Forest Transportation Systems as a Key Factor in Quality Management of Forest Ecosystems

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1. Introduction

Forests and forested land cover 24,018 km² in the Republic of Croatia, which accounts for 42% of its land surface. Its greatest part consists of state-owned forests (2,018,987 ha or 75.10%), which are, just as other forests owned by state institutions (87,930 ha or 3.30%), managed by the company »Hrvatske Šume« Ltd. Zagreb, through its 16 Forest Administration Units, distributed throughout the territory of the Republic of Croatia. A significantly smaller forest surface is in private ownership (581,770 ha or 21.60%).

It is indisputable that the forest transportation system is a required and above all necessary precondition in today's modern, technologically advanced, rational, economical, ecologically orientated, environmentally-friendly management of forest ecosystems, based on biodiversity, natural forests and income sustainability.

Type, amount and layout of all forest transportation system components have to be carefully planned in order to establish a truly optimal forest transportation system within a forest. The optimal quality of a primary forest transportation system is estimated from economic, technical-technological, environmental (ecological-esthetical) and sociological point of view, and it is necessary to achieve harmony among all the mentioned evaluation criteria, as well as reach the level of overall optimization (all evaluation criteria have to be brought within the limits of acceptability).

Each evaluation criterion of the optimal quality of the existing transportation system is composed of complex dominant influential factors (which combine close and mutually dependent simple dominant influential factors).

1.1 Environmental component of establishing the forest transportation system

As it was mentioned previously, the forest transportation system is an indispensable and obligatory component in quality management of forest ecosystems. Forest roads, both primary and secondary, are still a foreign body in a forest, therefore, in their planning, design, construction and maintenance (repairs) and possible reconstruction, we should take into account the minimal disruption of the laws, relations and balance existing in a forest ecosystem. When individual primary forest roads or secondary forest roads of permanent character (skid roads) are no longer necessary for forest ecosystem management, or in time they have lost most of its function because of which they had been built, they should be

closed down, disbanded, and the surface on which they had been built should be restored to its previous purpose (productive forest land) by technical and biological methods. The procedure of removing the unnecessary (redundant) forest roads and restoring the habitat is neither cheap nor short, but it is necessary and, in the end, cost-effective in the long run.

Evaluation criteria for optimization network of truck forest roads	Complex dominant influential factors
The first priority evaluation level of truck forest road network optimality	
Economical criteria	Suitability of soil for truck forest road construction
	Terrain slope
	Existing traffic infrastructure
	Hydrographic network
Technical-technological criteria	Purpose of forests and forest land
	Forest owner
	Harvesting volume quality
	Applied technology and means of work
The second priority evaluation level of truck forest road network optimality	
Environmental-ecological criteria	Protected areas and buildings
	Protective areas and landscapes
	Danger of forest fire
Sociological criteria	Access to villages and hamlets
	Access to farm buildings
	Access to hunting lodges and weekend-houses
	Access to tourist and recreation buildings

Fig. 1. Structure of evaluation criteria for the optimal quality of the primary forest transport system estimation.

In the overall procedure of establishing each of the components of an optimal forest transportation system, the forest experts-designers should be guided with the idea of achieving an undivided whole consisting of constituents-habitat-forest road. In order to make that possible, the most important rules for the establishment of environmentally-ecologically-esthetically suitable truck forest roads in the planning and designing stage will be stated below:

While planning the environmentally-ecologically-esthetically suitable truck forest roads, the following remarks should be adhered to.

- Forest opening should be based on the *Studies of Primary and Secondary Forest Opening* of certain forest areas made according to a scientific-expert principle, because this is the only way to produce comprehensive, generally acceptable solutions.

- The production of a *Study of Primary and Secondary Forest Opening* should include all physical and legal entities (private forest owners, local government and self-government units, relevant ministries and institutions, etc.) which find it in their interest to participate in forestry planning (in this case, in planning truck forest roads).

- Bounded areas (protective zones) should be laid around the waterway network at a distance of at least 50 m.

- Truck forest road routes should not be laid in the immediate vicinity of accumulations and water-protective areas, unless it is absolutely necessary or contrary to the laws and sub-acts. Furthermore, lakes, surface waterways of permanent and periodic character, as well as the areas around water surfaces should be avoided.

- Low-land truck forest roads in the immediate vicinity of waterways may influence on the disruption of the underground water system, which would alter the microclimatic conditions of the site, resulting in a physiological decline of trees, lower quality of harvesting volume, and in the end, dieback and degradation of forests. The communication among underground water (even by means of artificially constructed technical objects) should be ensured.

- Because of rough ground conditions and required communication, it is necessary to set a truck forest road crossing over the waterway, subject to prior water management use approval, waterways should be crossed in their upper flow, and the road should not in any way influence on the change of the waterway direction and course. From the ecological and technical point of view, bridges would be preferred over roads, but they are expensive and non-profitable when it comes to low flow waterways.

- It is good to prefer soft construction material categories (soil with smaller or greater share of rock and softer rock), because on the one hand, earthwork expenses are low, and on the other, these categories have qualities sufficient for forming a quality truck forest road structure. The key factor in categorizing construction land favorability is its internal strength and hardness, or the share of rocky material of certain hardness in the overall amount of soil.

- Non-bearing base substratum, or soils having poor bearing capacity or none at all, should be avoided, because the construction procedure requires the use of one of the stabilization methods (soil improvement) or delivery of significant quantity of rock material in forming the truck forest road structure. Furthermore, such soils are quite often erosive, which increases the subsequent costs of truck forest road maintenance, as well as repair of possible damage and disturbing the forest ecosystem balance.

- Various categories of average terrain inclination are not equally favorable for truck forest road construction; therefore, it might be concluded that it is more favorable to construct truck forest roads on terrains with gentler average inclination than those with greater average inclination. Average terrain inclination has a direct influence on the transversal terrain inclination (terrain inclination perpendicular to the truck forest road axis), which dictates the terrain configuration at the truck forest road cross-section and has an influence on the amount of excavation and material filling during construction.

- In average terrain inclination of over 70%, it is very difficult to make stable excavation and embankment slopes in truck forest road construction of a normal cross section profile of fill slopes, so the danger of erosive processes is quite serious. In addition, in the process of construction, the level line elevation must be lowered deep below the terrain elevation at least for the roadway width, in order to make a normal cross-section

profile of the fill slope (or the technology of embankment construction is used on inclined terrains with the use of excavators). Therefore, forest road construction on inclined terrains, particularly on slopes with an inclination of over 70%, is very expensive and demanding, it significantly encroaches upon the forest ecosystem and causes possible significant damage on the same, so truck forest road construction is not recommended on the slopes with an inclination of over 70%.

