-2017, specific gravity of timber harvesting from the calculated felling rate was determined for the areas of the region.

It can be seen that the highest concentration of the specific gravity of timber harvesting (the level of development of wood resources) is in the range of 7-30% with a road density of 1-12 km / 1000 ha. The median of the obtained values is 3% at 18.7 km / thousand ha. The data obtained indicates the most characteristic ratio of logging and road density in the regions (figure 4).
Figure 4. Specific gravity of timber harvesting of the calculated felling rate in the areas of the region.

4. Conclusion
The results of our studies allow us to make the following conclusions.

The structure and density of the forest transport infrastructure of the Krasnoyarsk Territory is uneven. Its design lacks regularity and validity, and the development of transport routes is chaotic.

The dependence of the performance indicators of the harvesting process on the density or length of transport routes is ambiguous and requires further study.

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