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FOREST REVIEW

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TESTING THE APPLICABILITY OF THE MATHEMATICAL MODEL FOR FOREST OPENNESS

TRAJANOV Z., NESTOROVSKI Lj., TRAJKOV P.
Ss. Cyril and Methodius University in Skopje, Faculty of Forestry in Skopje, Skopje, Macedonia
Corresponding author e-mail address: zdrtrajanov@gmail.com

ABSTRACT: In order to establish the applicability of the mathematical model for determining the theoretical optimal density of the forest roads in Republic of Macedonia, a testing of the model in practice has been conducted. Mathematically, the theoretical optimal density is acquired as a sum of the optimal density of forest roads and the density of the receptors. Additionally, models for the optimal density of forest roads have been graphically designed in the software ARC MAP. The existing network of forest roads, as well as the area which is theoretically opened, have been taken as a basis for these graphic models. Additionally, the necessity for building new forest roads in order to create the complete network of forest roads in the area has been determined. At that, the new roads have been designed on the basis of the optimal distance of the forest roads acquired according to the mathematical model for optimization of the density of truck roads. Seven forest economic units at the area of the Forestry Plackovica in Radovis have been tested, and at the results that were obtained from the design of the optimal network and the theoretical optimal density of the forest roads, average relative absolute variation of 14% has been determined. The results that were obtained confirm the application of the mathematical model which was set for the optimal density of forest roads in Republic of Macedonia, drawing a conclusion that certain deviations from the mathematical solution are possible.
Key words: forest openness, optimal density, theoretical density, receptors, mathematical model, relative absolute variation

1 INTRODUCTION

The building of the forest road network in Republic of Macedonia is in an advanced phase in most of the economic forests. Therefore, when finding a solution for the optimal density of forest roads it is necessary that the existing road network is included.

In the past, in Republic of Macedonia, there have been mistakes in relation to the development of the forest road network, because according to the Law it is allowed the planning of the roads to be connected strictly with the designing of the special plans for forest management. Thus, in many situations the lack of professional solutions when designing forest roads is evident. The road network has been developed, and is still being developed, without a precise mathematical model for forest openness, and without appropriate design documentation, i.e. without creating general plans for forest openness.

For the needs of this research, seven forest economic units in the Public Company "Macedonian Forests", Forestry Plackovica – Radovis, have been covered. These forests have: different openness, different form of cultivation, different models of management, and so on.

At all these forest economic units the existing roads, as well as the area that is opened by these roads in relation to the mathematical model for optimization have been considered. In that way the real area which has been opened with the forest roads is obtained.

For the non-opened area there is a design of a road network according to the mathematical model for theoretical optimal density in order to create the complete road network. In the end one gets results about the current density of the forest road network, i.e. the final necessary density of the road network for each of the forest economic units that have been tested.

In the future, in Republic of Macedonia, it would be best that before designing the special plan for forest management, one to design a general plan for forest opening on the basis of the real situation of the forest transport and the appropriate mathematical model for forest openness, for every forest economic unit.

2 METHOD OF WORK

In order to establish the applicability of the mathematical model for theoretical optimal density, an appropriate testing has been conducted in the department of the Public Enterprise "Macedonian Forests", Forestry Plackovica in Radovis, for the forest economic units: Smrdesnik, Radoviska River – Oraovicka River, Konecka Mountain, Goten, Sirava River, Smiljanska River – Left River, Plackovica and Lomija River.

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 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.

With the research we have come to the conclusion that in all the researched cuttings the assortment technology has been applied. This means that after the cutting the wood is trimmed on the very spot by the tree-stump. The assortments are made after the trimming. In all the researched cases two types of assortments have been produced: fire or spatial wood, and technological tree or logs. At the production, not much attention has been given to adjusting the cutting to the technology of skidding, i.e. the type of the skidding method.

The theoretical model for forest openness is presented in Figure 1; at that this model for forest openness is in the form of irregular chess field, typical for mountain terrains which are usual in the Republic of Macedonia.

