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QUALITY PLANNING OF FOREST ROAD NETWORK – PRECONDITION OF BUILDING AND MAINTENANCE COST RATIONALISATION

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Abstract: *The establishing of the optimum forest road network on the terrain consists of the following work stages: planning, designing, building with supervision and maintenance (Pentek et al., 2004). The basic assumption of this research is how to reduce subsequent costs of forest road network building and maintenance by their quality, timely planning and the use of contemporary work technologies (GIS, GPS, computer programmes, etc.) and by the implementation of the adequate truck (haul) forest road categorization. The traffic volume on truck forest roads of economic forests is primarily under the influence of the truck transport of timber assortments (Pentek et al., 2006). According to the truck forest road categorization system based on the analysis of the traffic volume (Nevečerel et al., 2007.), technical features of the individual truck forest road category have been defined. The standard of maintenance within each of separate categories has also been determined. The cost comparison of the currently valid and planned forest opening system has been made on the example of the management unit Veprinačke šume and results were projected on the area of the whole Croatia. The results have confirmed the research hypothesis, so the Study of the primary forest opening, based on the suggested opening system has to become a legal obligation as soon as possible and not, as until now, based on the choice of the individual person.*

1. Introduction

Planning, designing, building with supervision and maintenance are the basic work phases of the complex procedure in establishing the optimum truck forest road network on the terrain. These components are interpenetrated, mutually tightly connected and the next work phase cannot be started before the previous phase has been finished in a quality way (Pentek et al., 2004.).

Today, geographic information system (GIS) is used in planning primary and secondary forest road network, i.e. in making Primary and secondary studies of forest opening (Pentek, 2002).

Potočnik et al. (2005) did the analysis of the primary forest roads in the forest area Dragatuš, management unit Stari trg where they established that the position and the distance of a certain truck forest road section from the public road, the skid roads and the position of a turning point on a truck forest road have the biggest influence on the cumulative traffic volume and the traffic frequency, presuming the constant habitat conditions. When truck forest roads are closer to the junction of the primary forest and public road infrastructure they have to be made by a higher building standard and maintained in a more quality way and in shorter time periods.

Although in Croatia since its independence, there has been a lot of work done regarding the quality improvement and making order in all work phases, there has still been left a lot of work and quite free space within which there will be interventions in order to raise the quality level of forest opening on even higher, in European proportions, respectable level (Pentek et al., 2006.)

Nevečerel et al. (2007.) based on the analysis of the truck forest road traffic volume due to transport of timber assortments by trucks and trailer trucks, develop their categorization system in the economic forests of Croatia. In this, the designed GIS system of the researched area and computer programmes ArcMap and ArcScene are used in the analysis of the primary forest road network.

2. Problem of research

2.1. Forest road categorization

Šikić et al. (1989.) divides forest roads to primary and secondary forest roads. Primary forest roads include forest roads, while secondary forest roads include strip roads and skid trails.

According to Šikić et al. (1989.) the economic truck road network in forestry is divided:

⇒ according to significance
⇒ according to traffic volume (gross ton/ha),
⇒ regarding the terrain configuration,
⇒ according to the size and frequency of timber transport,

Pičman et al. (1996.), distinguish truck forest roads regarding the frequency of use and regarding the need for maintenance:

- primary truck forest roads, which are used during the whole year and demand regular maintenance,
- secondary truck forest roads, which are used from time to time, when necessary, so their maintenance is also periodical.

According to the terrain configuration, forest roads are divided into: low-land, hilly and mountainous.

Apart from the division of forest roads in the Republic of Croatia, it is necessary to mention some of divisions in other countries.

Classification of forest roads according to FAO (1976.):

- ✓ transport roads:
  - ✓ primary or main,
  - ✓ secondary or side,
- ✓ strip roads,
- ✓ approach roads.

Table 1: Division of forest roads on steep terrains (FAO, 1998.)

Road type	Road use	Road formation width	Carriage way width	Maximum gradient:	
				Transport direction	Non transport direction
		m		%	
Main truck	Truck, Pickup (Permanent)	5.0	4.5	9	6

forest road					
Secondary truck forest road	Truck, Pickup (Temporary)	4.5	3.5	10(12)*	8
Skid road	Wheeled skidder Wheeled tractor Crawler tractor	3.5	-	12(20)*	10

*maximum gradient for short distances only

In Germany, according to Dietz et al. (1984.), forest roads are divided into five classes based on the number of traffic lanes, carriageway width, permitted load, minimum radius of horizontal curves and permitted longitudinal grade. They are:

- main truck forest roads (1^{st} class),
- primary truck forest roads (2^{nd} class),
- secondary truck forest roads (3^{rd} class),
- strip roads (4^{th} class),
- skid trails (5^{th} class).

