DEVELOPMENT AND PERSPECTIVE OF THE FOREST ROAD INFRASTRUCTURE IN THE REPUBLIC OF MACEDONIA

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Abstract: This paper determines the historical development of infrastructure in the forest, streaming the development of the forest road network as a dominant element of infrastructure. The paper also covers the current condition with the openness of forests in Republic of Macedonia. On the basis of scientific research, the results from the optimal density of forest roads are determined. The paper also covers the period for which it is expected to achieve the goals of optimization which is the most efficient forest management without significantly affecting the ecological functions of the forest.

Key words: forest roads, existing road density, optimal road density, the Republic of Macedonia

INTRODUCTION

Forest infrastructure consists of both forest and the public roads that traverse across the forest and create a network of forest roads.

Therefore, in a theoretical manner, the network of forest roads should adequately open the entire forest area. However, in this case, the adequacy does not refer to the distance between the roads, but to the commercial needs and the economic value of particular areas in the forest.

The occurrence, state and preservation of the forest depend on natural factors which in addition are impacted by various human related factors and forest management. Namely, the human population has always wanted to put nature under control and thus put the forest under control, that is, to manage natural resources in order to fulfill their own needs which are getting bigger and bigger due to existential, cultural and economical aspects.

In that context, people build infrastructure as a system that will allow unrestricted transport and the possibility to complete all the goals related to forest management.

On the other hand, nature and its forces have a destructive impact and occasionally damage all the objects that are artificially produced, i.e. all objects built against natural laws.

Hence, the infrastructure development is linked with: natural conditions, historical development, cultural and socio-economic development, development of forestry as a commercial activity etc. All these factors have had an impact and will have an impact on the level of construction and management of the forest roads.

RESEARCH PROBLEM AND RESEARCH AREA

The forest infrastructure in the Republic of Macedonia is closely related to the road traffic and the development of forest roads. This conclusion is drawn from the fact that the entire traffic in the forest management at this point is con-
ducted through forest truck roads. In a historical context, in the Republic of Macedonia, there have been several attempts to conduct transport: by means of rafting, whetstone (transport aided by gravity), rail road transport, long wire lines etc. All these attempts, from a historical aspect, have been unsuccessful and economically unprofitable.

The natural conditions in the Republic of Macedonia have determined the forest road infrastructure to a great length. Forests in the Republic of Macedonia are closely linked to mountain regions, more than 92% of the area consists of hills and mountains, therefore, we are actually talking about a mountain forest road network.

Under the mountain conditions in the Republic of Macedonia, the salience of the terrain is typically mountain-alpine where a great massif is a dominant creator of the mountain and is intersected by major and minor watercourses which form minor massifs spread in various directions. What dominates here are moderately steep and steep gradients of 11-31° and rarely very steep terrains wider than 31° as well as milder terrains narrower than 11°.

These mountainous terrains have typical mountain hydrography formed by small watercourses which further on form rivers. Due to the gradient of the terrain and in accordance with the geological foundation, they often create hollow riverbeds and typical canyons.

The geological foundation is heterogenous and very often, at very small areas one can see diverse geological structures - all silicate and limestone foundations are equally represented.

However, these geological formations are usually created by the following soil types: eutheric cambisol, dystric cambisol, rendzina etc.

The mountain conditions as well as the impact of the climate presented through the break of the Mediterranean climate as well as the continental climate have determined the vegetation and biodiversity. In general, there is a zone representation of the vegetative types: at the lowest point, there are shrubs, i.e. reduced oak plants, then come the quality high trunk breech plants, then come the low trunk breech plants. On the higher mountain grounds there are spruces and juniper trees and at the top there are the mountain grass fields. The total area of forests and forest land in the Republic of Macedonia is 987,545 ha. Forests comprise 900,876 ha of the entire area [8] State Statistics Office - Republic of Macedonia.

According to the manner of cultivation of the plants, the most dominant ones are the coppice forests with an area of 568,177 ha, which is 63.07% of the entire forest area, these are followed by high forests with an area of 272,898 ha, i.e. 30.29% and finally shrubs with an area of 59,800 ha, i.e. 6.64% (Trajanov, Nestorovski 2008).

The total volume of wood in the Republic of Macedonia is 85,902,795 m3 with an average volume of wood of 95 m3/ha and a current growth of 2.00 m3/ha. The maximum allowed felling quantity at the annual level is 1,094,815 which is 1.27% of the total volume of wood, i.e. 61% of the entire current growth [8].

In general, these are heavy mountain ranges managed by the Republic of Macedonia. These areas have a limited forest quality and quantity which makes the construction of forest roads even more difficult.