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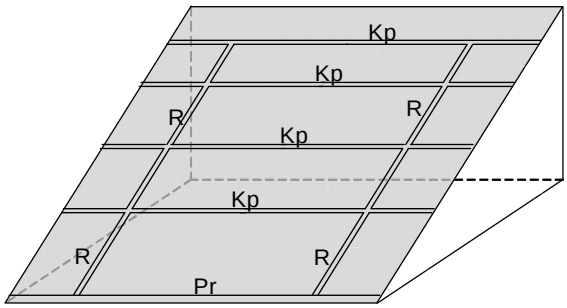

Kp – Truck road R- Receptor Pr – Public road

Figure 1: Graphic display of the theoretical model for forest openness in mountain conditions

Truck roads are roads built in the forest, which are used for transport (export) of wood assortments. These roads thoroughly open the area so that the skidding of all the wood assortments can be made from the place of cutting to the truck road. In mountain conditions these roads are usually built horizontally or under a mild longitudinal gradient on a slope, and that is why they are also called storey truck roads.

Receptors are truck roads which are primarily used for the transport of wood assortments to the final consumer. They are positioned in such a way so that they redirect the movement from the truck roads towards them. In certain situations a partial skidding of wood assortments can be made on the receptors, but their role is not primarily for that purpose. These roads are used for a longer period of time during the year.

The approach to a solution for the optimal network of forest roads could be very different, but in practice it has been proven that the best solution is reached if one starts from the economic moment, i.e. minimal costs for transport are requested, and at that the network of forest roads must fulfill all the necessary conditions for normal forests' management on the basis of ecological principles.

In solving this problem it has been noted that there is different relation between the optimal density of truck roads and the optimal density of receptors. That is why two analyses are conducted, with which the optimal density of truck roads is separately calculated, i.e. with a separate mathematical procedure the optimal density of the receptors is determined.

Mathematically, the theoretical optimal density (Gkptheo) is acquired as a sum of the optimal density of forest roads and the optimal density of the receptors.

$$Gkp_{teol} = Gkp + GR \qquad (1)$$

Gkp - density of truck roads
GR - density of receptors

2.1 Optimization of the road network

The methodology described in Z. Trajanov [5] has been used in the production of this scientific paper. The optimal density of road network is calculated by differential calculations, i.e. the first deduction from the total costs for transport.

The equation (1) is used for calculating the optimal density of road network for wood transport.

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

Total costs for tractor skidding - *Tsum,* are calculated with the equation (2).

$$T_{sum} = T_t + T_{kp} + T_{dp} \qquad (3)$$

Tt – costs for tractor skidding
Tkp – costs for truck roads
Tdp – costs for tractor roads

This formula is the basis for calculating the optimal density of road network. Similar methodology has also been used in other researches from this area, in the Republic of Macedonia, researches of R. Akimovski [2]. The reason why this methodology is being used, as well as the introduction of changes, is because of the new mathematical software which can solve complicated problems. Therefore, in contrast to the past situations when many parameters have been neglected in order to get simpler formulae for calculation, the new software solutions do not put limits to the number of unknown parameters and the combining of various mathematical operations. The new software also provides us with flexibility, i.e. easy calculations for each situation separately, all in order to get more accurate results. This paper will analyze the solutions obtained for a specific situation in the practice of skidding of wood assortments with tractors, in the mountain Plackovica in the Republic of Macedonia.

The optimal density of forest roads does not offer a complete solution for the density of forest roads in real circumstances where there is a necessity for joining the storey roads, as well as real losses in the aspect of errors in the design of the existing road network, the relief of the terrain and so on.

The solution is improved with completing the model and using the density of receptors in the final calculations for theoretical optimal density of forest roads.

The density of receptors is calculated with a differential calculation, estimating the first deduction according to the equation:

$$\frac{DTR_{sum}}{DGR} = 0 \qquad (4)$$

TR_{sum} -Total costs for receptors

This methodology is thoroughly elaborated on by Z. Trajanov [6].

In order to establish the applicability of the theoretical mathematical model in real conditions of a forest openness it is necessary all the roads to be designed completely, i.e. a general plan for forest opening to be made. When designing the new roads in the aspect of forest openness, the most useful tool for the designer is the optimal distance of forest roads in the area.