The following recommendations are stated for the design of environmentally-ecologically-esthetically suitable truck forest roads:

- The main truck forest road projects should be produced by authorized independent designers – foresters, who will gain the mentioned title by taking a professional examination at the *Chamber of Forestry*, and later on design the proscribed number of truck forest road kilometers, first with the guidance of a senior authorized designer, and only then independently.
- It is necessary to have good *Technical Requirements for Truck Forest Roads* in the framework of which the basic components of truck forest road main design content should be defined, with a detailed analysis of each sub-appendix in order to achieve uniformity and standardized quality of produced projects.
- A professional, qualified committee for the revision of produced projects should be constituted within the Chamber of Forestry, which would ensure the credibility and quality of technical documentation prior to starting a construction business.
- Integrating the truck forest road level line into the existing longitudinal profile of the terrain is one of the more sensitive and more responsible jobs of a designer in the very procedure of project production. The positionally (horizontally) fixed route (in the direction of x and y coordinates) should be defined in the direction of the z-axis as well. Balance should be found between the efforts to integrate the route as well as possible into its surroundings and satisfying minimal proscribed technical requirements of a certain truck forest road category.
- From the point of view of minimal costs of subsequent upper structure maintenance, the most favorable solution would be to design the truck forest route level line on an inclination of 4 to 6%. This is also a favorable longitudinal inclination for traffic operation. On level line inclinations greater than 8%, besides other drainage structures, it is necessary to make soakaways (transversal drainage ditches over the truck forest road structure at an angle of 30° on the longitudinal road axis).
- Maximal values of longitudinal inclinations of truck forest road level line should remain within permitted limits, while the same should be applied only on the most difficult parts of the route and on as short a distance as possible. The consequence of the use of great road inclinations in longitudinal direction is a significant problem which leads to harmful erosive effects of water on the upper structure and its washing away. This automatically requires high maintenance costs and investment into the construction of drainage elements.
- The maximal permitted longitudinal level line slopes are connected with the truck forest road category and the terrain configuration opened by a road. Before, between and after the maximal longitudinal slopes, smaller level line slopes are integrated, in order to provide a relief to the vehicle engine, as well as to reduce the strength of erosive influence of water.

- The distance between oppositely directed vertical curve apex should be at least 60 m (the exact value depends on the value of level line grade change points) in order to ensure a straight level line stroke of minimally 35 m between the end of the previous and the beginning of the following vertical curve arc (it would be better if we could achieve greater distances). We are often torn between the wish to follow the ground conditions as well as gaining minimal costs (greater distance between vertical curve apex are proportional to the earthwork volume and its value), and simultaneously respect the rules described in this passage.

- Considering the level line slopes, the grade change points become round in concave or convex vertical curve arches. The following factors must be decisive in the choice of vertical curve radius: safety against grinding of the bottom part of the vehicle against the truck forest road surface, safety against lifting the wheels off the road under the influence of the centrifugal force, and sufficient visibility of the road in case two vehicles meet at the vertical grade change point. The minimal radius of concave vertical curves amounts to 200 m, while the least radius of convex vertical curves amounts to 400 m.

- The reduction of the level line longitudinal slope at steep and step-like terrains is often possible only by increasing the earthwork volume. This is more expensive at the beginning, but in the end, it is a much better solution because the overall costs in the truck forest road depreciation period are definitely reduced when compared with maintaining greater level line slopes with fewer initial construction costs.

- The truck forest road route level line should be laid in a way as to avoid the deep cuttings and high embankments (over 3 m) because, besides representing an aggression to the environment, they also have little esthetic value. The so-called „dead sections" of truck forest roads render it more difficult to perform works of forest harvesting, and other primary or secondary forest roads cannot be connected to them. The same are justified in the case of the necessary crossing of truck forest road route over prominent ridges and larger lowlands when the terrain configuration simply does not enable a different, better solution.

- In designing level line, account should be taken of the land mass distribution diagram. A quality distribution of land masses presupposes equal amounts of excavation and embankment at a distance of up to 50 m, with at least oscillations of the cube profile ordinate curve as possible around the x-axis. This puts the cheaper side material transport into the limelight, thus avoiding the longitudinal material transport at longer sections.

- Often not even the use of the greatest allowed level line slopes can negotiate a certain altitude difference, which is why truck forest road constructive elements are made, characteristic, above all, for mountainous and hilly areas – switchback. When they are unavoidable, switchbacks should be laid on locations of milder transversal terrain slopes (up to 40%), in order to avoid greater works on the terrain and the necessity of constructing retaining walls, but also for reducing danger of stimulating erosion processes.

- In lowland areas, special attention should be paid to raising the truck forest road route level line, owing to drainage above the surrounding terrain, that is, above the level of the highest water. The level line slope must amount to a minimum of 0.5%, because in smaller level line slopes there is more damage on the upper structure due to the interaction between vehicles and water retaining on the roadway.

- Minimal diameters of horizontal circular arches amount to 20 m and they should be avoided, because they have an indirect influence on the truck forest road width by widening the road in the curves, reducing the safety of operation speed and having a negative influence on the safety of traffic. However, the fact is that we often follow the terrain owing to the road construction cost-effectiveness in the hilly and mountainous area, which of course, has an influence on laying the route with smaller diameters. Therefore, it is necessary to find an optimal compromise in such terrains between the well-integrated truck forest roads into the terrain contours on the one hand, and the safety of traffic, minimal diameters of horizontal curves, cost-effectiveness of construction and other relevant environmental, technical, financial, ecological and social factors, on the other.

- Passing areas (full or partial) are built on straight lines, outside vertical curves, on smaller longitudinal level line slopes and points with good visibility, often on the excavation side of fill slopes (due to stability), at a distance of 200 to 500 m. Their task is to ensure the possibility of evasion of two vehicles moving in opposite directions, as truck forest roads are made with one lane.

- Taking into consideration everything that was said before, a passing area should be located, according to the designer's evaluation and perhaps according to the collected samples, where there is material, which by using certain contemporary, environmentally friendly work technologies and technical means, might be used for the building into the upper structure. That is a soft and averagely tough rocky material, in which excavations can be done by means of a hydraulic hammer excavator (without the use of explosives). In this way, we avoid the opening of stone material borrow pits (quarry) in a forest, thus completely reducing or decreasing the need for the supply and delivery of stone material of a certain granulation from often very distant quarries (the overall costs of procurement and remote transport of the stone material do not incur the total expenses of truck forest road construction).

