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TRANSPORTATION COSTS AS AN INDICATOR FOR DETERMINATION OF THE OPTIMAL ROAD DENSITY

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ABSTRACT: The main purpose of this scientific paper is to offer a new model of optimal forest road network density in high mountain regions. The model should establish a connection between the density of the road network and costs incurred in the transportation of wood during forest utilization. The new model is based on the relationship between the minimum cost of wood transport and optimal density of the road network.
Costs that arise from the building of road network show complex mathematical dependence that can be solved with differential calculations or the first derivative of the total cost of transportation. This method can easily reach the optimal density of the road network.
Keywords: forest, optimal road, network, skidding, costs.

1 INTRODUCTION

In practice, the question for optimal road density for transport of wood assortments has often been an issue. Overall, we can assume that the transport in forests could be distinguished according to the following characteristics: the natural features of the area, the technology of work, the potential of the forest, as well as the methods of forest utilization.

The optimal road network explains the smallest production costs in the phase of wood transport, where all the work tasks which arise with one contemporary forest management will be accomplished, and the environmental i.e. the protection function of the forest will be fulfilled as well.

At the same time the forest road network should evenly open the whole area, where the evenness does not apply to the distance between roads, but to the economic requirements, and to the economic importance of some parts of the forest.

The different situations that happen during the process of wood transport could be presented with the transport costs which are under the influence of the road network density, through complex mathematical variations, or rather with differential calculations, i.e. with calculating the first deduction from the total costs of transport.

In this paper, the research was made in three different ways of skidding: skidding with animals (horses), skidding with adapted tractor Ford 5600 and skidding with cable railway (type KOLER). This is old machinery which often suffers from breakdowns. The research was conducted on Plackovica and Kozuf mountains in the Republic of Macedonia. The gradient of the terrain varied from 30 to 45 %, and the dominant wood type is beech, with assortment wood structure: 60% firewood and 40% technological tree or logs. In this research the skidding with the animals and the tractor was mostly done in fall, only a small part was done in increase, whereas with the cable railway the total skidding was done in increase.

2 METHOD

When calculating the optimal forest road network, as basis we took the ideal model, i.e. one can start from the following conditions:

The density of truck roads is calculated with the equation (1):

$$Gkp = \frac{Lkp}{F} \qquad (1)$$

Gkp - density of truck roads
Lkp - length of truck roads
F - area

This methodology takes as basis all the dependably changeable parameters of the forest road density. It could be simplified i.e. some elements can be set as a constant of some factor, or to be compounded if there are more input parameters which could make a certain process or factor more precise.

The optimal density of road network is calculated with the help of differential calculations of the total transport costs, i.e. defining the minimum costs. The equation (2) is used to calculate the optimal density of truck road network.

$$\frac{DTsum}{DGkp} = 0 \qquad (2)$$

Tsum - total skidding costs
Gkp - density of truck roads

This method allow us to make different analyses through which a certain factor could be tested within the framework of its minimum and maximum span.

The methodology of work is presented in the scientific paper of Z. Trajanov [8] and the scientific paper of Z. Trajanov and Lj. Nestorovski [9].

3 RESULTS

According to the research of Z. Trajanov [8,9], with an assumed period of 100 years, i.e. the felling cycle of reproductive woodcutting, the volume of wood which is to be used in the area is being defined, on average $Q[m^3/ha] = 300$, which equals 3 m^3/ha average annual increase. With that, according to the differential method, i.e. equation (2), the following results have been acquired for the real situations researched on field.

Table I: The optimal road network density for the researched skidding models.

Models	*Gkpa*	*Gkpt*	*Gkpz*
Gkp[300m/ha]	24,99	21,64	17,07

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From the chart one can see that the optimal density of the forest truck road network varies from 17,07 *m/ha* when skidding with forestry cable crane (*Gkpz), 21,64 m/ha* when skidding with a tractor (*Gkpt),* to 24,99 *m/ha* when skidding with a horse (*Gkpa).*

The economic model also allows us to come to the solution by using a graphic chart (Fig. 1). The results acquired could be seen in the graphic presentation of the diagram, where the relation of the costs for wood transport with the density of the forest truck roads is shown. The minimum costs present the point of optimal density of road network.

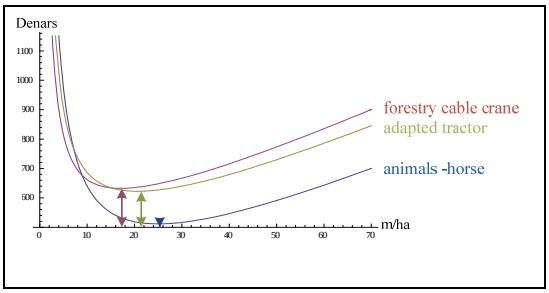

Figure 1: Relation of the costs for wood transport to the optimal density of the researched skidding models

Despite allowing the determination of the optimal density, this model also allows further analyses. In this situation, the influence of the used volume of wood, i.e. the production capacity of a certain forest has been elaborated on. The results acquired for the optimal density of truck road network are shown in Table II.

Table II: Relation of the road network density to the amount of the volume of wood.

volume of wood	animals -horse	adapted tractor	forestry cable crane
Q[m³/ha]		*Gkp [m/ha]*	
100	13,3	11,1	8,4
200	20,1	17,1	13,3
300	25,0	21,6	17,1
400	28,9	25,1	20,1
500	32,2	28,1	22,7
600	35,1	30,7	24,9

The data from Table II is graphically presented in Fig. 2.

