

Determination of the optimal density of the forest road network

TIHOMIR KRUMOV*

Department of Technology and Mechanization in Forestry, Faculty of Forestry, University of Forestry, Sofia, Bulgaria

*Corresponding author: t_p.krumov@abv.bg

Citation: Krumov T. (2019): Determination of the optimal density of the forest road network. J. For. Sci., 65: 438–444.

Abstract: The forest road network is invariably linked to forestry and logging, as it transports logging products and products needed for forestry activities. Constructing and maintaining it in good condition are essential. In view of the economic situation in the country and the financial difficulties faced by forest holdings in the construction and maintenance of the forest road network, it is necessary to determine the optimal hauling distance and the optimal density of the primary forest road network. The analysis of the forest road network in the territory of the State Educational Experimental Forestry Enterprise “Georgi Avramov”, Yundola village, showed that the density of the primary forest road network is several times higher than the national average, namely $20.31 \text{ m} \cdot \text{ha}^{-1}$, yet it does not reach the optimal road network density calculated at the farm, of $30.9 \text{ m} \cdot \text{ha}^{-1}$, at a hauling distance of 323.15 m.

Keywords: forestry; timber transport; export; transportation; transportation costs; cost; logging

A characteristic feature of logging activities in forest management is that it is dominated by transport operations related to the transportation, hauling of timber from logging site through temporary warehouses and/or cargo points to consumer centres (JEKOV 2003).

Roads are therefore of paramount importance in forestry (HRISTOV 1982; MARINOV 2013).

In forest areas, timber transport is carried out on permanent or temporary roads forming a forest road network (MOLOVA 2002).

It satisfies not only logging but also other areas of people’s lives (tourism, social activities, etc.) (TRAJANOVET et al. 2015).

The forest road network is subjected to several phases of work (RYAN et al. 2004), including the planning, design, construction and maintenance of roads.

When planning and constructing forest roads, it is necessary to take into account the physical, eco-

nomic and environmental characteristics of the area (AKAY 2006).

This is required because the density of the forest road network depends on a number of factors: configuration and slope of the terrain, type of felling and the way the plantations are restored, amount of timber, yield per unit area, duration of logging, the type, quality and value of timber harvested from the plantations, investments available for the construction of forest roads, etc. (KHRISTOV 1982; NAJAFI 2008; NAGHDI et al. 2009). The more severe the terrain, the higher the cost of constructing forest roads. Therefore, the density of the forest road network in the mountainous and hilly woodlands is usually lower. This, of course, adversely affects the intensity of the forestry.

It has been established that the main factors for the density of the forest road network are the required capital investment. The larger these invest-

<https://doi.org/10.17221/101/2019-JFS>

ments are, the greater is the density of the forest road network and the greater the cost of maintaining it in good order and condition (HRISTOV 1982). On the other hand, the cost of transporting wood is reduced and better conditions are created for its more complete and rational use (HRISTOV 1982; MOLOVA 2002).

The optimal road density is an important factor that helps forest engineers optimize harvesting costs by using an appropriate forest road network (GHAFFARIAN et al. 2003). There is a direct link between the hauling distance and the distance between roads (TAN 1992). The density of the primary forest road network is more important, because the more densely its highways and branches are located, the shorter the distances in the transportation and hauling of wood and, accordingly, the lower the costs of its transportation from the cutting sites to the consumer centres (MOSTAFANEJAD 1995; EGHTESEADI et al. 2002; NAGHDI et al. 2005; EGHTESEADI 2008; GHAFFARIAN, SOBHANI 2008)

In view of the above citation, the purpose of the study is to propose an approach to optimizing the density of the forest road network at the State Educational Experimental Forestry Enterprise “Georgi Avramov”, Yundola village. The density determina-

tion will be justified on the basis of optimization of the costs of haulage and transportation and the cost of construction, repair and maintenance of forest roads corresponding to one cubic meter of timber harvested and transported through the forest road network.

MATERIAL AND METHODS

Object

The object of the present study is the forest road network in the territory of the Educational Experimental Forestry Enterprise “GS Avramov”, Yundola village, Pazardzhik district (Fig. 1). The territory is located partly on the slopes of the Rhodope Mountains and Rila Mountain. The forests at the State Enterprise “Avramov” occupy 5131.6 ha, with afforestation over 94.5%.

By its nature, the relief of the enterprise is typically mountainous. The higher parts of the ridges are more gentle, the tops are rounded and the slopes smaller.