- Drainage ditches of trapeze or triangle shape (grader ditches) are always at the internal (excavating) fill slope side. Water from the drainage ditches can be drained into the surrounding terrain, and in order for the ditches to preserve their function, they need to be regularly maintained.

- Pipe culverts should be built on the crossing of truck forest road routes over small capacity surface waterways, which, considering their cross-section might be round or square, and they are most often made of reinforced concrete. The diameter dimension is determined with regard to the calculated water flow. Each culvert, regardless of its dimension, must be set in an appropriate way at sufficient depth under the level line elevation (so that during traffic operation they would not break).

- The junction of truck forest and asphalt public roads (crossroads) should be made in accordance with the proscribed Technical Requirements. The approach from a truck forest road into an asphalt public road should be elevated between 2% and 4%, so that during precipitations the stone material would not be washed away from the truck forest road into the public road, thus endangering traffic. If it is not possible to follow the proscribed inclinations, then the end of the truck forest road superstructure (20 m in length) should be made with concrete or asphalt carpet.

- The retaining walls are used for the stabilization of embankment slope, shortening the length of embankment and reducing the volume of material that should be fitted into

the embankment on steep terrains. There are several forms of retaining walls, but regarding all of them, attention should be paid to regular dimensioning and fitting into the environment (which will best be achieved by using autochthonous stone material, which besides their functionality will provide the retaining walls with a more prominent esthetic function). Similarly, lining walls built on the excavation side of the fill slope and serving for the repair of excavation slopes (they do not carry the traffic burden).

- Owing to the evaluated construction material category, while forming cross-sections, it is necessary to make the excavation slopes and the embankment slopes at a certain inclination. Besides reducing the possibility of material sliding down to the surface of the roadway and endangering traffic (at the excavation side), as well as material sliding down the embankment, damaging trees at the lower side of the truck forest road and stimulating erosion processes, it also achieves an esthetic effect and a more pleasant surroundings for the drivers. Besides the mentioned ones, there are other technical recovery methods of excavation and embankment inclinations, which should definitely be combined with biological methods of recovery, because that is the only way to achieve the ultimate effect.

2. Research area

2.1 Classification of forest transportation systems

Forest transportation systems may be classified into primary, secondary and special-purpose forest transportation systems. Public roads are a generally common good owned by the Republic of Croatia, and according to the Public Roads Act (Official Gazette no. 180/04, 82/06, 138/06, 146/08, 152/08, 38/09, 124/09, 153/09, 73/10 and 91/10), depending on social, traffic and economic significance, they may be: motorways, state roads, county roads and local roads.

Primary forest transportation system consists of all categories of truck forest roads, as well as public roads which may be used for forestry operations (these are often lower level public roads – county roads and local roads). Forest roads are permanent construction facilities, enabling constant motorcar traffic for the completion of tasks anticipated by the Management Plan. With their construction, the amount of productive land in a forest is permanently reduced (except in the case of their closing down and revitalizing sites). They consist of a lower structure and an upper structure with all technical characteristics of a road. They may be divided on the basis of several criteria.

The components of secondary forest transportation system are secondary forest roads: skid roads, skid trails and cable yarder corridors. Their main purpose is timber extraction from the bunching point to roadside landing (primary timber transport) and, occasionally, completing assignments anticipated by the Management Plan. From the roadside landing to the ultimate user, timber may be transported by constructed transportation systems (forest and public roads, as well as railroads) or waterways (rivers, lakes, seas, oceans).

Skid roads are construction facilities of permanent character (except in the case of their closing down and revitalizing sites), built only with a lower structure. They are associated with sloping terrains, heavier material construction categories and the presence of surface obstacles.

Skid trails are secondary forest roads of temporary character, made by cutting a route through a forest, possible extraction of stumps and a repeated passing of a timber extraction machine (skidder, forwarder) on the same route. They are characteristic of flat terrains, lighter material construction categories and the absence of surface obstacles (easily passable terrains).
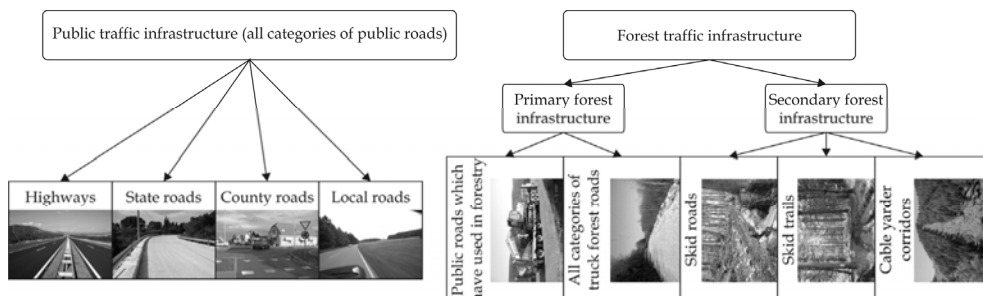

Fig. 2. Classification of forest transportation system.

2.2 Stages of establishing an optimal forest transportation system network

Establishing an optimal network of forest roads in the field has to unfold through the following operational stages: planning, designing, construction with supervision and maintenance/repairing (*Pentek et al. 2004*). These stages are mutually related and dependent, they should be performed in the order as they are stated, taking into account the unfeasibility of each of the operational stages in case the previous one has not been completed in a satisfying manner.

Besides the mentioned, always present stages of forest transportation system optimization, there are occasionally two additional operational stages: stage of forest roads reconstruction (in order to increase their standards when it comes to forest roads, or turning skid roads into forest roads) and the stage of forest road removing/restoring (besides the revitalization/restoration of sites, or restoring the function and form of a site as close as possible to what it had been before the road was built).

2.3 Planning of forest roads

A comprehensive planning of forest roads is the first, initial and unavoidable stage of establishing an optimal forest transportation system network in the field. In the last 20 years, GIS (Geographical Information System) is applied in primary and secondary forest opening, in combination with other contemporary technologies (*Pentek, 2007a*). The data required for making a quality GIS of a research area are collected from the following sources (*Pentek, 2002*): thematic maps, computer databases, written databases, Management Plans, field measurements, field observations and notes, other sources, arithmetic and logical operations with the data from previously mentioned sources.