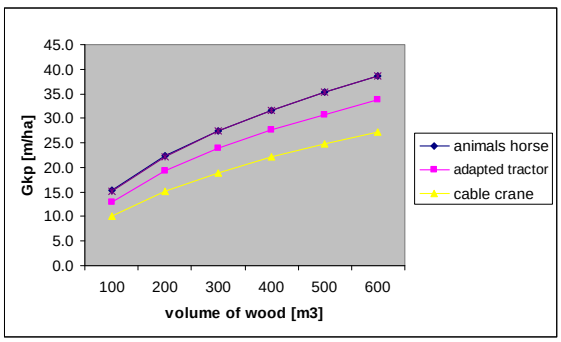

Figure 2: Relation of the road network density to the amount of the volume of wood

From the diagram on Fig. 2 can see that with the increase of the volume of wood, the density of the optimal road network also increases.

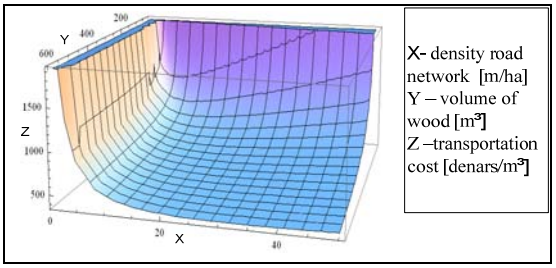

Figure 3: Relation of the total costs at horse skidding, to the volume of wood and the density of the road network

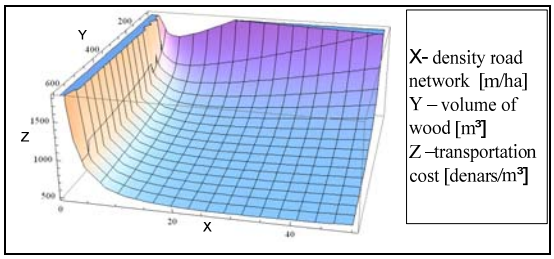

Figure 4: Relation of the total costs at adapted tractor skidding, to the volume of wood and the density of the road network

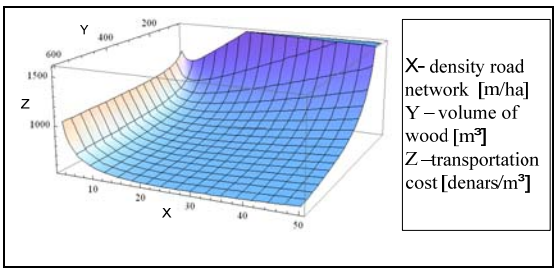

Figure 5: Relation of the total costs at forestry cable crane skidding, to the volume of wood and the density of the road network

The Figs. 3, 4 and 5 show the interrelation of: the transport costs, the volume of wood that is used during the period of 100 years, and the density of the road network at the skidding with horses, tractor, and forestry cable crane. In these diagrams one could notice more regularities and tendencies which present a clear guideline in which direction the network of forest roads should be developed:

- The means of skidding affects the density of the road network, at that with all means of skidding the same tendencies have been noticed.
- The transport costs are reduced with the increase of the volume of wood which is being used.
- The transport costs are in relation to the density of the road network.
- The transport costs are very high when the density of the road network is small; with the increase of density, the costs are quickly reduced and reach the minimum; in extension to this the costs have a slight increase with the increase of the density of the road network.

- The point of minimum transport costs presents the optimal density of the road network.

The diagrams determine the negative moments which must be very careful avoided in the forestry practice when projecting and measuring the dimensions of the road network. The situations when there is small volume of wood which is to be used, and when there is a very low openness of the forest, have a very negative influence on the transport costs. The diagram with red shades shows the area of big costs, which in practice should be avoided, in order to keep the profitability of the work.

The diagrams also determine the positive moments which should be favorized in practice. Thus, the increase of the exploitation of the volume of wood, and the higher extent of openness, have a positive influence on the reduction of the transport costs, up to a certain point. The diagram with blue shades shows the area of small costs, which in practice should be used, in order to keep the profitability of the work.

The diagram also determines the optimum, i.e. the minimum costs which in practice are most wanted. At this, the minimum itself is not a very distinguished point, but with small deviations it is kept both in the part with a smaller density, as well as in the part with the bigger density of roads. However, the part with higher density is more lenient, that could lead one to a conclusion that if a deviation is needed to be done, it should be done at the expense of the increase of the road density.

4 CONCLUSIONS

- There is no universal solution to the problem of optimal density of the road network. A reason for that are the many parameters which are changeable, but have an influence on the optimization of the transport costs.
- The economic method of minimum costs presents useful information about the trends and relations of the optimal truck road network.
- The point of minimum transport costs presents optimal density of the road network.
- The optimal density of the forest truck road network at the research model, i.e. the average use of 300 m^3/ha in a period of 100 years, is within the range of: 17,07 *m/ha* when skidding with forestry cable crane, *21,64 m/ha* when skidding with a tractor, and 24,99 *m/ha* when skidding with a horse.
- In practice the best financial results would be acquired if one could project an ideal road network which is in correlation with minimum transport costs. If deviations are needed, it is better to make them at the expense of the increase of the density of the road network, because in that case smaller losses are made.

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