The distribution of the timber production area according to the slopes of the terrains on which it

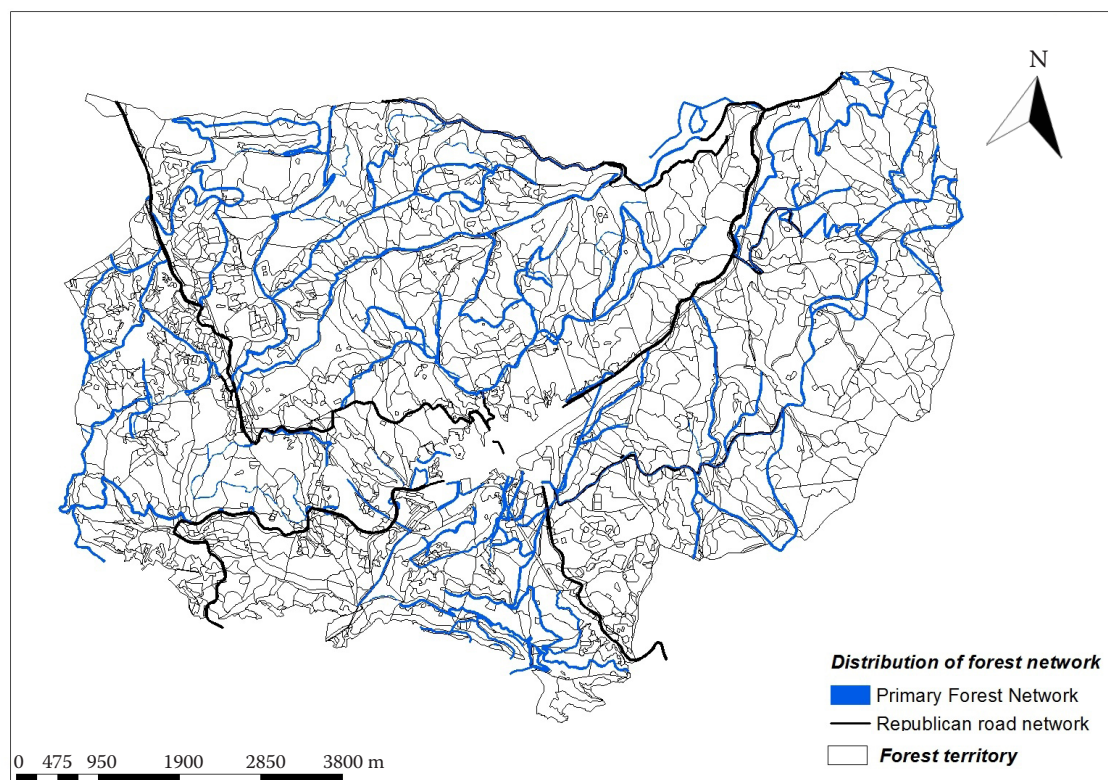


Fig. 1. Distribution of the forest-road network at the territory of “Avramov” State Enterprise, village of Yundola

Table 1. Distribution of wood production area by slope of the terrain (LUP 2018)

Grades of slope	Equal (0°–4°)	Small inclination (5°–10°)	Tilted (11°–20°)	Steep (21°–30°)	Very steep (30°)	Total
Area (ha)	21.6	292.4	2,557.7	1,795.1	139.2	4,806
Percentage (%)	0.4	6.1	53.2	37.4	2.9	100

Table 2. Distribution of timber production area by terrain (LUP 2018)

Exposure	Shady (N, NE, NW, E)	Sunny (SE, SW, W, S)	Total
Area (ha)	2,683.6	2,122.4	4,806
Percentage (%)	55.8	44.2	100

is located is presented in Table 1. It shows that the major part (53.2%) of the area is located in sloping terrains (11°–20°), and 37.4% of the area are in a steep terrain. The very steep terrain covers only 2.9% of the timber production area. This largely defines the holding as a favourable terrain for forestry activities – felling, afforestation, road construction and others (LUP 2018).

The prevailing part of the timber production area of the farm is located on shady exposure – 55.8%, with the prevailing northern one – 19.5%. Sunny exposure accounts for 44.1%, with the largest part located on southern slopes – 14.2% (Table 2). The majority of shady exposures require additional means of maintaining the road network, as moisture retention is expected to further impair its condition.