The result of a contemporary approach to forest opening are the Studies of Forest Opening (primary and secondary), made for the period of 10 (20) years, after which they are renewed or revised. These documents are considered as a part of tactical planning in forestry. Tactical

plans provide answers to the question of what to do in order to achieve the set goals of strategic planning and what decisions are necessary for that (*Kangas and Kangas, 2002*), and they are made for a shorter period of time (depending on the circumstances, they cover a period of 5 to 20 years); they result in a list of measures (operations or interventions) planned to be done within the following time period.

2.3.1 A study of primary forest opening

Every good Study of Primary Forest Opening should contain the following data:

- for the existing forest transportation system:
    - a complete (updated) cadastre of the existing primary forest transportation system,
    - a complete (updated) cadastre of the existing secondary forest transportation system,
    - the existing primary and secondary road density (m/ha),
    - the existing mean distance of timber extraction for each particular compartment (m),
    - the target primary road density and the target (planned) mean distance of timber extraction calculated from it,
    - numerical, graphical and pictorial (map) results of the analysis of the existing relative primary openness;
- for the improved primary forest transportation system:
    - numerical, graphical and pictorial (map) results of the analysis of the existing relative primary openness for the improved primary forest transportation system,
    - primary road density of the improved primary forest transportation system (m/ha),
    - mean distance of timber extraction for each particular compartment (m),
    - conceptual route of planned truck forest roads (defined by the coordinates of route break-points),
    - category of each conceptual truck forest road route,
    - cost component (anticipated expenses) and economic justification for the construction of each conceptual truck forest road route,
    - dynamics of the construction of the overall (optimal) future primary forest transportation system network, aligned with the proscribed works in the Management Plan,
    - dynamics of the maintenance of the overall (optimal) future primary forest transportation system network,
    - other data significant for any of the stages of establishing the optimal primary forest transportation system network.

2.3.2 Primary road density

Primary road density represents the sum of lengths of all components of primary forest transportation system (which influence on the openness of the respective area) divided with the surface on which the respective roads are located. It is expressed in m/ha or km/1000 ha. *Šikić et al.* (1989) defined the fundamental criteria on the basis of which a certain road, or a particular part of it, is taken into consideration when calculating primary road density.

Pentek (2002) distinguishes five basic variants of primary road density:

- The existing primary road density – calculated for the existing (real) primary forest transportation network of a certain forest area, often a Management Unit,
- Minimum required primary road density – set for a greater forest area, in most cases related to a relief area, used in the strategic planning of forest-management area as a minimum goal which should be reached within a given time period for a more rational forest management,
- Planned primary road density – it is also set for a greater forest area (relief area), and serves as a marker within a defined time period in the strategic planning of forest-management area and in making long-range plans of primary forest transportation system construction,
- Target primary road density – most often defined for a management unit area and represents the final goal of primary road density of a certain forest area; it is closely connected with the methods and procedures of timber harvesting, as well as morphological relief characteristics in a specific Management Unit; it is used in the context of tactical planning and making Studies of Primary Forest Opening,
- Optimal primary road density – calculated by applying a known method of primary forest transportation system optimization; it is related to the management unit surface area and is most often based on the model of minimum overall cost of timber harvesting.

Relief area of the Republic Croatia	Minimum required road density	Planned road density 2010th	Planned road density 2020th
	km/1000 ha		
Low-land area (Flat terrain)	7.00	15.00	It is not the subject of research
Hilly area	12.00	20.00	25.00
Mountainous area	15.00	25.00	30.00
Karst area	No data	10.00	15.00

Table 1. Minimum required (*Šikić et al. 1989*)., planned 2010th(*Anon., 1997*) and planned 2020th (*Pentek et al. 2007a, Pentek et al. 2011)* primary road density for different relief areas in Croatia.

2.4 Truck forest roads designing

To design a certain truck forest road (*Pentek, 2010b*) means to conceptualize it, describe it and present it arithmetically and graphically. Only a completely finished main truck forest road design may be analyzed, and construction may ensue after its approval.

Designing truck forest roads consists of collecting general and technical data, as well as route layout and design creation. The first stage of designing includes collecting general and technical data, which present a basis for making a feasibility study. Route layout (field measurement) and design creation (office data processing and print-out of results) represents a designing components which combines all field and office route layout work, making of investment program, as well as conceptual, general and main forest road design.

Truck forest road layout is performed by way of a direct layout. The result of the planning stage, observed from the level of a single truck forest road, is a larger number of projected

zero line variants (at least three) on forest-management contour maps with the scale 1:10000 or even better 1:5000 in digital form. These are the so called conceptual layouts of the future truck forest road.
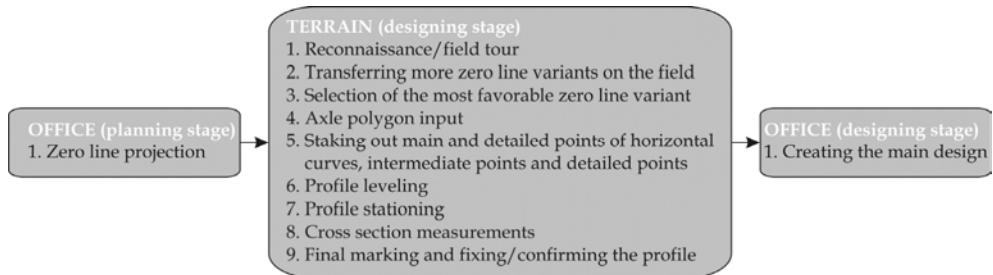

Fig. 3. Direct layout – basic operation stages.

Two procedures may be applied in truck forest road designing (*Pentek, 2010*), according to the valid regulations – short procedure: implies the making of the conceptual and main truck forest road design; and full or complete procedure: encompasses the making of conceptual, general and main truck forest road design.

Conceptual design – this design deals with the conceptual layouts of truck forest roads, along with the making of technical and economic study. It is made on contour maps with the scale 1:5000, 1:10000, 1:25000 and 1:50000. Maps need to have a marked management division – borders Management Units, compartments and sub-compartments as well as a complete cadastre of primary forest transportation system (if possible, also the cadastre of secondary forest roads). Important components of the maps are permanent and occasional waterways. It is necessary to be acquainted with the Management Plan, as well as study the information about growing stock, harvesting volume (allowable cut) and timber assortment structure of an individual compartment and a harvesting plan. The contour map has to contain more zero line variants for each truck forest road. At the same time, attention should be paid to key points, which have to be connected by the future route, as well as to the position and capacity of landings, branching of skid roads, etc. All zero line variants are transferred to the field, the most favourable one is chosen, and then follows the making of a rough cost estimate and a technical and economic study for it.