From here the main focus of this paper is correct projection of the road network in the future, based on scientific, economic and environmental principles.

### Table 1. Forest structure in the Republic of Macedonia according to the manner of cultivation

<table>
<thead>
<tr>
<th>Type of forest</th>
<th>Area (ha)</th>
<th>Area %</th>
<th>Volume of wood (m³)</th>
<th>Volume of wood (m³/ha)</th>
<th>Current growth (m³)</th>
<th>Current growth (m³/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High forest</td>
<td>272,898</td>
<td>30.29</td>
<td>54,118,283</td>
<td>198.31</td>
<td>1,030,181</td>
<td>3.77</td>
</tr>
<tr>
<td>Coppice forest</td>
<td>568,177</td>
<td>63.07</td>
<td>30,954,768</td>
<td>54.48</td>
<td>747,300</td>
<td>1.32</td>
</tr>
<tr>
<td>Shrubs</td>
<td>59,800</td>
<td>6.64</td>
<td>829,744</td>
<td>13.88</td>
<td>24,557</td>
<td>0.41</td>
</tr>
<tr>
<td>Total</td>
<td>900,875</td>
<td>100.00</td>
<td>85,902,795</td>
<td>95.35</td>
<td>1,802,038</td>
<td>2.00</td>
</tr>
</tbody>
</table>
CONDITIONS OF FOREST ROADS IN THE REPUBLIC OF MACEDONIA

The Republic of Macedonia has 13,263 km of roads that traverse across the forests, 3,326 km of which are public roads and 9,937 km are forest roads. The average density of transparency of the forest and public roads that traverse the forest is 13.43 m/ha [7] Public enterprise Macedonian Forest.

The forest roads of highest quality that have asphalt or macadam, are primarily used to link villages, forest buildings or to open great forest areas and they represent a major artery of wood transport. These roads are called receptors (R) (Image 1) and they are usually part of the public roads category. These roads always end up at the main public roads network (Pr) which are maintained by the Public Enterprise Makedonija Pat.

These roads are linked with the forest roads (Fr) which depend on the felling quantity in the area and serve as additions to the receptors. These roads are built by means of investment by the Public Enterprise Macedonian Forests. This enterprise helps in the engineering, construction and maintenance of all forest roads. These roads are usually firm or mild land roads.

![Image 1. Outlined representation of the setting of: public roads, receptors and forest truck roads in mountain conditions](image)

[Pr]- public roads: [R] - receptors: [Ftr] - forest truck roads

In the Republic of Macedonia, there are parts of the forest which are not transparent, i.e. they cannot be managed. Those are usually ravines and other unfavorable formations. What is a great concern is the fact that a great deal of the low-quality and degraded forests are not transparent as well. These forests are difficult to cultivate and their preservation from various influences is difficult, and these forests are mainly damaged by forest fires.

RESEARCH METHODS

There are a few special models that have been developed in order to establish the optimal density of the receptors and special models to measure the optimal density of the forest truck roads.

The theoretical initial model (Akimovski, 1968) is based on an ideal model of opening a rectangular area.

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

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

$$G_{kp} = \frac{L_{kp}}{F} \quad \text{[m/ha]}$$  (1)

$G_{kp}$ - density of truck roads
$L_{kp}$ - length of truck roads
$F$ - area

This model will further be mathematically developed in order to draw near to the realistic situations. In such a manner, the correction of the length in the skidding phase during a risky gradient of the terrain has been calculated. In addition, the ideal field for skidding in uplift and drop-off have been measured (Trajanov et al., 2013)

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.

$$\frac{DT_{sum}}{DG_{kp}} = 0$$  (2)

$DT_{sum}$ – total transport costs
$DG_{kp}$ - density of truck roads

$G_{kp}$ - density of truck roads
The transport costs while managing the forests are calculated as costs for the construction and maintenance of truck roads and costs for near transport (skidding) (Trajanov et al., 2014).

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

The optimal density of the receptors in general is mathematically linked to the export (transport) of wood with trucks and in addition, it is linked to the transport of people, use of the mountain area as well as other commercial activities at the transparent area (Trajanov, 2008).

The projection of the development of the forest truck roads network is calculated with the method of trends helped by a linear function will be used along with the method of average rate of construction of forest roads during the last few years.

RESULTS AND DISCUSSION ON THE OPTIMAL DENSITY OF THE FOREST ROAD NETWORK

The optimal density of the forest truck roads depends on the used volume of wood, i.e. the productive capacity of a particular forest. The results of the optimal density of the truck road network are presented in Table 2. Moreover, there are two other models that have been developed depending on the different supply means: a tractor (Trajanov et al., 2008) and a horse (Trajanov et al., 2009).

