Research of the Logging Trucks Speed Dependence on Natural and Climatic Factors

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Abstract. One of the parameters that allow us to predict the capacity of forest roads is the speed of the logging truck. It can act as an indicator of the road condition and be used as an optimality criterion for optimizing timber transport processes in the development of forest massive. This article is devoted to the study of the dependence of this indicator on natural and climatic factors when driving on various categories of forest roads at different times of the year. The object of the research is automobile logging roads located in the intensively used logging areas of the Krasnoyarsk territory. To obtain regression equations, the planning of the experiment was performed. Regression models were found that describe the influence of road slope and the amount of precipitation on the speed of a logging truck. The indicated dependencies are obtained for different categories of roads and periods of the year when driving in empty and cargo directions. All equations have fairly high accuracy and are statistically significant. The constructed dependencies are graphically illustrated. The results obtained can be used in planning the development of a road network in the forest area, selecting means, methods, and volumes of wood removal.

1. Introduction

When determining the accessibility of forest resources, an important element is the calculation of the maximum possible volume of wood removal under certain natural-climatic and production conditions.

The capacity of transport routes depends on a large number of factors: road conditions (carriageway width, longitudinal slope, radius of curves in the plan, visibility distance, etc.), composition of the cars flow, the availability of regulation means, weather and climatic conditions, the possibility of maneuvering the car across the roadway, psychophysiological characteristics of drivers and vehicle design [1, 2]. Changes in these factors lead to significant fluctuations in throughput during the day, logging period, and year. With a frequent location of obstacles on the road, significant speed fluctuations occur, resulting in an appearance of a large number of cars moving in groups, as well as a decrease in the average speed of the entire stream.

Analyzing the presented information, factors can be divided into two groups: controlled factors related to a person (the condition of the road surface, geometric parameters of the road, intersections, and junctions of roads) and unmanaged natural and climatic factors.

Traffic conditions on the roads during the period of adverse weather events are much more difficult than in the summer with a dry, clean surface and roadsides. The differences are determined by a number of factors, the main ones are:
- a decrease in grip qualities of the coating, change in the mechanical interaction of the car with the road and deterioration of the evenness of the coating under the influence of precipitation, ice, fog, high humidity, and other factors:
- an increase in resistance to movement due to deposits of snow, mud, ice, the appearance of irregularities on the road, which reduces the free power of the car engine;
- changing the shape and appearance of the roadway and shoulders, changing the parameters of the transverse profile due to snow deposits and formation after rolling, which leads to a change in the driver's perception of the road;
- a decrease in meteorological visibility during periods of fog, precipitation, blizzard, blinding sun, which changes the driver's perception of driving conditions;
- deterioration of the operational and technical qualities of the vehicle and systems for ensuring the convenience and safety of traffic, which include the brake system, steering, safety and visibility systems, and the signal system.

The higher the category of road, the intensity and speed of traffic, the less noticeable the impact of natural and climatic factors on the traffic mode. Among them, the greatest influence has precipitation of various types, the slope of the transport path, the visibility distance and wind speed. At the same time, they have different meanings at different times of the year on different categories of timber roads (highway, branch and logging road).

The development of mathematical dependencies for calculating the speed of timber transport is a topical task. To date, the works of many scientists have been published on this issue. In the works [3-5], calculated dependencies are given for determining the speed of a logging truck train in all traffic modes, taking into account all the main factors that affect traffic indicators. The results obtained are characterized by high accuracy and closeness to real values. However, the influence of natural and climatic factors in these studies is partially reflected. This view of the solution to the task can be called one-sided since, in the conditions of the domestic logging industry, the problem of seasonality is critical and determining in the issue of wood removal.

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The object of the researches [6, 7] is the characteristics of the roads used for timber removal. The authors use practical observations of individual sections of the road to identify patterns in changing speed modes of moving vehicles. The obtained dependencies can be used to model the movement of logging equipment. This approach, based on practical observations and projection of results to similar situations, is scientifically sound and is often applied in practice. However, the accuracy of calculations is not high enough for practical application, use in mathematical or computer modeling. The reason is the mutual influence of factors that takes place in practice. In this regard, it becomes difficult to distinguish the influence of a single factor for its projection on another situation and is not feasible in practice.