General design – made on the basis of previously made and approved conceptual design. Tachometry measurement is made around the operative polygon of conceptual route (in order to make a contour plan). Then, a contour plan is made in the office, the axle polygon is integrated into the zero line, horizontal curves of the selected radius are determined and drawn in. A longitudinal section is drawn on the basis of a situation plan, and cross sections are made based on a round level line in order to make a report of land work cubage. General design provides more realistic technical and economic indicators on the future truck forest road than the conceptual design.

Main design – made on the basis of the conceptual and general design, or just on the conceptual design. This is the most comprehensive design, which represents the basis for commencing the construction procedure.

• Court Register Certificate	• Declaration of conformity of project documentation	• Drawn longitudinal section
• Certificate on the Appointment of an Architect	• Calculation of mechanical resistance and stability	• Normal cross sections
• Certificate on Architect Authorization	• Technical description of forest road layout	• Drawn cross sections
• Ownership Certificate and a copy of cadastre plan	• Position plan	• Land mass cubage and a quantity statement
• Certificate of Title and a land register transcript	• Detailed position plan	• Mass-haul diagram
• Record of zero line handover	• Print-out of longitudinal section	• Bill of quantities
• Record of staked-out route handover	• Data on horizontal and vertical curves	• Estimate – priced bill of quantities
• Fire protection document		

Table 2. Basic components of the main truck forest road design.

2.5 Truck forest road construction with supervision

Following the designing stage, there is the construction stage with supervision, representing the greatest expense in the overall process of making a new truck forest road. In the Republic of Croatia (*Pentek, 2010*), the construction procedure, in the widest sense of the word, is performed through the following operational stages:

• carrying out the public tender procedure and the selection of the most favorable tenderer,
• signing the Implementation of Works Contract and reporting the work-site to relevant institutions,
• record on possession of site,
• renewal of construction stake-out of truck forest road axle layout,
• execution of works of truck forest road construction,
• permanent and occasional work supervision,
• taking-over certificate.

The works during truck forest road construction (*Pentek, 2010*) are divided into several main groups: preparatory works, works on lower structure, improvement of the soil with various stabilization methods, works on facilities of underground and surface drainage, works on incline/slope stabilization, works on upper structure and other works.

Until the middle of the 1990s, the construction of truck forest roads in all relief conditions was performed by means of dozers, while explosives and pneumatic hammers were used on rocky soils. Nowadays, in general, dozers are used in lowlands and for lighter material construction categories, while excavators fitted with hydraulic hammers are used on sloping terrains and rocky media. Explosives are applied only for the toughest rocks where the use of a hydraulic hammer would not yield satisfying results.

The choice of technology to be used in the construction of a certain truck forest road depends on the following: relief characteristics of the terrain where the works are performed, material construction categories on the truck forest road route, economic indicators, availability of construction machinery and equipment, valid regulations in the area of forestry, civil engineering, protection of nature and the environment, as well as other influential factors.

Lowland area (flat terrain)	Hilly and mountainous area (inclined terrain)
• non-bearing and poor capacity soil (necessary soil stabilization)	• heavy material construction categories (sometimes the use of explosives required)
• lack of rocky material on the forest road route	• large transversal inclinations of grounds
• distance of a quarry from the site (high cost of stone material transport)	• deep cuttings and high embankments (construction of retaining and revetment walls)
• developed hydrographic network – constant large flow waterways (necessary construction of bridges)	• danger of stimulating erosion processes
• high level of underground water (construction of embankment in order to raise the forest road level line, construction of drainage ditches)	• necessity of using larger longitudinal level line slopes
• significant oscillations of water levels in a forest stand (construction of overflow channels),	• necessity of using minimum horizontal curves radius
• avoiding the compartmentalization of forest areas (necessary construction of culverts)	• danger of sudden rush of water on the forest road route (construction of drainage ditches, culverts and soakaways)

Table 3. Most important problems encountered during truck forest road construction.

The construction of truck forest roads should be approached in a very responsible and professional manner, at the same time trying to the utmost to minimize their harmful (negative) influence on the forest ecosystem. Soil compaction and reduction of airiness, interruption of waterways, reduced biological activity in the soil, erosion, floods, landslide sites, etc., represent just some of the consequences of the construction and use of truck forest roads. A good way of achieving a balance between the forest ecosystem and truck forest roads is through high expertise and constant professional improvement of forest road designers, developed awareness of maintaining the forest ecosystem and knowledge of its functioning as a whole, good Technical Requirements for Forest Roads, valid and consistently respected regulations, good and thoroughly respected procedures of establishing optimal primary forest transportation system network (according to defined operational stages), and a selection of ecologically suitable construction technologies and construction supervision on more levels.

Expert supervision of truck forest roads construction on more levels is necessary in order to ensure the adherence to project documentation (main design of truck forest road), or transferring the vision and conception of forest roads designers from paper into the forest ecosystem. It is recommended to have designer's supervision because, besides guaranteeing expertise and a good knowledge of project documentation of a certain forest road, this kind of supervision provides good and fast elimination of possible vagueness or disputable situations.

Constant and occasional work supervision is performed on more levels:

- the construction site superintendent controls the machinist and keeps the Engineering Log and Engineering Record on a daily basis,
- the supervising engineer controls the contractors (machinist and construction site superintendent) and signs the Engineering Log and Engineering Record on a daily basis,
- occasionally and if necessary, the main supervising engineer controls the works,
- the final works control is performed by the Committee for Handover of Works.

2.6 Truck forest roads maintenance

Maintenance of truck forest roads represents a series of construction-technical procedures, which should be performed regularly in order to keep the roads in their original condition, in which they may complete all the tasks proscribed by the Management Plan. Construction cost and costs of truck forest road maintenance in the period of its depreciation (25 – 40 years, depending on the authors and calculation method) constitute the overall costs of truck forest road management.

As a rule (in normal weather conditions, the usual regime of usage and similar site and stand conditions), well-built truck forest roads require lower maintenance costs during the depreciation period than those truck forest roads in the construction of which the costs were cut down at the expense of quality or the works were in a hurry (each work needs to be realized within a certain time factor). In the end, the overall costs of well-built and well-kept truck forest roads are considerably lower than those of badly and quickly built roads (which often in certain periods of the year, during rough weather, cannot complete their tasks).

