Bases of transport development organization of leased forest plots taking into account climate

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Abstract. The article raises the issues of zoning of rental forests taking into account climatic factors for the purpose of rational transport development of forests. The basis of the methodology for taking into account the influence of climatic factors in the organization and planning of forest transport processes through the average speed of timber trucks is proposed. The results of studies are given that allow taking into account the climatic parameters of the area where the enterprise is located.

1. Introduction
Insufficient provision of rental forests with transport network continues to be one of the key problems of the modern forests of Russia. The solution of this question is the most important stage in the program of work of the modern timber processing enterprise. According to the existing forest legislation \cite{1} the enterprise must have a forest development plan, the preparation of which is impossible without the development of an optimal transport network of forest roads. Without taking local conditions into account as fully as possible, the transport development strategy seems unlikely.

One of the factors that have the greatest impact on forest roads is the climate. A significant part of the forest resource bases of logging enterprises is located in areas with unfavorable soil and hydrological conditions, which leads to seasonality in the work of logging and forest transportation sites of enterprises. Thus, the identification of the degree of climatic influence factors on the processes of logging and forest transport operations is a very important and urgent problem, especially in recent years, when abnormal climate fluctuations cause significant interruptions in the work of enterprises, associated primarily with the late onset of frost or heavy snow. Abnormally hot summer, in turn, leads to an increase in the number of forest fires, prevention and control of which are also the problem of tenants.

2. Methods and Materials

2.1. The main provisions of the optimization of forests transport development taking into account climatic factors
The density of the transport network of a logging enterprise is traditionally considered one of the most important indicators of its production activities. In modern realities, this parameter continues to remain
significantly less than the normative values, which is due to both economic and legislative difficulties. On the other hand, the transport component of the enterprise is increasingly beginning to have an unstable climatic situation observed in recent years. Therefore, when solving the problems of optimizing the location of transport routes in rental forests, one should pay attention not only to traditional restrictions, such as soil and hydrological conditions of the area, the availability of local road-building materials, technological features of forest transport, but also to the climate of the region where this company is located.

Transport and technological processes are carried out in the open air, being under the direct influence of all climatic factors and weather phenomena. Climate and weather significantly affect both the state of the driving surfaces on which the forest machines move, the components, assemblies and systems of the machines themselves, as well as the emotional and psychological state of the driver (operator). In addition, weather and climate determine not only seasonal changes in the subject of labor (whole tree), but also the conditions of the logging and transport process, which determines its safety and effectiveness. In order to organize transport and technological processes in such a way as to ensure efficient and safe execution of all operations in different weather and climate conditions, it is necessary to understand and evaluate these effects and dependencies.

The theory of organization of logging and transport processes taking into account the influence of climate is a qualitative and quantitative description of the nature and patterns of changes in the parameters and characteristics of processes occurring under the influence of climatic factors. Using the methodology of the system approach, the structural diagram of the system can be represented in the form of the following subsystems: "environment" - "operator (driver)" - "forest machine" - "driving surface".

The peculiarity of the impact of weather and climatic factors on the functioning of the logging and transport system, shown in table 1, is that one part of the meteorological elements simultaneously affects all or several subsystems, while the other only affects some of them.