The optimal distance of roads Rкp is calculated according to the formula:

$$Rkp = \frac{1ha}{Gkp} \qquad (5)$$

Gkp–Optimal density of truck roads

With this tool the designer can come to a decision whether to design a certain road or roads, i.e. whether there is economic justifiability from the designing of new roads.

Whenever one talks about a solution for theoretical optimal density of the road network, one must make a distinction between two procedures for establishing the solution:

- A mathematical procedure for determining the theoretical optimal density
- A designed optimal density which is acquired with a direct designing of the road network on the basis of previously determined mathematical principles

In order to see the applicability of the mathematical model for theoretical optimal density in the department of the Public Company "Macedonian Forests", Forestry "Plackovica" in Radovis, electronic maps for all the forest economic units have been designed in GIS, on which the existing roads have been displayed. By using the mathematical model, i.e. previously defined buffers in relation to: the means of skidding, technology of work, relief, wood allowable as a potential for use and so on, the open area is being defined. This method is elaborated on by Pentek T. [8] and Danilovic M. [9]. In the non-opened areas, new roads have been designed in order to open the total area in the forest economic unit.

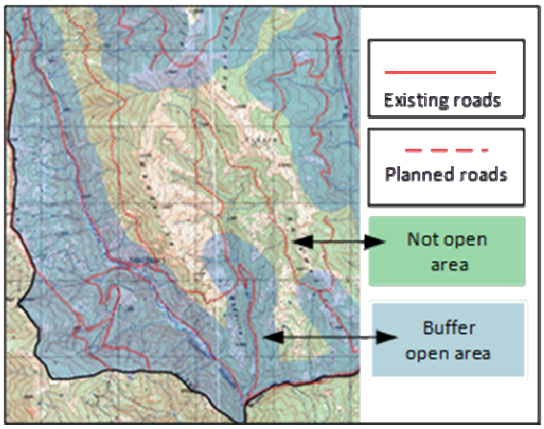

Figure 2: Graphic display of the existing and the planned road network

In Figure 2, there is a segment of the electronic map for the forest economic unit Smiljanska River. The open part of the area segmented with buffers is displayed in the image, marked with blue color. The remaining part is not open and that is where new roads are being designed.

The area which was opened with the newly planned roads is also tested with buffers, in order to determine the total open area. At that, it was insisted on the total open area to be over 90%.

3 RESULTS - TESTING OF THE THEORETICAL OPTIMAL DENSITY OF FOREST ROADS

According to the research, a connection between the density of the road network and the volume of wood that would be used when managing the forests can be established. The data for the optimal density of the road network according to the wood coverage is given in Figure 3.

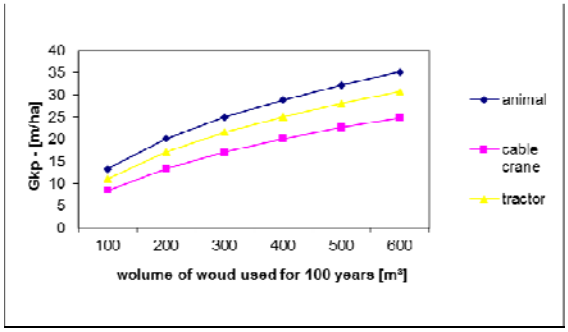

Figure 3: Relation of the optimal road network density to the amount of the volume of wood used for 100 years

From the Figure 3 one can see that with the increase of the volume of used wood, the density of the optimal road network also increases.

The results for optimal density of forest roads with horse skidding are presented in the scientific paper of Z. Trajanov [5] and [7].

One can also come to a conclusion that there is an obvious distinction of the optimal density of forest roads in relation to the different means of skidding. In the further estimations the tractor will be taken as a referential means of skidding, for which average values for the optimal density of forest roads are acquired. The tractor is also the most commonly used mechanical means of skidding in the Republic of Macedonia.

In table I, data about the areas of the forest economic units, as well as data about the possible usage of wood allowable in the period of a hundred years are presented. Additionally, data about the condition of the density of forest roads, the mathematical projection of the optimal density and the density of receptors determined according to the mathematical model are elaborated on.

The sum of these mathematical densities gives the relative optimal density of the forest roads. At the forest economic units with a lower potential of use of the wood allowable, a lower density of forest roads will be designed. The lowest theoretical optimal density is planned for the FEU Smrdesnik, with density of 14,89 m/ha. The highest theoretical optimal density of forest roads is planned for the FEU Plackovica – Lomija River, with density of 34,95 m/ha.