<table>
<thead>
<tr>
<th>Volume of wood</th>
<th>Animals Horse</th>
<th>Adjusted tractor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q[ m/ha]</td>
<td>Gftr [ m/ha]</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>8.4</td>
<td>8.2</td>
</tr>
<tr>
<td>100</td>
<td>13.3</td>
<td>11.1</td>
</tr>
<tr>
<td>200</td>
<td>20.1</td>
<td>17.1</td>
</tr>
<tr>
<td>300</td>
<td>25.0</td>
<td>21.6</td>
</tr>
<tr>
<td>400</td>
<td>28.9</td>
<td>25.1</td>
</tr>
<tr>
<td>500</td>
<td>32.2</td>
<td>28.1</td>
</tr>
<tr>
<td>600</td>
<td>35.1</td>
<td>30.7</td>
</tr>
</tbody>
</table>

The data in Table 2 show a graphical representation of diagram 1. The graph shows that with the increase in the volume of wood, there is an increase of the optimal density of the road network. Research like this one was made (Pentek et al., 1987) for all regions in Croatia, whereupon it was concluded that the openness is 15.64 m/ha in 2011 in mountainous regions and in 2020 it was planned to open 30 m/ha.

In general practice, the solution to the optimal density of the forest roads network cannot be generalized. Hence, every open field should be developed according to the model of the general plan of opening of the forests which comprises all specifics of the field as well as the supply technology, the construction of the forest roads and wood transport. Such a model was made (Danilović et al., 2014).

However, if we want to calculate the optimal density of the network of forest roads, we can establish it as a subordination of the allowed felling quantity in the Republic of Macedonia. Namely, the mass used in a period of 100 years is related to the allowed annual felling quantity at the moment. In Table 3, we can see that the optimal density of the roads with a horse supply is 14.5 m/ha, while the density with a tractor supply is 12.7 m/ha. A comparison can be made with the conditions of roads in Europe and Turkey (Demir, 2007).

This is true in respect to the truck roads constructed in accordance with the felling quantity and this is mainly related to the supply phase.
This density requires an additional density of the receptors, i.e. the public roads that, according to some analysis are 4-7 m/ha (Trajanov, 2008) and the annihilation of all unproductive roads. Only in this case we will be able to talk about a useful model of a theoretical calculation of the optimal density of forest roads.

The density of the receptors and unproductive roads will be a subject of future research.

Projection of the development of the forest road network

The projection of the development of the forest truck roads network can be calculated by several methods. On this occasion, the method of trends helped by a linear function will be used along with the method of average rate of construction of forest roads during the last few years.

Development of the forest road network as a trend resulting from road construction

The road network projection can be derived as a trend resulting from the analysis of recent studies that show the level of development of the forest truck roads network.

In the forestry of the Republic of Macedonia, there are some data about the condition and the transparency of forests with forest roads and there are a few sources: the annual reports by the State Statistical Office, the archive of the Public Enterprise (PE) Macedonian Forests, the scientific research papers in this field etc.

The development of the forest road network and the forest traffic are based on the modest road network that has been used after World War II. According to the data from Akimovski et al. (1966) in the Republic of Macedonia in 1966 there was a truck road network of 2.6 m/ha. The development and management of the forests also prompted the development of the forest road network.

According to the data collected from various sources, Table 4 presents the conditions of the road network in the Republic of Macedonia in different time intervals. The data about the road conditions in 1979 and 1982 are collected from the annual statistic report. The data from 1990 are collected from a research paper by Angelov (1992), and the data on the road network condition in 1999, 2012 and 2015 are collected from the PE Macedonian Forests.

Table 4 shows the density of the road network that is constantly growing. It reached 13.43 m/ha

<table>
<thead>
<tr>
<th>Year</th>
<th>Area</th>
<th>Road length</th>
<th>Forest roads</th>
<th>Public roads</th>
<th>Gfrf</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ha</td>
<td>km</td>
<td>firm soft</td>
<td>asphalt firm soft asphalt</td>
<td>m/ha</td>
</tr>
<tr>
<td>1979</td>
<td>905.653</td>
<td>2,922</td>
<td>1,206 1,716</td>
<td></td>
<td>3.23</td>
</tr>
<tr>
<td>1990</td>
<td>951.570</td>
<td>7,808</td>
<td>562 6,228</td>
<td>1,018</td>
<td>8.21</td>
</tr>
<tr>
<td>1999</td>
<td>953.430</td>
<td>9,687</td>
<td>1,157 5,244</td>
<td>187 606 676</td>
<td>1,817 10.16</td>
</tr>
<tr>
<td>2012</td>
<td>958.721</td>
<td>10,882</td>
<td>1,256 6,043</td>
<td>355 663 543</td>
<td>2,023 11.35</td>
</tr>
<tr>
<td>2015</td>
<td>987.545</td>
<td>13,263</td>
<td>1,346 8,185</td>
<td>406 675 556</td>
<td>2,095 13.43</td>
</tr>
</tbody>
</table>