**Table 1.** The impact of weather and climate factors on the cutting and transport system.

| Weather and climate factors | Operator (Driver) | Forest machine (mechanism) | The object of labor (whole tree, stem) | Driving surface (road) | Performance indicators |
|-----------------------------|-------------------|----------------------------|--------------------------------------|-----------------------|-----------------------|
| Atmospheric pressure        | $P_0 \cdot t_0 \cdot V_i$ | $N_0, q$                  | -                                    | -                     | $C_1$                 |
| Temperature                 | $P_0 \cdot t_0 \cdot V_i$ | $N_0, q, U, K_0$          | $t_0, A_p$                           | $\omega, \varphi$    | $T_0, C_0, C_1$       |
| Humidity                    | $P_0 \cdot t_0 \cdot V_i$ | $N_0$                     | $t_0$                                | $\omega, \varphi$    | $C_0, C_1$            |
| Visibility                  | $P_0 \cdot t_0 \cdot V_i$ | $W, U, K_0$               | $K_i$                                | $\omega, \varphi$    | $T_0, C_0, C_1$       |
| Rainfall                    | $P_0 \cdot t_0 \cdot V_i$ | $W, U, K_0$               | $K_i$                                | $\omega, \varphi$    | $T_0, C_0, C_1$       |
| Snow                        | $P_0 \cdot t_0 \cdot V_i$ | $W, U, K_0$               | $K_i$                                | $\omega, \varphi$    | $T_0, C_0, C_1$       |
| Wind                        | $P_0 \cdot t_0 \cdot V_i$ | $U, K_0$                  | $K_i$                                | $\omega$             | $T_0, C_0, C_1$       |
| Snowstorm                   | $P_0 \cdot t_0 \cdot V_i$ | $W, U, K_0$               | $K_i$                                | $\omega, \varphi$    | $T_0, C_0, C_1$       |
| Ice                         | $P_0 \cdot t_0 \cdot V_i$ | $U, K_0$                  | $K_i$                                | $\varphi$            | $C_0, C_1$            |
| thunderstorm                | $P_0 \cdot t_0 \cdot V_i$ | $K_i$                     | $K_i$                                | -                    | $T_0, C_1$            |

where, $P_i$ – psychological tension, $t_i$ – reaction time, $V_i$ – information processing speed, $N_0$– engine power, $q$ – fuel consumption, $U$ – stability, controllability, $K_0$– security, $W$ – visibility, $t_0$ – storage time, $A_p$– specific work of cutting and sawing, $K_i$– roll safety, $\omega$– resistance to movement, $\varphi$– adhesion coefficient, $S_i$ – visibility distance, $T_i$ – continuity, $C_i$ – transport component of cost, $C_i$– road component of cost.

At the end of the 70s at the Department of Land Transport Forest of Forest Engineering Academy Professor B Alyin with his team began research work aimed at developing the applied aspects of logging meteorology [2]. The main objective of these studies was the development and justification of
logging technologies and transport operations, which make it possible to take into account and effectively use the weather and climatic conditions of the region, as well as to reduce damage from dangerous meteorological phenomena.

As a result of the initial analysis, it was found that the climatic factors have the greatest impact on the forest transport process, which primarily determines the seasonality of logging. In turn, in the forest transport process, the most dependent on weather and climate are secondary roads the performance of which is determined, first of all, by soil moisture and its deformation modulus. Therefore, to improve the efficiency of forest dirt roads, the rational organization of the entire forest transport process, knowledge of the laws governing changes in soil moisture and their water-thermal regime is necessary.

In the forest industry, up to the present time, there are no long-term systematic observations of soil moisture of forest roads. However, agroclimatology has accumulated a large long-term statistical material of observations of soil moisture in the open field. These data, as can be seen from the studies [2], can also be used to determine the estimated soil moisture on summer dirt roads. The possibility of such an approach is based on a close correlation between the soil moisture of the open field and the soil moisture of the secondary roads soil bed at their location in the same soil-hydrological conditions. The difference will be only in the absolute values of soil moisture in the field and in the roadbed, due to the presence of drainage system and construction of the canvas. This difference can be taken into account by the transition correlation coefficient from soil moisture in the field to soil moisture of the subgrade.

When creating an optimization system logging processes of development of forests taking into account the influence of climatic factors is most appropriate to start with zoning of the territory of the forest resource base and forest transport routes, taking into account seasonality. It is necessary to take into account not only the requirements for transport, but also to take into account the features of logging [3], to ensure the continuity of the chain "logging - forest transport".