In Austria, Trzesniowski (1988.) divides forest roads according to the building standard into:

- main truck forest roads,
- secondary truck forest roads,
- planned forest ways,
- main and secondary skid trails.

Table 2: Technical features of forest roads in Austria (Stampfer, 2006.)

Characteristic feature	Main road	Primary haul road	Secondary haul road	Skidding road	Skidding trail
Utilization	Truck	Truck	Truck	Tractor	Tractor
Passability	Permanent	Permanent	Seasonal	Seasonal	Seasonal
Lanes	2 (1)	1	1	1	1
Road width, m	7 - 9	3.5 – 4.5	3 - 4	2.5 - 3.5	2.5 - 3.5
Crown width, m	> 9/10	5 - 7	5 - 6	-	-
Superstructure	Strong	Strong	Low	Exception	-
Bearing index, (Ev^2 MN/m^2)	> 120	> 80	> 60	-	-
Radius of curvature, m	> 40/50	> 20(16)	> 20(16)	-	-
Gradient, %	2 – 6	2 - 8(10)	2 - 8(10)	< 20/25	< 20/25

Table 3: Classification of forest roads and their basic technical features in Canada (Stjernberg, 1982.)

	Primary	Secondary		Tertiary	
		A	B	Summer	Winter
Min. road width, m	9.8	7.9	4.6	4.6	4.6
Min. depth of fill over roadbed, m	0.9	0.6	0.3 - 0.5	0.3 - 0.5	minimal
Min. gravel, m	0.15 - 0.20	0.15 - 0.20	0.15	nil	nil

	pit run	pit run	pit run		
Type of roadbed	vegetative matter	vegetative matter	vegetative matter	vegetative matter	snow & ice
Max. degree of curve, deg	6 - 8	6 - 8	10 - 12	12 - 14	12 - 14
Max. percent grade, %	6 - 8	6 - 8	10 - 12	10 - 12	10
Extent of life, years	10+	10+	7 - 9	1 - 2	1 season
m^3 of fill/km	10,000	5,200	2,400	2,400	minimal

In Slovenia Potočnik, (1996.), divides truck forest roads into three categories based on their multiple uses:

- ✓ **first category**, marked **G I/1**, which includes truck forest roads with dominant public use and non forest traffic and which lead to villages, farms, mountain houses and tourist facilities;
- ✓ **second category**, marked **G I/2**, which includes truck forest roads with relatively frequent public use (sports people, army, police, villagers, holiday-makers…), but this public use is not so emphasised as in the first category;
- ✓ **third category** which includes truck forest roads intended for forest ecosystem management, which are the most numerous and are divided into two subgroups:
  - **G II** – main truck forest roads, daily number of vehicles on the junction of a truck forest road and a public road is above 12,
  - **G III** – secondary truck forest roads, daily number of vehicles on the junction of a truck forest road and a public road is less than 12.

Table 4: Categorization of forest roads with basic technical features in New Zealand (Larcombe, 1999.)

Road class	Speed	Road width	Max. gradient	Volume	Description
	km/h	m	%	t pa.	
Arterial	70	9	5	> 250,000	Highest standard
Secondary	50	7	7	60,000 - 250,000	Medium standard
Spur	30	4.3	10	< 60,000	Lowest standard
Establishment	25	2.5	25	Light vehicles	Temporary tracks
Skidder tracks	20	2.5	25	Skidders	Temporary tracks

Table 5: Technical features of forest roads in the USA (Anon., 2000)

	Subgrade width	Min. curve radius	Max. gradient	Road duration
	feet (meters)	feet (meters)	%	
High use roads	16 - 22 (4.88 - 6.71)	70 (21.34)	14	Generally permanent
Medium use roads	14 - 16 (4.27 - 4.88)	50 (15.24)	18(20)	Semi-permanent or permanent

Low use roads	12 - 16 (3.66 - 4.88)	50 (15.24)	20(30)	Short term

2.2. Forest openness in the Republic of Croatia (existing and planned)

The openness of the certain forest area by forest roads is calculated regarding the relation of the total quantity of forest roads indicated in meters with the surface on which roads exist, expressed in hectares. Regarding the type of roads we can speak about two types of openness: primary openness – openness by truck forest roads and secondary openness - openness by skid roads and skid trails.