Methods

Roads of different purpose and economic importance are located in the territory of the holding. The inventory of the existing forest road network is made on the basis of the following main points:

- (i) Determining the length of roads relevant to forest management.
- (ii) Determining the length of roads available within the holding provided that both tractor and engine gravitate towards them.

Taking into account the total timber production area, the density, expressed in linear meters, per hectare of timber production area (Formula 1) is as follows:

$$d = L/S \text{ (m} \cdot \text{ha}^{-1}\text{)} \quad (1)$$

where:

d – density of the highway network,
 L – length of the forest-road network,
 S – area covered by roads.

Roads for transportation are surface roads that connect the intersections to temporary warehouses and/or loading points. They pass through the slopes and gullies at the enterprise. These paths are characterized by straight and inverse slopes and sharp curves. They are suitable for use only during some seasons of the year, so their length and condition were not the subject of the study.

The use of up-to-date and effective geospatial data visualization software programs enables a more in-depth analysis of the forest road network (JANUSZ, ŁUCZKOWSKI 2017). To get a general idea of the location of the forest road network on the farm, a map was developed using the ArcGIS (ESRI).

For the determination of the cost of hauling 1 m³ of wood to different distances of transportation, the sum of average costs, complex costs and the cost of making roads is used.

The methods of descriptive statistics were used to determine the cost of hauling 1 m³ of wood. As concerns the wood transport from the clearing to the road, in determining the basic numerical characteristics of the parameters (Formula 2) (STATKOV 1975) it is necessary to modify the cost of transport depending on the export. The regression equation will then be used to determine the coefficients of the regression Formula:

$$Y = A + B \times x \text{ (EUR} \cdot \text{m}^{-3}\text{)} \quad (2)$$

where:

Y – cost of extracted per 1 m³ of wood (EUR),
 x – perpendicular export distance (km),

<https://doi.org/10.17221/101/2019-JFS>

A, B – coefficients that depend on the type of vehicles used and the technology, the configuration and slope of the terrain, etc., for the additional cost of transporting 1 m³ of timber transported over a distance of 1 m (coefficient B – we need them to calculate the optimal export distance).

In order to find the values of the coefficients A and B , we need to know the cost of exporting 1 m³ of wood for the different export distances.

In order to find the values of coefficients A and B , we need to know the cost of hauling 1 m³ of wood to different hauling distances.

Determination of optimal export distances

To calculate an optimal hauling distance, the technical parameters and data available for the gravel path will be used.

Costs of the construction, repair and maintenance of 1 km of forest road network are calculated on the basis of averaged values for these activities obtained by conducting a study of the actual announced parameters in the public procurement of the official and completely free access – Public Procurement Portal (PPP). The depreciation period for roads with similar pavement is 50 years.

The total cost of the construction, repair and maintenance of 1 km of gravel road network with gravel pavement is determined by the following Formula (3):

$$b = b_1 + b_2 + b_3 \quad (3)$$

where:

b_1 – cost of construction,

b_2 – repair costs,

b_3 – maintenance costs.

The cost of construction 1 km times in 1 year. For this purpose we will use the Formula (4):

$$b_1' = \frac{b_1}{a_{nep.}} \quad (\text{EUR} \cdot \text{km}^{-1}) \quad (4)$$

where:

b_1 – cost of construction,

$a_{nep.}$ – depreciation period.

Therefore, the Formula (5) will take the following form:

$$b = b_1' + b_2 + b_3 \quad (5)$$

The well-known formula of Hristov and Statkov (HRISTOV, STATKOV 1978) will be used to deter-

mine the cost of constructing and maintaining 1 km of gravelled forest road:

$$a = 100 \times \sqrt{\frac{b}{0.35 \times B \times V}} \quad (\text{m}) \quad (6)$$

where:

a – optimum export distance recorded on the road without taking into account the slope of the terrain (m),

b – cost of construction,

B – export value per 1 m³ (EUR·m⁻³),

V – volume of timber exported per year from an area of 100 ha (m³).

Determination of the optimal density of the PMF – d

Based on the optimal distances in timber haulage, the optimal density of the forest road network (PMF – d) corresponding to a unit of forest area (1 or 100 ha) can also be determined. If the most economical average perpendicular distance at haulage is x , then the width of the working field will be a and its area corresponding to 1 km from the highway will be $1,000 a$ or (Formula 7):

$$d = \frac{2,500}{x} = \frac{1,000 \times a}{10,000} \quad (\text{ha}) \quad (7)$$

The density of the primary forest road network expressed in meters per hectare will then be determined by the following Formula (8):

$$d = \frac{1,000}{10,000} \times a = \frac{10,000}{a} \quad (\text{m} \cdot \text{ha}^{-1}) \quad (8)$$

RESULTS AND ANALYSIS

After an in-depth analysis of the available map materials (on paper and digital models) with the help of the ArcGis (10.0, ESRI) it was concluded that the UOGS forest road network has undergone significant development and is 136.1 km long (Table 3).