2.6.1 Forest road maintenance types

According to the frequency and regularity of performing maintenance works, there are several types of maintenance:

- Regular maintenance – consists of constant visiting and inspections of truck forest roads, as well as establishing possible defects and damages. Besides recording damages, we should also determine the measures for their elimination, define the time for the performance of works, necessary material, machinery and the number of workers, as well as calculate the costs of repair. The following works form a part of regular maintenance: cleaning of drainage ditches, culverts and other drainage facilities, cleaning of road upper structure, maintenance of incline/slope and road shoulders, mowing grass, maintenance of plants, etc.
- **Investment maintenance** – implies larger works on the earth road structure, replacement of damaged and worn-out culverts and drainages, repair of retaining and revetment walls, etc.
- **Periodic maintenance** – related to a certain period, season or particular circumstances (e.g. snow cleaning, works after sudden floods, etc.).

According to the component of a truck forest road being maintained, road maintenance may be divided into:

- lower structure maintenance:
  - maintenance of the earth road structure,
  - maintenance of the surface and underground drainage system,
  - maintenance of retaining and revetment walls,
  - maintenance of cuttings and embankment slopes,
  - vegetation maintenance (also includes road shoulder maintenance),
  - bridge maintenance;
- upper structure maintenance.

3. Research goals and methods

3.1 Research goal

Research Goals are defined by these encompassed and logical units:

- classification of Management Units (MU) and Forest Administration Units (FAU) into relief categories,
- establish the existing primary road density (Management Units, FAUs and relief categories),
- calculate the length of the planned truck forest road network (in FAUs and in relief areas, with the purpose of achieving the planned primary road density until 2010 and 2020),
- calculate the construction cost of the planned truck forest road network (in FAUs and in relief areas, with the purpose of achieving the planned primary road density until 2010 and 2020),
- suggest guidelines for further primary opening of the forests of the Republic of Croatia.

3.2 Research methods

3.2.1 Classification of MUs and FAUs into relief categories

There are four categories of relief areas: lowland area, hilly area, mountainous area and karst area. According to Management Plans, each Management Unit is located within its relief category. The surfaces of each relief category on the level of FAUs were summed up in order to calculate first the absolute, and then the percentage share of each relief category in the overall FAU surface.

3.2.2 Establish the existing primary road density

The existing primary road density by Management Units will be determined on the basis of the cadastre of primary forest transportation system, constituted on the level of the company »Hrvatske Šume« Ltd. Zagreb, as it was on 31st December 2009. This is followed by the collection of all data from all Management Units of the same relief category on the level of FAUs and the overall research area.

3.2.3 Calculate the length of the planned truck forest road network

The difference between the existing and the planned primary road density (year 2010 and 2020) of an individual FAU and its surface gives the overall length of planned truck forest roads which ought to be built. It is assumed that all future truck forest roads will be a part of the calculation of openness with their entire length. Planned primary road density in 2020 for lowland relief area has not been calculated; lowland area has not been the subject of research neither the length nor the cost of planned truck forest road network in 2020.

3.2.4 Calculate the construction cost of the planned truck forest road network

Cost analysis of the new planned truck forest road network will be constructed according to technical characteristics of forest roads proscribed by the valid Technical Requirements for Industrial Roads (*Šikić et al., 1989*) and planned costs of truck forest road construction in various relief categories by the company »Hrvatske Šume« Ltd. Zagreb.

3.2.5 Suggest guidelines for further primary opening of the forests in the republic of Croatia

The dynamics and the priorities of the development of the existing primary forest transportation system network will be defined through a detailed analysis of the need for the construction of primary forest transportation system for the following 20 years, upon examination of the past dynamics of truck forest road construction, taking into consideration the financial, productional, organizational, expert and technical-technological capacities of the company »Hrvatske Šume« Ltd. Zagreb.

4. Research area

Research was conducted on the area of 15 Forest Administration Units which are a part of the company »Hrvatske Šume« Ltd. Zagreb. Owing to the lack of data, FAU Split was not included in the research.

Fig. 4. Location and area of each Forest Administration Unit.

5. Research results

5.1 Classification of FAUs into relief categories and determining the existing primary road density

On the basis of the conducted relief area classification (Fig. 5.), FAUs have been grouped into relief categories for the purpose of easy reference and result comparability.
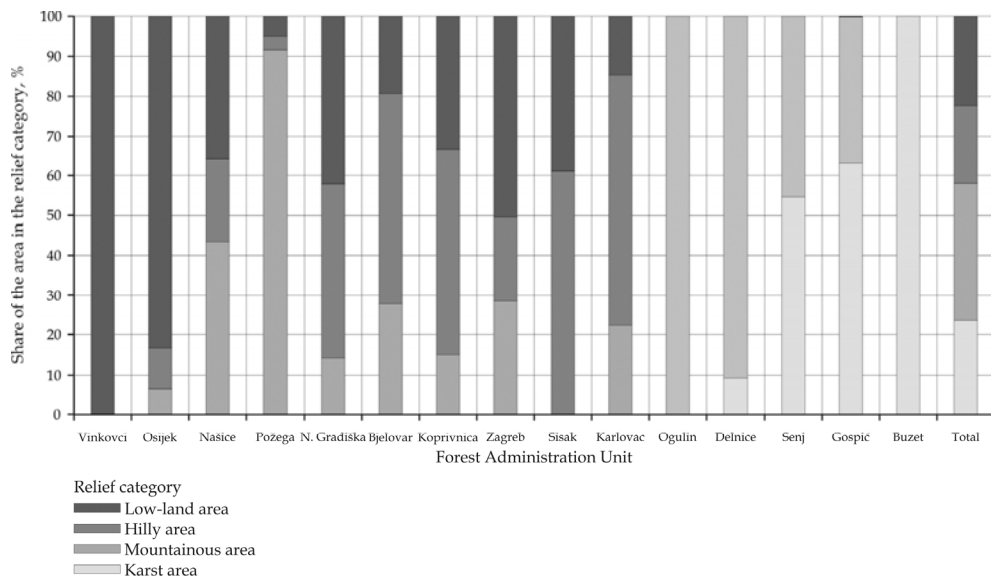
Fig. 5. The share of relief area in each of the FAU.

In the overall forest surface under research (1,442,140 ha), the lowland area accounts for 322,320 ha (22.35%), the hilly area for 282,560 ha (19.59%), the mountainous area for 497,830 ha (34.52%) and the karst area for 339,430 ha (23.54%). Only three FAUs are located with their entire surface in one relief category (FAU Vinkovci in lowland area, FAU Ogulin in the mountainous area and FAU Buzet in the karst area). The areas under management by the other FAUs stretch throughout two (four FAUs) or three (eight FAUs) relief categories.