According to laws which are in force in the Republic of Croatia, there are no unique measures for evaluating a degree of primary openness. It is considered that a truck forest road or its parts open a forest area only if they influence the skidding distance. It is considered that a truck forest road influences a skidding distance if it passes up to 300 m from the forest edge and if timber loading is possible on it. We use the following criteria for determining and comparing the degree of openness (Šikić et al., 1989.):

- a truck forest road which passes through a forest will be taken into calculation by its whole length,
- a truck forest road which passes along the forest edge or on a distance of up to 300 m from the forest edge is taken into calculation with 50% of its length,
- a truck forest road which comes vertically to the forest edge and finishes there, is taken into calculation with only 500 m of length,
- a truck forest road without built pavement structure (earth roads) which does not open a forest during the whole year, but only during a dry period, is not taken into calculation.

Truck forest roads managed by the firm "Hrvatske šume", d.o.o. stretch (Pentek et al., 2007.) on completely overgrown area (without Forest Administration Split) of 1,282,076 ha and their total length is 15,547 km.

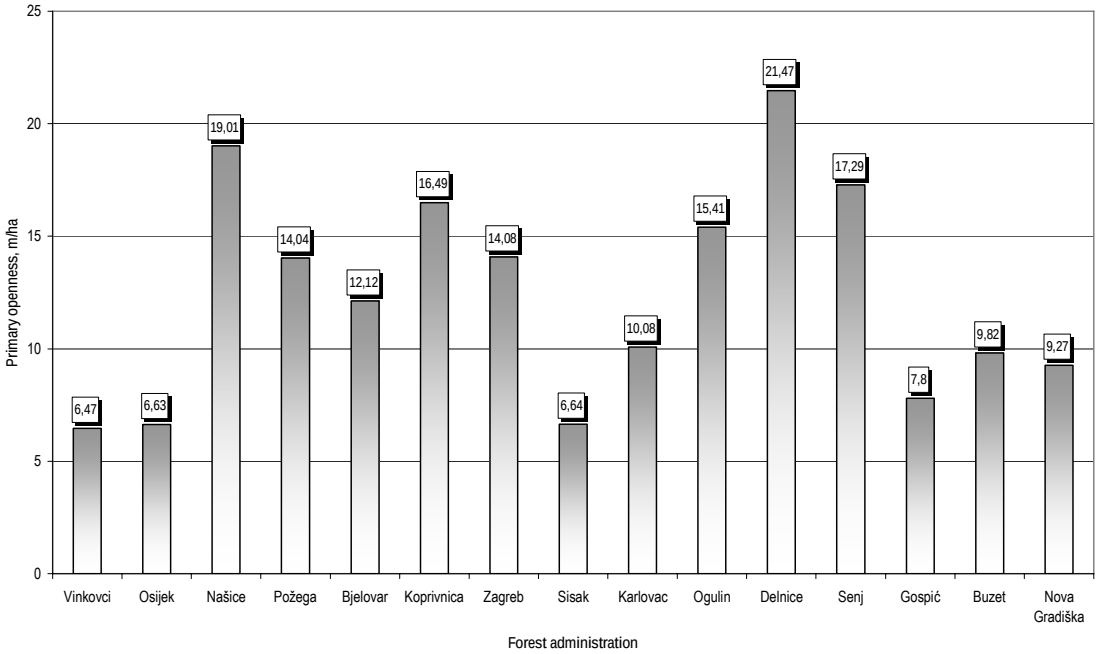

Figure 1: Existing primary openness of forests in the Republic of Croatia shown according to Forest administrations

Table 6: Minimum, planned and aimed openness of various forest areas in the Republic of Croatia (Pentek et al. 2007)

Forest area	Minimum openness m/ha	Planned openness 2010 m/ha	Aimed openness 2020 m/ha
Low-land	7.00	15.00	18.00
Hilly	12.00	20.00	25.00
Mountainous	15.00	25.00	30.00
Karst	–	10.00	15.00

Apart from the standard openness which, without the average timber skidding distance, tells us little about the quality of truck forest road spatial distribution, the relative openness of forests by forest roads should be used in planning truck forest roads.