Table 3. Optimal density of the felling quantity of the road network depending on the use of the felling quantity

<table>
<thead>
<tr>
<th>Type of forest</th>
<th>Felling quantity (m³/ha)</th>
<th>Use in a 100 year period (m³/ha)</th>
<th>Optimal density horse m/ha</th>
<th>Optimal density tractor m/ha</th>
<th>Optimal road length horse km</th>
<th>Optimal road length tractor km</th>
</tr>
</thead>
<tbody>
<tr>
<td>High forest</td>
<td>2.29</td>
<td>229</td>
<td>21.3</td>
<td>17.8</td>
<td>5,813</td>
<td>4,858</td>
</tr>
<tr>
<td>Coppice forest</td>
<td>0.80</td>
<td>80</td>
<td>12.2</td>
<td>10.9</td>
<td>6,932</td>
<td>6,193</td>
</tr>
<tr>
<td>Shrubs</td>
<td>0.25</td>
<td>25</td>
<td>6.0</td>
<td>6.4</td>
<td>359</td>
<td>383</td>
</tr>
<tr>
<td>Average</td>
<td>14.5</td>
<td></td>
<td>12.7</td>
<td></td>
<td>13,103</td>
<td>11,433</td>
</tr>
</tbody>
</table>
in 2015. These results easily show the mathematical subordination. In this case, the trend is calculated as a linear function (3) in the subordination of the density of roads and time (the particular year).

\[ Y = 0.223477 \cdot X - 437.406 \] (3)

These results are graphically presented in diagram 2.

The advantage of this approach in the calculation of the projection with the help of the linear trend is that it can analyze the realistic development of the road network in the aspect of the construction of new roads but also of the documenting of the roads which are mostly or completely damaged and cannot be recorded in the statistics as existing roads.

The disadvantage of the model is that it does not have a strong reference to the linear trend during the period when the construction is more intense as well as during the period when there is a break in the future forest road construction. These aspects of the forest road construction can influence future results, i.e. they can change the projected trend of increased road network construction.

**Development of the forest road network as a current rate of road building**

On the basis of an average value of the forest road building rate during the last few years (2010-2014), we can see future development of the forest road network. Thus, the average length of forest road construction in the last few years (2010-2014) has resulted in 182.5 km of new forest roads. As a result of this rate of newly constructed roads, we get the mathematical projection of the future infrastructure development. The results are shown in diagram 3.

This method is quite easy and simple to calculate. The disadvantage of this method is that it does not consider the roads that ought to be removed from the registry due to various reasons, for example: destruction by erosion, destruction of avalanches, destruction of vegetation etc. Another setback is the current reduced trend of forest road construction in recent years for which we have calculated an average rate of new road construction. Hence, in the future, there might be some changes in the trend of the growing density of road network.
CONCLUSION

- The forest infrastructure in the Republic of Macedonia is associated with mountain ranges where the forest is located. This is the case of difficult conditions in which forest roads are built and the potential of the forest is relatively small, bearing a volume of wood of 95 m³/ha and a current growth of 2 m³/ha;
- The development of forest infrastructure is impacted by public roads which are built in the forest as well as the roads that are used for forest management;
- The density of the forest road network in the Republic of Macedonia is 13.43 m/ha;
- The optimal density in the Republic of Macedonia is projected on the basis of adequate research which is focused on creating a model which will allow a practical transport within the management of the forests without making a negative impact upon the economic development of the forest. During a 100-year period of use of 200 m³ of forests (which corresponds to the current growth within 100 years), during the supply carried out with a horse, the optimal density would be 20.1 m²/ha, while the supply by means of a tractor would yield 17.1 m²/ha;
- If we establish the optimal density of truck forest roads in accordance with the allowed felling quantity, the optimal density when the supply is carried out with a horse would be 14.5 m²/ha, while the supply carried out with a truck would be 12.7 m²/ha;
- The calculated density of forest roads should be added to the density of the receptors and at the same time, the unproductive roads should be annihilated. In that case, we can talk about a useful method of theoretical estimation of the optimal network of forest roads;
- Achieving the estimated projections for the development of the optimal density of the forest roads is calculated according to the method of using a linear function of the trend in road building up to this moment or the method of the current rate of forest road building. With both methods we got approximately the same results.

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