2.2. Basic principles of forest zoning

As the main principles of the enlarged zoning of forest areas in their transport development, the following principles can be specified:

- fragmentation of the forest by insurmountable obstacles in the form of railways not equipped with crossings, pipelines, water protection zones, etc;
- allocation of zones of unconditional winter transport, determined by obstacles, that can be overcome only in the winter period. These include large rivers crossing the forest, where there are no year-round crossings, long swamps and lakes;
- allocation of seasonal removal zones.

As already mentioned, the seasonal zoning of transport accessibility should be linked to the seasonal planning of logging operations [4], thus there is a possibility of close synchronization of harvesting and transportation of wood, which allows for a more rhythmic supply of timber to the enterprise and reduce losses from long-term storage of wood at forest terminals [5].

Depending on the bearing capacity [4], forest soils can be divided into 4 groups, on the basis of which there are four zones of seasonal transport accessibility according to soil conditions:

I. only winter timber removal;
II. transportation in the winter and summer;
III. transportation in the winter and summer-autumn period;
IV. year-round transportation.

In the spring, it is most expedient to transport the timber along year-round roads or work from stocks collected at terminals on paved roads and accumulated during winter harvesting, as such wood is less prone to spoilage and quality decrease.

It is preferable to conduct territorial zoning according to seasonal transport accessibility for the entire rental area in order to draw up a development plan for the entire rental period.
Thus, when setting the mentioned task of transport optimization it is necessary to rely on the following key points:

- The planning period is 10 years.
- The iterative step in planning is 1 month.
- The forest is considered as fragmented.
- The nodes of the transport network are forest terminals, organized at highways and branches.
- Year-round and seasonal branches, highways and public roads are considered as components of the transport network.
- The transport network is “pulsating”.
- The relevance of the road is determined by the cost of transportation, consisting of road, transport and climate components.

2.3. Accounting speed parameters in the system to optimize the transport of forest development

The speed of the timber truck \([6, 7]\) can act as a central indicator of the state of the road and be used as a criterion in systems for optimizing forest transport processes in the development of leased forest.

For a complex assessment of influence of various climatic factors, the average annual security factor of the estimated speed should be used \([8]\). Taking as a basis the data of climate directories, it is necessary to obtain the probability of occurrence of meteorological phenomena. The calculated dependence for determining the average annual security factor of the estimated speed in this case is as follows (1):

\[
\bar{K}_{as} = \int K_{cs}(x) \cdot A_T \cdot P(x) dx,
\]

where, \(K_{cs}(x)\) –the coefficient of security of the calculated speed of the meteorological factor; \(A_T\) – time action meteorological factor operator; \(P(x)\) –probability of action of the meteorological factor \(x\).

The greatest influence of climatic factors is affected by forest roads with transitional type of coating, as well as secondary roads \([1, 9]\). During the period of increased moisture, such roads, especially with a dirt surface, are prone to rutting.

Thus, the speed indicator is advisable to use to assess the degree of patency of forest roads in real time. Having established the relationship between the high-speed regime of the forest road and climatic factors, we get the opportunity to quickly respond to the negative effects of climate, timely restricting movement. On the other hand, it becomes possible to predict the possible state of the transport network, having on hand an accumulated array of speed data (for both light and heavy road trains, taking into account the road structures used for transportation) and the climatic parameters of the region, by establishing possible critical periods when there is a danger of the destruction of the road by timber trucks.

The basis of the proposed methodology was the study of the data of the waybills of the timber road trains operated by OAO Timber Industry Complex Kipelovo (The Vologodskaya region). Records of the local weather station (atmospheric pressure, air humidity, rainfall, wind speed, average daily air temperature) and the main climatic parameters for the Vologodskaya Region (albedo, average soil temperature) were used as a source of meteorological data \([10, 11]\).

The studied road trains were divided into two groups: "Group 1" (based on MAZ type vehicles) and "Group 2 " (based on Ural type vehicles). The roads were divided into the following categories: 1 - year-round main roads; 2 - branches of summer action; 3 - branches of winter action.