3. Research aim and methods

Based on the truck forest road categorization performed in previously published papers, the aim of the research is to define technical features of a certain category. Also, it is desired to prescribe the volume and frequency of maintenance works for each category of forest roads. Furthermore, we will try to do a cost analysis of currently valid and suggested forest opening system (based on the new model of the truck forest road categorization) on the researched area. The results of the analysis will be projected on the whole Croatia.

The basic presumption of the research is that all truck forest roads need not be of the same category, thus of the same technical features, but there should be some differences among them. This difference is primarily conditioned by a traffic volume caused by truck units driving in transport of timber assortments from economic forests to public road systems. High category truck forest roads (those with higher traffic volume) should be built and maintained by a higher standard, which is more financially demanding. It is vice versa for low category truck forest roads.

4. Research area

Research was carried out in the area of the management unit Veprinačke šume, Forest Office Opatija, Forest Administration Buzet. Cost analysis results were projected on the whole Croatia, so the whole country can be considered the research area.

The total surface area of the management unit is 1 950.87 ha out of which 1 899.23 ha is overgrown. The management unit Veprinačke šume is a part of the mountain massif Ćićarija and is located between 45˚20' and 45˚24' of the northern geographical latitude and 14˚11' and 14˚16' of the eastern geographical longitude. The highest point is on 1 144.00 m of height above sea level, while the lowest point is on 760.00 m of height above sea level. The half-tree length method is used in felling and processing works. Skidders type LKT 80/81, Timberjack 260C, and Belt are used in timber skidding. The annual cut is of a good quality and the main economic species is beech.

Basic features of forest opening and timber skidding on the researched area are steep and indented mountainous terrain, the richness of karst relief phenomena, shallow soils, rocky foundation and heavy civil engineering material categories. The average terrain slope is 5-30°. From the mentioned features the need for good primary and secondary openness is obvious. Due to terrain configuration and developed orography, secondary forest roads have to be built.

Primary openness is 8.58 m/ha, i.e. 16.78 m/ha if we take the old Italian public road with the pavement structure made of crushed stone into calculation. The secondary openness is 101.94 m/ha.

5. Research results

5.1. Technical features of truck forest roads categorized according to traffic volume

The simulation of the truck forest road traffic volume was carried out on previously designed GIS management unit Veprinačke šume. They were first divided into five, then in four categories (Nevečerel et al., 2007.). For each truck forest road category, basic technical features were defined which are shown in tables 7, 8 and 9.

Table 7: Elements of horizontal route development

Forest road category	Mean of transport	Number of traffic lanes	Carriage way width	Shoulder width	Road width	Minimum radius		Distance between passing areas
						Circular arc	Serpentine	
			cm	cm	cm	m		m
I	Trailer truck	2	7.00	1.00	9.00	50	12	-
II	Trailer truck	2 (1)	6.00	0.75	7.50	40	12	- (300)
III	Trailer truck	1	5.00	0.50	6.00	20	12	400
IV	Trailer truck (truck)	1	4.00	0.50	5.00	18	10	500

Minimum radius between horizontal circular arcs of the opposite direction is minimum 20 meters for categories I and II and minimum 10 meters for truck forest road categories III and IV.

Circular turning points are made on distances of minimum 1500 meters in truck forest road categories I, II and III (radius 12 meters), i.e. minimum 2000 meters in truck forest road category IV (radius 10 meters). In categories III and IV, circular turning points can be replaced by T shape turning points.

Table 8: Elements of vertical route development

Truck forest road category	Maximum longitudinal slope	Minimum radius:		Minimum distance between vertical curves:		Max. depth of cuts	Max. height of fill
		Concave curves	Convex curves	of different directions	of the same direction		
	%	m		m		m	
I	6	1000	1000	50	40	2.00	1.50
II	6(8)*	500	800	45	35	2.50	1.50
III	8(12)*	300	500	40	30	3.00	2.50
IV	10(14)*	200	400	30	25	3.00	2.50

* can be used only in exceptional cases and shorter distances

Table 9: Pavement structure and road facilities

	Category I	Category II	Category III	Category IV
Superstructure	✓	✓	✓	✓
Superstructure type	asphalt (crushed stone)	crushed stone	crushed stone	crushed stone