In the lowland area, the average existing primary road density amounts to 8.85 m/ha, in the hilly area 11.26 m/ha, in the mountainous area 15.64 m/ha and in the karst area 7.63 m/ha.

By comparing the existing density of the primary forest transportation system by a particular relief area category, we may conclude the following: in the lowland area, the greatest primary road density exists in the FAU Karlovac (16.08 m/ha), and the least in FAU Osijek (4.37 m/ha); in the hilly area, FAU Koprivnica (17.02 m/ha) has the best primary road density, while FAU Sisak (6.88 m/ha) has the lowest classical primary openness; in the mountainous area, the highest degree of classical primary openness is in the FAU Našice (23.27 m/ha), and the lowest in FAU Gospić (10.32 m/ha); in the karst area the greatest priary road density is present in FAU Delnice (12.47 /ha), and the lowest in FAU Gospić (5.76 ha).

5.2 Calculate the length of planned truck forest road network in 2010 and 2020

The primary road density in 2010 and 2020 was calculated according to relief categories and the overall surface of each FAU. The length of truck forest roads to be built until the expiration of the planned period was set for both variants of primary road density. The results are shown in the Tables 5 and 6.

The data from the Tables 4 and 5 show that, although we stepped out of 2010, primary road density defined as planned for that year (Table 1) has not been achieved in any FAU in the whole area. In FAU Karlovac (lowland) and in FAU Delnice and Senj (karst) the planned primary road density for 2010 was exceeded (FAU Karlovac built 13.13 km, FAU Delnice 21.97 km, and FAU Senj 82.36 km of truck forest roads which influence on primary road density more than was planned).

Forest Administration Unit	Total area of FAU	Low-land area		Hilly area		Mountainous area		Karst area	
		Area	RD	Area	RD	Area	RD	Area	RD
	1000 ha	1000 ha	km/1000 ha	1000 ha	km/1000 ha	1000 ha	km/1000ha	1000 ha	km/1000 ha
VINKOVCI	72.37	72.37	6.84	-	-	-	-	-	-
OSIJEK	62.83	52.41	4.37	6.35	6.99	4.07	11.06	-	-
NAŠICE	82.95	29.73	12.70	17.26	16.84	35.96	23.27	-	-
POŽEGA	51.23	2.60	5.14	1.70	12.76	46.93	15.59	-	-
NOVA GRADIŠKA	73.57	31.07	8.73	32.21	8.52	10.29	11.70	-	-
BJELOVAR	131.83	25.42	11.92	69.84	11.68	36.57	11.84	-	-
KOPRIVNICA	62.37	20.79	13.74	32.29	17.02	9.29	17.50	-	-
ZAGREB	81.52	41.13	10.88	17.21	13.26	23.18	15.90	-	-
SISAK	87.99	34.28	6.68	53.71	6.88	-	-	-	-
KARLOVAC	82.45	12.11	16.08	51.99	11.32	18.35	12.02	-	-
OGULIN	59.58	-	-	-	-	59.58	14.11	-	-
DELNICE	96.31	-	-	-	-	87.41	22.55	8.90	12.47
SENJ	112.19	-	-	-	-	51.01	17.03	61.18	11.35
GOSPIĆ	312.67	0.41	12.10	-	-	115.19	10.32	197.07	5.76
BUZET	72.28	-	-	-	-	-	-	72.28	9.01
Total/Average	1,442.14	322.32	8.85	282.56	11.26	497.83	15.64	339.43	7.63

Table 4. Existing primary road density (RD) by relief areas in each FAU.

The greatest volume of new truck forest road construction should be carried out in FAU Gospić (2,529.04 km). According to relief areas, truck forest roads should be constructed mostly in FAU Vinkovci (590.36 km) in the lowland area, in FAU Sisak (704.66 km) in the hilly area in the mountainous area (1,691.35 km) and in the karst area (836.50 km) in FAU Gospić.

Planned primary road density for 2010 in the lowland area, in comparison with the existing primary road density in the same relief area, implicates the need of very intensive interventions of truck forest road construction (especially in the area of FAU Vinkovci and Osijek).

The obtained results should be observed in the context of historic guidelines in lowland forest management in FAU Vinkovci and Osijek (compartments of a symmetrical

quadrangular shape with dimensions 750x750 m with a regular pattern of secondary forest roads, so called »*šljukarica*«, with the mutual distance among the middle of the passages (axle) from 37.5 m (*Posarić, 2007*)), but also in the sense of new (today accepted) technologies of timber harvesting in Croatian low-land forests.

Forest Administration Unit	Length of TFR									
	Low-land area		Hilly area		Mountainous area		Karst area		Total	
	km	km/1000 ha	km	km/1000 ha	km	km/1000 ha	km	km/1000 ha	km	km/1000 ha
VINKOVCI	590.36	8.16	-	-	-	-	-	-	590.36	8.16
OSIJEK	557.21	10.63	82.64	13.01	56.75	13.94	-	-	696.60	11.09
NAŠICE	68.41	2.30	54.47	3.16	62.21	1.73	-	-	185.09	2.23
POŽEGA	25.64	9.86	12.31	7.24	441.60	9.41	-	-	479.55	9.36
NOVA GRADIŠKA	194.70	6.27	369.93	11.48	136.81	13.30	-	-	701.44	9.53
BJELOVAR	78.39	3.08	581.08	8.32	481.14	13.16	-	-	1,140.61	8.65
KOPRIVNICA	26.19	1.26	96.12	2.98	69.64	7.50	-	-	191.95	3.08
ZAGREB	169.36	4.12	116.04	6.74	211.03	9.10	-	-	496.43	6.09
SISAK	285.38	8.32	704.66	13.12	-	-	-	-	990.04	11.25
KARLOVAC	0.00 (+13.13)*	-	451.44	8.68	238.12	12.98	-	-	689.56	8.36
OGULIN	-	-	-	-	648.54	10.89	-	-	648.54	10.89
DELNICE	-	-	-	-	213.99	2.45	0.00 (+21.97)*	-	213.99	2.22
SENJ	-	-	-	-	406.62	7.97	0.00 (+82.36)*	-	406.62	3.62
GOSPIĆ	1.19	-	-	-	1,691.35	14.68	836.50	4.24	2,529.04	8.09
BUZET	-		-	-	-	-	71.52	0.99	71.52	0.99
Total	**1,996.83**	**6.20**	**2,468.69**	**8.74**	**4,657.80**	**9.36**	**908.02**	**2.68**	**10,031.34**	**6.96**

* FAU Karlovac (low-land area), Delnice and Senj (karst area) built more roads than planned so the need to build by 2010. in these FAU is 0.00 km.