In the paper [8], mathematical dependencies describing the influence of climate factors on the speed of different groups of logging trucks are presented. However, this study does not reflect the dependence on such a factor as terrain, which has a significant impact on this indicator.

The purpose of these studies is to find the dependence of the logging trucks speed on such natural and climatic factors as the transport path slope and the amount of precipitation when driving on different categories of timber roads (highway, branch, logging road) at different times of the year.

2. Theory and experimental
The object of the study was automobile forest roads located in the intensively used logging areas of the Krasnoyarsk territory (Yeniseisky, Motyginsky). The study used data on the speed of logging trucks when transporting wood from the forest territory to the coastal lower warehouses during the logging season 2019-2020. Data on natural and climatic factors for similar periods of time were analyzed, which are stored in archived weather data on an electronic resource rp5.ru according to the corresponding meteorological posts (Yeniseisky, Motyginsky).

Due to the heterogeneity of natural-climatic and production conditions in different time intervals, as well as the possibility of their classification by the closest characteristics, the entire logging process
including taking into account the wood removal from the forest territory) is divided into five periods [9]: winter, winter-spring, spring, summer, and autumn. However, the winter-spring and autumn periods fall on off-road, when no removal is carried out, so they were not analyzed. The values for the experiment were taken under the following temperature conditions: in winter at negative temperatures during the day and night, in winter-spring at negative temperatures at night and positive temperatures during the day, in summer at positive temperatures during the day and night.

In addition to climatic factors, the speed of removal is also affected by production ones. The most significant are the type of road (highway, branch, logging road) and the direction of traffic (freight, empty). For each of these conditions, its own dependence is built.

Such factors as visibility distance and wind speed have almost no effect on the logging truck speed when moving along the branch and logging road, but can affect it when moving along the highway. To identify the dependence of the logging truck speed on the highway from all the considered factors, as well as the cross-factor dependence, 75 observations were made, consisting of measurements of the truck speed on the highway, the value of the slope, amount of precipitation, visibility distance, wind speed. The researches were conducted under other equal conditions: the section without turns is more than 300 m, the analyzed slope ±20 is more than 300 m. In this case, a uniform speed is achieved without the influence of these factors.

For the experiment, information was collected from the following resources:
- summary report of the movement (position) of a logging truck along its route, generated from a GLONASS source into the Microsoft Excel table editor;
- maps https://www.google.com;
- Google Earth Pro program;
- archive of meteorological data https://rp5.by/Weather_in_Krasnoyarsk

The routes of the logging truck in the cargo and empty directions were analyzed. The slope magnitude, type of road, amount of precipitation, visibility range, the wind speed was taken into account, and the speed of the logging truck was recorded with the corresponding values of factors.

To construct a regression dependence of the logging truck speed on the considered factors, the following designations were introduced: y - the studied output parameter (speed), the factors: $x_1$ – the slope value, $x_2$ - the amount of precipitation, $x_3$ - visibility range, $x_4$ – wind speed. Based on the obtained values of the pair correlation coefficients, it was concluded that there is a significant dependence between the factors $x_2$ and $x_3$, $x_3$ and $x_4$ (correlation coefficients $r_{x_2x_3} = -0.67, r_{x_3x_4} = -0.68$) and weak influence of factor $x_4$ on the output parameter ($r_{yx_4} = -0.16$). Therefore, factors $x_3$ and $x_4$ are excluded from consideration. Thus, to study the dependence of logging trucks speed on natural and climatic factors, the following indicators are considered: the value of road slope, taking into account the rise or descent, and the amount of precipitation.

To collect data, the planning of a passive experiment was carried out, in which the speed of a logging truck was recorded under various conditions (table 1).