Stabilisation	✓ (when needed)	✓ (when needed)	✓ (when needed)	–
Pavement structure	Mc.Adam (in two layers)	Mc.Adam (in two layers)	Mc.Adam (in two layers) crushed stone	crushed stone
Pavement structure thickness	40+5	30+10	20+5 (25)	20
Drainage ditches	✓	✓	✓	–
Bridges	✓ (when needed)	✓ (when needed)	–	–
Pipe culverts	✓	✓	✓	–
Soakaways	✓	✓	✓	✓
Overflow channel	–	✓	✓	✓

5.2. Volume and frequency of maintenance works of a certain forest road category

Various truck forest road categories are maintained differently where the volume (intensity) and frequency (time distance) of works have to be determined.

The surface of truck forest roads is exposed to atmosphere influences and vehicle pressure when surface damages of the pavement structure occur – potholes, grooves and ruts. Losses on a pavement structure occur under the influence of heavy rains, passage of vehicles and timber skidding on the road.

When fill and cuts are maintained, the prescribed slope inclination has to be maintained. Unstable stones and smaller earth fall which show the tendency of separating or sliding have to be taken from the cut slope.

Drainage ditches are cleaned in a way to enable free drainage from the pavement surface. Free profile of the pipe culverts by removing sediments, vegetation, branches, etc. has to be maintained as soon it is noticed. Soakaways, overflow channels and pipe culverts have to be renovated if their function is significantly impaired.

When shoulders are maintained, necessary compactness has to be ensured, as well as adequate transverse gradient.

The maintenance of retaining and revetment walls means the control of their stability and functionality and if they are worn out, they have to be returned to the initial condition.

Table 10: Maintenance of different truck forest road category

Description of work	**Truck forest road category**			
	I	**II**	**III**	**IV**
	Time distance of maintenance, year			
Maintenance of pavement structure	3 (when needed)	1	3	5
Maintenance of cuts and fills	1	2	3	5
Cleaning of drainage ditches	1 (when needed)	1 (when needed)	1 (when needed)	1 (when needed)
Rehabilitation of drainage facilities (pipe culverts, soakaways, overflow channels)	when needed	when needed	when needed	when needed
Shoulder rehabilitation	1	2	3	5
Maintenance of retaining and revetment walls	3	3	3	5

5.3. Cost comparison of the valid and suggested forest opening system on the example of the management unit Veprinačke šume

By comparing the existing situation with the suggested forest opening system using previously developed computer optimisation model of truck forest roads (Pentek, 2002.) two models of primary forest road network were developed. In the first case, new truck forest roads were added to the existing primary forest road infrastructure network until the criterion of the excellent relative openness was satisfied. In the second case, so-called zero condition was simulated, when the complete opening of the researched area by truck forest roads was carried out from the very beginning by using the computer model (in the management unit Veprinačke šume there had been only two public roads).

Table 11: The analysis of the forest road infrastructure for present, improved and modelled condition in the management unit Veprinačke šume

	Present condition	Improved condition	Modelled condition
Truck forest road length, m	17,707	21,890	20,904
Public road length, m	16,936	16,936	16,936
Total road length, m	34,643	38,826	37,840
Openness by truck forest roads, m/ha	**9.08**	**11.22**	**10.72**
Openness by public roads, m/ha	**8.68**	**8.68**	**8.68**
Total openness, m/ha	**17.76**	**19.90**	**19.40**
Total relative openness, %	77	86	91
Estimate of relative openness	4	5	5
Mean skidding distance, m	344	317	289
Cost of building and maintenance of truck forest roads for existing forest opening system, EUR	1,239,508	1,532,303	1,463,307
Cost of building and maintenance of truck forest roads for suggested forest opening system, EUR	885,363	1,094,502	1,045,219

The price of building and maintenance of category III truck forest roads, represents the planned price of truck forest road building and maintenance on the researched area. By the analysis of real prices of ftruck orest road building and maintenance in the last 10 years in the management unit Veprinačke šume, compatibility with planned prices has been noticed.

We obtained prices of building truck forest roads in categories I, II and IV by correcting defined technical features of category III forest roads (in accordance with tables 7, 8 and 9) on already made main designs of truck forest roads. Designs were made by the Faculty of Forestry at the University in Zagreb (they were made by the same designer) in a computer programme „CESTA“ which is the official programme for designing truck forest roads in the Republic of Croatia and they refer to concrete, mostly real truck forest roads in the management unit Veprinačke šume and neighbouring, very similar, management units.