Roads on the farm are of different layout, category and purpose. Using the tools of the software program, a visual representation of the forest road network is presented, through property and floor selection.

Part of the following motorways is located in the territory of the surveyed area:

(i) Velingrad-Yundola-Yakoruda, 9,500 km long;

(ii) Yundola-Belmeken, 8,700 km long;

(iii) Yundola-Belovo, 5,600 km long;

Applying Formula 1, it is established that the existing car network at the enterprise is well devel-

Table 3. Density of the forest road network (area – 5,131.6 ha, d.f. – durable flooring)

Forest-road network	National Road Network		Forest-road network on the territory of experimental forestry enterprise		Common forest-road network		Ratio	
	Length (km)	Density (m·ha ⁻¹)	Length (km)	Density (m·ha ⁻¹)	Length (km)	Density (m·ha ⁻¹)	with/without d.f.	National Forest Network/Forest Road Network
with d.f.	23.8	4.6	8.1	1.6	31.9	6.22		
without d.f.	0.0	0.0	104.2	20.3	104.2	20.31	0.31	0.21
Total	23.8	4.6	112.3	21.9	136.1	26.53		

oped. The current saturation of the roads for the transportation of timber is 26.53 m·ha⁻¹ and does not belong to the forestry enterprise. The location of these roads is such that it favours the proper absorption of the section.

The area identified by a survey is 136,100 km of primary forest road network. This represents 20.31 m·ha⁻¹. The most important of them are: Starina-Chelebiytsa, Chelebiytsa-Sechenitsi, etc.

After a study of the annual use for 2018 and an analysis of the costs depending on the hauling distance, the cost of hauling 1 m³ of wood from the felling site to the highway was determined. The data are presented in Table 4.

From Table 4 it follows that the cost of 1 m³ of timber extracted increases with the increase in hauling distances.

Using the data on hauling distances, the quantities of timber extracted and the cost of 1 m³ of timber extracted, we determine the coefficients *A* and *B*, using the regression analysis methodology and the least-squares method from which we obtain (Fig. 2).

Following the graphical representation of the data in Table 4 and statistical processing, the following regression equation according to Formula 2 is derived:

$$y = 1.7468 \times x + 8.7628 \quad (9)$$

The data shows that $R^2 = 0.962$, ie 96.2% of the change in *Y* is due to the factor *x* and is described by the linear model. The remaining 3.8% are due to unmanageable factors.

From Formula (9) it can be concluded that the additional cost of transporting 1 m³ of wood hauled to a distance of 1 m is 0.89 EUR.

Based on the average processing of data obtained from the Public Procurement Portal (POP) on construction costs (10997.44 EUR per km), repair

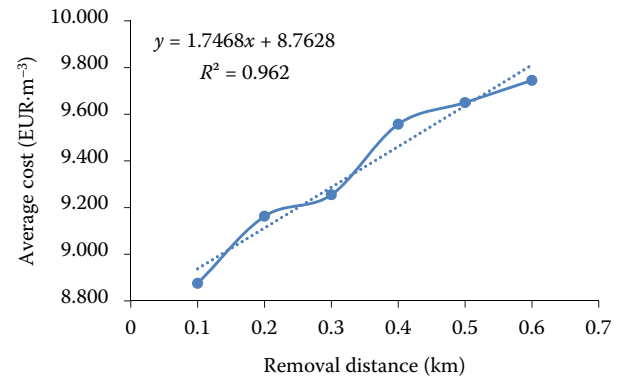


Fig. 2. Change in timber transport costs

Table 4. Haulage value at UGSD Yundola for 2018

Hauling distance (km)	Quantity of wood (m ³)	Expenditures (EUR)	Average cost (EUR·m ⁻³)	Road construction costs (EUR·m ⁻¹)	Total (EUR)
0.1	3,953	17945.91	4.54	109.97	114.52
0.2	2,748	12879.28	4.69	109.97	114.66
0.3	1,954	9250.13	4.73	109.97	114.71
0.4	2,621	12812.92	4.89	109.97	114.86
0.5	123	467.65	4.94	109.97	114.91
0.6	105	523.40	4.98	109.97	114.96