The implementation of the optimal density of forest roads, as well as the optimal density of the receptors, determined by models, in practice is followed by certain deviations which depend on many factors. Such factors are: the natural circumstances of the terrain, the condition of the forest, the condition of the bare parts in the forest, the models for the forest management, the technology of transport of wood assortments, the way of cultivation of the outer forest borders, the condition of the urban areas in the forest, and so on. All these factors oscillate in various areas of forest openness and additionally make the problem complicated for solving.

In the real circumstances, a factor which mostly influences the implementation of the theoretical optimal network of forest roads is the existing road network. All the errors which occur from the unplanned development of the road network are somehow implemented in the solution.

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Table I: The condition of the forest openness and the theoretical optimal density of the road network according to forest economic units

Forest economic unit	Area	Used wood allowable	Density of forest roads			
			Condition until 2016	Optimal	receptors	Theoretical optimal
name	[ha]	[m³/100 years]	[m/ha]	[m/ha]	[m/ha]	[m/ha]
Smrdesnik	5,470.00	111,00	7,90	11,86	3,02	14,89
Radoviska River - O.R.	8,600.67	139,00	11,80	13,67	3,37	17,04
Konecka Mountain	3,381.93	157,00	21,70	14,82	3,59	18,42
Goten	6,228.00	160,00	8,58	15,00	3,63	18,63
Sirava River	4,921.68	138,00	7,97	19,02	4,43	23,45
Smiljanska River - L.R.	4,612.40	362,00	19,13	23,83	5,46	29,29
Plackovica – Lomija River	2,387.30	513,00	29,49	28,45	6,50	34,95
Sum/Average	35601,98	225,71	15,22	18,09	4,29	22,25

The existing roads can make higher or lower density of the forest roads in relation to the optimal density. The final effect would be worse financial results, i.e. leaving the level of minimal transport costs.

A checkpoint on the mathematical model for theoretical optimal density could be conducted with the model for graphic designing of the total road network. The complete designing of the forest roads will be made on the basis of the already existing road network, with the help of the mathematical models for optimization and testing of the total solution.

Table II presents the values about the condition of the open and non-open area with forest roads, i.e. a display of the theoretical openness of the forest. In the table there are also values about the length of the existing roads, as well as values about the length of the newly planned roads and the density of those roads.

Table II: The open and non-open area by FEU, existing and planned road network with estimated density of the forest roads

Forest economic unit	Total area	Open area	Non-open area	Relative openness	Existing roads	Density of the open area	Planned roads	Density of the non-open area
	ha	ha	ha	%	m	m/ha	m	m/ha
Smrdesnik	5470,00	2657,59	2812,41	49	43213	16,26	36430	13,0
Radoviska R - O.R.	8600,67	4625,45	3975,22	54	101488	21,94	41484	10,4
Konecka Mountain	3381,93	3128,49	253,44	93	73388	23,46	0	0,0
Goten	6228,00	3286,71	2941,29	53	53436	16,26	43027	14,6
Sirava River	4921,68	2352,45	2569,23	48	39226	16,67	51988	20,2
Smiljanska R - L.R.	4612,40	3901,00	711,40	85	88235	22,62	17993	25,3
Plackovica -Lomija	2387,30	2210,00	177,30	93	74401	33,67	6183	34,9
Sum/Average	35601,9	22161,6	13593,1	62	473388	21,36	197106	14,7

The theoretical openness of the forests is within the range of 48 % (not enough openness) up to 93 % (excellent openness). The average real openness is 62 % which means low openness. The problem of the real forest openness is thoroughly elaborated on by T. Pentek [1].

In table III, the values about the projected optimal density of the forest roads, for all the forest economic units in Radovis, are presented.

With mathematical analysis, a correlation between the two trends has been established (theoretical openness in relation to the projected openness of the forest) of 0.89, which points to a high level of dependence, i.e. a confirmation about the applicability of the offered solution. The relative variations are within the range of -15% to 27%. The relative absolute variation has been estimated about each of the forest economic units, at which deviations within the range of 1 to 27% have been obtained.