We used the official Pricelist of Hrvatske šume d.o.o. Zagreb, in making a cost estimate.

Table 12: Price of building and maintenance and the total price of a certain forest road category in the depreciation period of 35 years

Truck forest road category	Planned building price	Planned maintenance price	Total price
sign	€	€	€
I	130,000	40,000	170,000
II	60,000	50,000	110,000

III	40,000	30,000	70,000
IV	30,000	20,000	50,000

5.4. Simulation of financial profit from the use of the suggested forest opening system on the level of the Republic of Croatia

Table 13: Building costs according to the existing and suggested forest opening system per Forest administration

Forest Administration	Openness		Forest road length	Cost of building truck forest roads per:	
	Existing	Planned 2010		Existing forest opening system	Suggested forest opening system
	m/ha		km	€	
Vinkovci	6.47	15.00	582	23.260.942	18.899.515
Osijek	6.63	16.00	537	21.470.812	17.445.034
Našice	19.01	20.00	78	3.110.089	2.526.947
Požega	14.04	20.00	290	11.613.618	9.436.065
Bjelovar	12.12	18.33	768	30.726.922	24.965.624
Koprivnica	16.49	16.67	10	417.216	338.988
Zagreb	14.08	17.50	258	10.308.500	8.375.656
Sisak	6.64	18.75	1016	40.644.144	33.023.367
Karlovac	10.08	18.75	666	26.627.998	21.635.248
Ogulin	15.41	22.50	368	14.719.407	11.959.518
Delnice	21.47	23.75	211	8.430.345	6.849.655
Senj	17.29	21.25	268	10.721.868	8.711.518
Gospić	7.80	20.00	3249	129.966.229	105.597.561
Buzet	9.82	15.00	328	13.110.862	10.652.575
Nova Gradiška	9.27	17.50	568	22.721.137	18.460.924
Total				367.850.086	298.878.195

The cost of maintenance of newly planned truck forest road network on the level of the Republic of Croatia, for depreciation period of 35 years, reduced to present value is 7,882,501.85 €/per year for the existing forest opening system and 5,911,876.39 €/per year for the suggested forest opening system.

6. Conclusions

- ⇒ Truck forest roads and even certain sections of the same truckforest road have to be built by taking into consideration various building standards, i.e. by applying different technical conditions. In this way it is possible to rationalise building costs and financial means kept in this way, invest into further opening of still unopened forests.
- ⇒ More frequent periodical and quality current maintenance has to be performed on forest roads of higher frequency.
- ⇒ Since many truck forest roads have to be built in the Republic of Croatia, till the aimed openness, the suggested forest opening system has to be applied with the aim of decrease costs of building and maintenance.
- ⇒ In management unit Veprinačke šume, by usage of computer optimisation model of truck forest roads combined with suggested forest opening system, we improved pre-existing condition of primary openness by building and brought relative openness to 86% with mean skidding distance of 317 meters. In the same time we decreased costs of building and maintenance of newly designed forest roads with total length of 4,183 m for 83,660 €.

⇒ If the primary openness of management unit Veprinačke šume is conducted from the beginning, by usage of computer optimisation model of truck forest roads with suggested forest opening system, we could spare 49,283 € when we compare improved present condition by achieving better relative openness (91% to the 86%) and shorter mean skidding distance (289 m to the 317 m).

⇒ Comparing forest road network costs of building and maintenance, in management unit Veprinačke šume, modelled condition for suggested forest opening system and existing forest opening system referred costs is reduced for 418,088 € (from 1,463,307 € to 1,045,219 €).

⇒ Simulation of required primary forest opening by use of suggested forest opening system, based on Forest administrations in the Republic of Croatia, fully supports new truck forest road categorization system. It is necessary to remark that simulation is performed for planned openness 2010. If the simulation is performed for aimed openness the results will be more impressive.

⇒ By applying the suggested forest opening system, the saving is achieved in relation to the existing forest opening system, from 18.75% during building and 25.00% during maintenance. The total saving is 21.43%, i.e. 137,943,782 EUR.

⇒ By reaching the planned openness 2010 it is necessary to build 9,196 km of truck forest roads with investment of 367,850,086 €. Costs of building will be lesser for 68,971,891 €, if new forest opening system is applied. In majority of Forest administrations planned openness 2010 will not be reached.

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