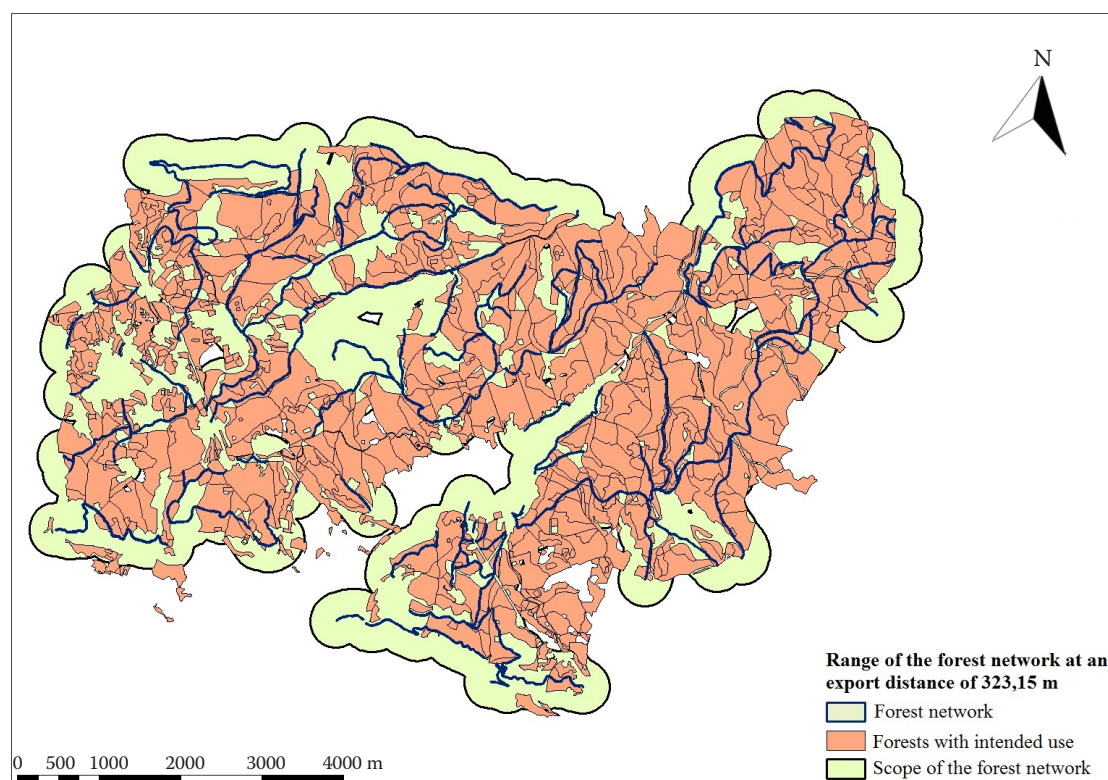


Fig. 3. Scope of the forest network

[383.63 EUR (0.383 EUR·m⁻¹)] and maintenance [255.75 EUR (0.255 EUR·m⁻¹)] Formulas 3 and 4 are applied.

In view of the recent practice of forest road construction, namely that they are constructed with the pavement of coarse stone fractions (gravel), it is assumed that the depreciation period in the calculation of the total cost of the newly constructed roads is $a_{\text{per.}} = 50$ years.

Substituting Formula 6, the total cost of constructing and maintaining 1 km of gravel road is 859.34 EUR per km.

From the reference for 2018, 13 503 m³ of timber was extracted from the whole territory of the SLS (5131.6 ha), therefore the volume of extracted timber per 100 ha of logging area is as follows:

$$V = 263.13 \text{ m}^3/100 \text{ ha.}$$

Therefore, by substituting the optimal hauling distance in Formula (6) and taking into account the gravel road, without taking into account the slope of the terrain, we can assume:

$$a = 323.15 \text{ m.}$$

Using the basic tools (“buffer”) of the ArcGis program, a map is drawn up showing the range of the forest road network at an optimal hauling distance of 323.15 m.

Fig. 3 shows that the forest road network covers more than 95% of the logging compartments and subdivisions intended for use.

After determining the optimal distances for timber hauling, the optimal density of the forest road network corresponding to a unit of forest area (1 or 100 ha) is also determined. Substituting the data obtained from Formula 6 to Formula 8, it is found that the density of the primary forest road network, expressed in meters per hectare, is 30.9 m·ha⁻¹.