Under the conditions of each of the experiments for three types of road: highways, branches, logging roads 5 measurements of the truck speed, the road slope were made tentatively in winter, spring and summer periods. The amount of precipitation was obtained on the basis of data provided on the website rp5.ru. The observation results for each experiment are statistically processed: the average value of the output parameter, the variance, the mean quadratic deviation, and the coefficient of variation are calculated. Based on the results obtained, the required number of observations in each experiment was determined with the accuracy of calculating the average value of the output parameter, taken equal to 5%.

| № of experiment | Factor values |
|-----------------|--------------|
|                 | $x_1$        | $x_2$        |
Statistical data obtained in accordance with the found sample volumes were processed using the Statistica system. The modeling was carried out using the least-squares method, and the parameter estimates of regression models were determined by the Levenberg-Marquardt method.

3. Results and discussion

Regression models reflecting the dependence of the logging truck speed on the amount of slope and precipitation for three types of roads (highway, branch, and logging road) when driving in the cargo and empty directions are presented in table 2. The indicated dependencies were obtained for the winter, spring and summer periods [9]. The found values of the coefficient (index) of determination \(R^2\) indicate a sufficiently high accuracy of the obtained equations (see table 2) [10].

Testing the hypothesis of statistical insignificance of the equation parameters using the Student's t-test made it possible to conclude with a 95% probability that they are statistically significant.

| №   | Period | Type of road | Movement direction | Regression model | \(R^2\) |
|-----|--------|--------------|--------------------|------------------|--------|
| 1   | winter | highway      | empty              | \(y = 54,419 + 0,13x_1 - 1,408x_2 - 0,275x_3^2\) | 0.72   |
| 2   |        | highway      | cargo              | \(y = 40,807 - 0,351x_1 - 0,864x_2 - 0,186x_3^2\) | 0.74   |
| 3   | branch | branch       | empty              | \(y = 34,544 - 0,256x_1 - 1,318x_2 - 0,113x_3^2\) | 0.74   |
| 4   |        | branch       | cargo              | \(y = 24,814 - 0,227x_1 - 0,406x_2 - 0,128x_3^2\) | 0.77   |
| 5   | logging road | logging road | empty              | \(y = 22,036 - 0,301x_1 - 0,487x_2 - 0,078x_3^2\) | 0.75   |
| 6   |        | logging road | cargo              | \(y = 14,531 - 0,168x_1 - 0,142x_2 - 0,048x_3^2\) | 0.71   |
| 7   | spring | highway      | empty              | \(y = 49,041 + 0,292x_1 - 1,758x_2 - 0,118x_3^2\) | 0.73   |
| 8   |        | highway      | cargo              | \(y = 39,101 + 0,663x_1 - 0,75x_2 - 0,231x_3^2\) | 0.8    |
| 9   | branch | branch       | empty              | \(y = 43,085 + 0,301x_1 - 1,101x_2 - 0,166x_3^2\) | 0.81   |
| 10  |        | branch       | cargo              | \(y = 34,965 + 0,713x_1 - 1,254x_2 - 0,165x_3^2\) | 0.9    |
| 11  | logging road | logging road | empty              | \(y = 19,28 - 0,028x_1 - 0,984x_2 - 0,048x_3^2\) | 0.73   |
| 12  |        | logging road | cargo              | \(y = 13,851 - 0,058x_1 - 0,633x_2 - 0,04x_3^2\) | 0.72   |
| 13  | summer | highway      | empty              | \(y = 42,572 - 1,479x_1 + 0,361x_2 - 0,035x_3^2\) | 0.81   |
| 14  |        | highway      | cargo              | \(y = 43,535 - 1,566x_1 + 0,331x_2 - 0,147x_3^2\) | 0.84   |
All regression models are reliable, as shown by checking their statistical insignificance using the Fisher F-test at a significance level of 0.05.

The graphs of the obtained dependencies are shown in figures 1-18.
Figure 5. Dependence of the logging truck speed on the slope value and amount of precipitation in the winter period on the logging road in the empty direction.

Figure 6. Dependence of the logging truck speed on the slope value and amount of precipitation in the winter period on the logging road in the cargo direction.