Using correlation analysis in the STATGRAPHICS system, the factors that have the strongest influence on the average speed of movement were selected. These include: time factor, road category, surface albedo, average soil temperature and average air temperature.

Based on the results of the analysis, the following conclusions can be drawn about the influence of these climatic factors on the average speed:

1. It is advisable to consider separately the model for timber trucks of Group 1 and Group 2;
2. A steady increase in the average speed for timber trains of Group 1 is observed in the warm period of the year (from May to September), with a significant decline in the autumn period and a slight increase in the winter months (figure 1);

3. For timber trucks of Group 2, a relatively stable average speed is observed during the period from November to February, with a significant decline in April and a slight increase in the summer months (figure 2);

![Figure 1](image1.png)

**Figure 1.** Change in the average speed of the group 1 timber trucks during the year.

![Figure 2](image2.png)

**Figure 2.** Change in the average speed of group 2 timber trucks during the year.

4. Timber trucks of the 1st group tend to decrease the average speed depending on the simplification of the road structure, while for road trains of the 2nd group the speeds of movement along highways and "winter roads" differ slightly, and a noticeable decrease in the average speed is clearly visible for the summer branches;

5. With an increase in the average soil temperature, the average speed of the Group 1 timber trucks increases more intensively than that of the group 2 timber trucks, which, in turn, clearly show a decline in the average speed at about zero temperatures.
6. With the increase in the average air temperature, the average speed of the Group 1 timber trucks changes little, however, when moving to a positive temperature range, a jump in the average speed is clearly noticeable, which is obviously due to a change in the vehicle’s adhesion to the road surface;

7. With an increase in the average air temperature, in the sub-zero temperature range, the average speed of Group 2 timber trucks gradually decreases. When crossing $0^\circ$ C, a gradual increase in the average speed of the trains.

At the next stage of the research, equations were obtained that describe the influence of climatic factors.

- for Group 1 timber trucks (km/h):
  \[
  V_1 = 0.162814 \cdot a + \frac{35.8485}{k_t} + 0.0443855 \cdot t_s^2 - 0.025966 \cdot t_a^2
  \]  

- for Group 2 timber trucks (km/h):
  \[
  V_2 = 0.192589 \cdot a + \frac{26.5996}{k_t} + 0.0409256 \cdot t_s^2 - 0.0412448 \cdot t_a^2
  \]

where, $a$ – surface albedo, %; $k_t$ – coefficient taking into account the category of (1.0 - highways; 2.0 - summer branches; 3.0 - winter branches); $t_s$ – average soil temperature, °C; $t_a$ – average air temperature, °C.

3. Conclusions

The theory of organizing logging and transport processes taking into account the influence of climate should be based on a qualitative and quantitative description of the nature and patterns of changes in the parameters and characteristics of logging and transport processes occurring under the influence of climatic factors.

The greatest impact of meteorological factors on the functioning of the logging and transport system is carried out through the interaction of the machine with the driving surface. The most dependent on the weather and climate are secondary roads, the performance of which is determined primarily by the moisture content of the soil and its deformation modulus.

To improve the efficiency of forest dirt roads, rational organization of the entire forest transport process requires knowledge of the laws of soil moisture changes, their water-thermal regime. Statistical processing of observations of soil moisture in different climatic zones and weather conditions will allow to establish the regularity of changes in moisture reserves for the year.

Seasonal zoning of transport accessibility of rental forests should be linked with seasonal planning of logging operations, thus there is a possibility of close synchronization of harvesting and transportation of wood.

The speed of the timber truck can be used as a criterion in systems for optimizing forest transport processes in the development of leased forests and act as a central indicator of the state of the forest road.

It is expedient to consider the differentiated models of the account of influence of climatic factors on average speed of the movement of the timber carrier, depending on its group and category of the forest road.

When creating optimization systems for the transport development of forests, it is necessary to take into account the influence of climatic factors through the average speed of trains, comparing it with the normative established for this section of the road, which makes it possible to judge the state of the road structure and allow timely removal of the forest road from operation.

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