DISCUSSION

Based on the calculations done, the following conclusions can be drawn: (i) It has been established that the density of the existing road network of “G. St. Avramov” training forest enterprise amounts to 26.53 m·ha⁻¹, including the republic roads. (ii) The analysis of the density of the forest road network shows that the primary forest road network

(20.31 m³·ha⁻¹) is very well developed compared to the average for the country (7.9 m³·ha⁻¹). (iii) It is estimated that the optimum distance in 2018 is 323.15 m. (iv) Following the application of GIS software, it is established that over 95% of the projected logging sites are within the optimal hauling distance. (v) On the basis of a survey it was found that the optimal density of the primary forest road network is 30.9 m³·ha⁻¹, which proves that the available 20.31 m³·ha⁻¹ forest road network approximates the optimum for the forestry enterprise at Yundola.

Acknowledgement

The present study has initiated and implemented with the support of the National Science Program "Young Scientists and Postdoctoral Students". We express our gratitude for the concern to the young researchers, scientists and professors of Bulgaria.

References

- Akay A. (2006): Minimizing total costs of forest roads with computer-aided design model. *Academy Proceedings in Engineering Sciences*, 31: 621–633.
- Eghtesadi A., Sobhani H., Rafatnia N. (2002): Study of timber transportation in the Vaz research forest. *Iranian Journal of Research and Construction*, 12: 23–34.
- Eghtesadi A. (2008): Evaluation of wood productivity rate in primary and secondary transportation in Nekachub region. *Iranian Journal Forestry Poplar Research*, 16: 274–291.
- Ghaffarian M.R., Sobhani H. (2008): Optimum road spacing of ground based skidding operations in Nowshahr, Iran. *Caspian Journal of Environmental Science*, 6: 105–112.
- Hristov S. (1982): *Forest transport*. Zemizdat-Sofia: 7–15.
- Hristov S., Statkov N. (1978): Optimal road network density in Bulgaria. *Zemizdat-Sofia*: 141–154.
- Janusz G., Łuczowski B. (2017): GIS maps and analysis in designing forest road system on mountainous areas. *Electronic Journal of Polish Agricultural Universities (EJPAU)*, 20. Available at <http://www.ejpau.media.pl/volume20/issue4/art-14.html>
- Jekov G. (2003): Concept for Analysis of the Forestry Network and the Unprocessed Forest Exploitation Area in the Republic of Bulgaria. *Sofia, University of Forestry*: 5–10.
- LUP (2018): Forest management plan of Training and Experimental Forest Range "G. St. Avramov": 25–68.
- Marinov K. (2013): Mechanization of forest activities. *Sofia, University of Forestry*: 7–15.
- Molova N. (2002): Forest road. *Sofia, University of Forestry*: 5–21.
- Mostafanehad A. (1995): Study of cost production of skidder Timberjack 450C and optimal length of skid trails. [Master Thesis.] Tehran, Tehran University.
- Naghdi R., Mohammadi S. (2009): Optimal Forest Road Density Based on Skidding and Road Construction Costs in Iranian Caspian Forests. *Caspian Journal of Environmental Science*, 7: 79–86.
- Naghdi R., Rafatnia N., Sobhani H., Jalali G.H., Hosseini S.M. (2005): A Survey of the Efficiency of Timberjack 450C Wheeled Skidder in Sheared Forests. *Journal of Natural Resources*, 57: 657–687.
- Najafi A., Sobhani H., Saeed A., Makhdom M., Mohajer M.M. (2008): Planning and assessment of alternative forest road and skidding networks. *Croatian Journal of Forestry Engineering*, 29: 63–73.
- Ryan T., Phillips H., Ramsay J., Dempsey J., *Forest Road Manual* (2004): Guidelines for the design, construction and management of forest roads. Dublin, COFORD, National Council for Forest Research and Development: 170.
- Statkov N. (1975): Status and prospects for development of the logging industry in Bulgaria. *Zemizdat-Sofia*: 57–60.
- Tan J. (1999): Locating forest roads by a spatial and heuristic procedure using microcomputers. *Journal of Forest Engineering*, 10: 91–100.
- Trajanov Z., Nestorovski L., Trajkov P. (2015): Development and perspective of forest road infrastructure in the Republic of Macedonia. *Belgrade, Glasnik Sumarskog fakulteta*: 141–148.

Received for publication July 23, 2019

Accepted after corrections November 18, 2019