Figure 7. Dependence of the logging truck speed on the slope value and amount of precipitation in the spring period on the highway in the empty direction.

Figure 8. Dependence of the logging truck speed on the slope value and amount of precipitation in the spring period on the highway in the cargo direction.

Figure 9. Dependence of the logging truck speed on the slope value and amount of precipitation in the spring period on the branch in the empty direction.

Figure 10. Dependence of the logging truck speed on the slope value and amount of precipitation in the spring period on the branch in the cargo direction.
Figure 11. Dependence of the logging truck speed on the slope value and amount of precipitation in the spring period on the logging road in the empty direction.

Figure 12. Dependence of the logging truck speed on the slope value and amount of precipitation in the spring period on the logging road in the cargo direction.

Figure 13. Dependence of a logging truck speed on the slope value and amount of precipitation in the summer period on the highway in the empty direction.

Figure 14. Dependence of the logging truck speed on the slope value and amount of precipitation in the summer period on the highway in the cargo direction.

Figure 15. Dependence of the logging truck speed on the slope value and amount of precipitation in the summer period on the branch in the empty direction.

Figure 16. Dependence of the logging truck speed on the slope value and amount of precipitation in the summer period on the branch in the cargo direction.
Evaluating the obtained dependencies presented graphically, the following conclusions can be drawn:

1. The speed of logging trucks is significantly reduced when the slope value changes (both up and down) in the winter period. In the empty direction, the dependence on precipitation is much higher. While if there is cargo in the logging truck, the dependence on precipitation is smoothed out.

2. In the spring period, the impact of precipitation on the speed of logging trucks is significantly higher. This fact is due to the technical and psychological features of managing logging equipment in difficult weather conditions. The dependence on the slope is identical to the winter time period. Similarly, the effect of the amount of precipitation is smoothed out in the loaded version of the movement of logging equipment.

3. Different models from the previous ones are typical for the summer period. In this case, for the highway and branch, the speed increases as the slope decreases. At the same time, a negative slope leads to an even greater increase in speed. The exception is the movement on the logging roads, where low speeds and the quality of roads practically do not allow to increase the speed at a negative slope, and the speed itself is quite stable and unchanged. The amount of precipitation when driving empty on highways and branches, as well as on highways in the loaded version, practically does not affect the speed. At the same time, when moving along the logging roads and in a loaded condition along the branches, the influence of precipitation on the speed is significant.

4. Discussion
The obtained regression models can be used for simulation modeling of the technological process of wood removal to the lower warehouse of logging enterprises in the Krasnoyarsk territory. With the practical application of these dependencies, it is possible to optimize the technological process of the operation of logging machines in certain natural and production conditions [11-13].

The discussion aspects of the work are the characteristics of logging equipment. To a certain extent, the influence of weather conditions and the amount of slope may vary depending on the condition and technical characteristics of logging trucks.

This aspect of the work is expected to be analyzed at the next stages of the study.
5. Conclusion
This study generally presents the results that systematize the knowledge accumulated to date on the issues under study, as well as offers a number of new approaches to assessing the speed of logging roads.

The dependencies of the logging equipment speed on the amount of precipitation and the terrain slope value are obtained. It is shown that both precipitation and terrain significantly affect the speed of equipment, and therefore the efficiency of wood removal from the forest territory. The results are obtained for empty and cargo directions, as well as for highways, branches, and logging roads. Such a variety of results makes it possible to get a complete picture of the movement of logging equipment throughout the logging period and to form plans for the activities of enterprises.

The results obtained can be used in planning the development of a road network in the forest area, selecting techniques, and methods of wood removal.

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Acknowledgement
The reported study was funded by Russian Foundation for Basic Research, Government of Krasnoyarsk Territory, Krasnoyarsk Regional Fund of Science, to the research project: «Development of the fundamental principles of forest infrastructure design as a dynamically changing system in the conditions of logging production », grant № 19-410-240005; The reported study was funded by
RFBR, the Government of Krasnoyarsk Territory, Krasnoyarsk Regional Fund and LLC "Krasresurs 24", project number 20-410-242901.