Table III: Variations between the real and the projected optimal density of forest roads by forest economic units

Forest economic unit	Projected optimal density Gkp (m/ha)	Theoretical optimal density Gkp (m/ha)	Variation Gkp	Absolute variation	Relative variation	Relative absolute variation
Smrdesnik	14,56	14,89	0,33	0,33	2%	2%
Radoviska R - O.R.	16,62	17,04	0,41	0,41	2%	2%
Konecka Mountain	21,70	18,42	-3,28	3,28	-15%	15%
Goten	15,49	18,63	3,14	3,14	20%	20%
Sirava River	18,53	23,45	4,92	4,92	27%	27%
Smiljanska River - L.R.	23,03	29,29	6,26	6,26	27%	27%
Plackovica-Lomija River	33,76	34,95	1,19	1,19	4%	4%
Average	20,53	22,25	1,85	2,79	10%	14%

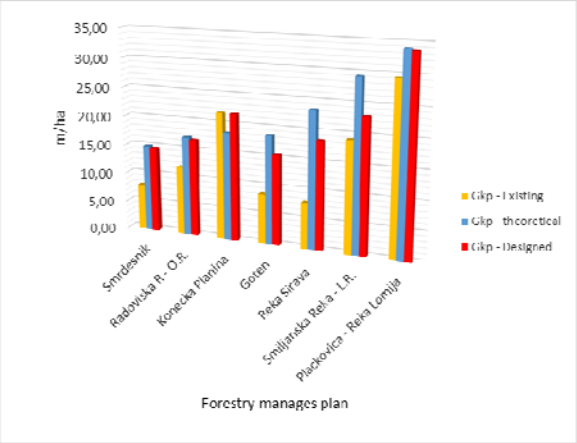

Figure 3: A comparison among the density of the road network, the theoretical optimal density and the projected optimal density of forest roads, by forest economic units.

A display of the condition of the density of forest roads, the mathematically obtained theoretical optimal density and the graphic-analytical projected optimal density for all the forest economic units in the Public Company "Macedonian Forests", Forestry "Plackovica" in Radovis, are presented in Figure 3.

4 DISCUSSION

The theoretical optimal density is acquired as a sum of the optimal density and the density of receptors. The theoretical optimal density is a mathematical quantity towards which one should strive when opening the forests. The results that were obtained confirm the application of the mathematical model which was set for the optimal density of forest roads in Republic of Macedonia, drawing a conclusion that certain deviations from the mathematical solution are possible. With mathematical analysis, a correlation between the two trends has been established (theoretical openness in relation to the projected openness of the forest) of 0.89, which points to a high level of dependence, i.e. a confirmation about the applicability of the offered solution. The relative variations are within the range of -15% to 27%. The relative absolute variation are within the range of 1 to 27% have been obtained.

5 CONCLUSIONS

- Mathematically, from the optimal density we get the Rkp – the optimal distance between two storey truck roads, which is the most useful tool for designing forest roads.
- The current density of the forest truck roads in the Forestry "Plackovica" is within the range of 7.97 m/ha to 29.49 m/ha. In average these forests are open with 15.22 m/ha.
- The existing roads can generate higher or lower density of forest roads in relation to the optimal density. The final effect is worse financial results, i.e. leaving the level of minimal transport costs.
- The theoretical optimal density of the forest truck roads in the Forestry "Plackovica" should be within the range of 14.89 m/ha to 34.95 m/ha. In average these forests should be open with 22.38 m/ha.
- The usable value of the theoretical optimal density has been tested by making the planned optimal density of forest roads, with the help of the buffer method with previously determined mathematical parameters.
- With mathematical analysis, a correlation between the two trends has been established (theoretical openness in relation to the projected openness of the forest) of 0,87% which points to a high level of dependence, i.e. a confirmation about the applicability of the offered solution. The average relative absolute variation is 14%.
- The relative optimal network is an accounting quantity; it can be lower or higher in relation to the existing road network. Thus, the relative variations are within the range of -15% to 27%.

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- In the future, this methodology should be tested on more samples in relation to more parameters, and in that way more precise conclusions could be drawn about its applicability in the forest practice in the Republic of Macedonia.

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