Table 5. Required length of truck forest roads that need to be built to achieve the planned primary road density for 2010 by the FAU and relief categories.

Forest Administration Unit	Length of TFR							
	Hilly area		Mountainous area		Karst area		Total	
	km	km/1000 ha	km	km/1000 ha	km	km/1000 ha	km	km/1000 ha
OSIJEK	114.39	18.01	77.10	18.94	-	-	191.49	3.05
NAŠICE	140.77	8.16	242.01	6.73	-	-	382.78	4.61
POŽEGA	20.81	12.24	676.25	14.41	-	-	697.06	13.61
NOVA GRADIŠKA	530.98	16.48	188.26	18.30	-	-	719.24	9.78
BJELOVAR	930.28	13.32	663.99	18.16	-	-	1,594.27	12.09
KOPRIVNICA	257.57	7.98	116.09	12.50	-	-	373.66	5.99
ZAGREB	202.09	11.74	326.93	14.10	-	-	529.02	6.49
SISAK	973.21	18.12	-	-	-	-	973.21	11.06
KARLOVAC	711.39	13.68	329.87	17.98	-	-	1,041.26	12.63
OGULIN	-	-	946.44	15.89	-	-	946.44	15.89
DELNICE	-	-	651.04	7.45	0.56*	0.06	651.60	6.77
SENJ	-	-	661.67	12.97	141.18*	2.31	802.85	7.16
GOSPIĆ	-	-	2,267.30	19.68	1,821.85	9.24	4,089.15	13.08
BUZET	-	-	-	-	432.92	5.99	432.92	5.99
Total	**3,881.49**	**13.74**	**7,146.95**	**14.36**	**2,396.51**	**7.06**	**13,424.95**	**9.31**

* Values are reduced by the length of more constructed forest roads in the FAU Delnice and Senj by 2010 shown in Table 5.

Table 6. Required length of truck forest roads that need to be built to achieve the planned primary road density for 2020 by the FAU and relief categories.

According to the openness plan for 2020, the greatest volume of new truck forest road construction should be carried out in FAU Gospić (4,089.15 km). Analyzing the relief areas, the construction of most truck forest roads will be required: in the hilly area in FAU Sisak (973.21 km), in the mountainous area (2,267.30 km) and in the karst area (1,821.85 km) in FAU Gospić.

Forest Administration Unit	Current (existing):		Planned 2010th:		Planned 2020th: (without low-land area)	
	RD	Length of TFR	RD	Length of new TFR	RD	Length of new TFR
	km/1000 ha	km	km/1000 ha	km	km/1000 ha	km
VINKOVCI	6.84	495.19	15.00	590.36		
OSIJEK	5.07	318.30	16.15	696.60	26.95	191.49
NAŠICE	18.14	1,505.06	20.38	185.09	28.38	382.78
POŽEGA	14.97	766.70	24.33	479.55	29.83	697.06
NOVA GRADIŠKA	9.05	666.06	18.59	701.44	26.21	719.24
BJELOVAR	11.77	1,551.74	20.42	1,140.61	26.72	1,594.27
KOPRIVNICA	16.00	997.95	19.08	191.95	26.12	373.66
ZAGREB	12.81	1,044.22	18.90	496.43	27.87	529.02
SISAK	6.80	598.36	18.05	990.04	25.00	973.21
KARLOVAC	12.17	1,003.77	20.38	689.56	26.30	1,041.26
OGULIN	14.11	840.96	25.00	648.54	30.00	946.44
DELNICE	21.62	2,082.23	23.61	213.99	28.61	651.60
SENJ	13.93	1,562.79	16.82	406.62	21.82	802.85
GOSPIĆ	7.44	2,327.56	15.53	2,529.04	20.53	4,089.15
BUZET	9.01	651,28	10.00	71.52	15.00	432.92
Total/Average	**11.38**	**16,412.17**	**18.25**	**10,031.34**	**24.19**	**13,424.95**

Table 7. Existing and planned primary road density for 2010 and 2020 by the FAU and the length of truck forest roads that need to be built.

Relief category	Length of TFR	Existing TFR density	Planned length of TFR 2010th	Planned TFR density (until 2010)	Planned length of TFR 2020th	Planned TFR density (until 2020)
	km	km/1000 ha	km	km/1000 ha	km	km/1000 ha
Low-land area	2,851.10	8.85	1,983.70	15.00		
Hilly area	3,182.51	11.26	2,468.69	20.00	3,881.49 (1,412.80)	25.00
Mountainous area	7,787.95	15.64	4,657.80	25.00	7,146.95 (2,489.15)	30.00
Karst area	2,590.61	7.63	803.69	10.00	2,500.84 (1,697.15)	15.00
Total/Average	**16,412.17**	**11.38**	**10,031.34**	**18.25**	**13,424.95 (3,393.61)**	**24.19**

() Length of forest roads that need to be constructed in 2010-2020 to achieve the planned openness 2020th.

Table 8. Existing and planned primary road density for 2010 and 2020 in different relief areas and length of truck forest roads that need to be built.

5.3 Calculation of the cost of planned truck forest road construction in 2010 and 2020

On the basis of planned costs of truck forest road construction for each relief area (*Anon., 2010*): lowland area (500,000.00 HRK/km), hilly area (350,000.00 HRK/km), mountainous area (250,000.00 HRK/km) and karst area (225,000.00 HRK/km) and the applicable Technical Requirements for Economic Roads (*Šikić et al. 1989*), the total price was calculated for all truck forest roads which need to be built for achieving the planned primary road density in 2010 and 2020.

Forest Administration Unit	The construction costs of a new truck forest roads network, €			
	Planned by 2010		Planned by 2020 (without low-land area)	
	kn	€*	kn	€*
VINKOVCI	295,180,000.00	40,056,234.51		
OSIJEK	321,716,500.00	43,657,265.30	59,311,500.00	8,048,632.54
NAŠICE	68,822,000.00	9,339,217.33	109,772,000.00	14,896,175.13
POŽEGA	127,528,500.00	17,305,750.74	176,346,000.00	23,930,336.51
NOVA	261,028,000.00	35,421,772.42	232,908,000.00	31,605,859.03
BJELOVAR	362,858,000.00	49,240,209.85	491,595,500.00	66,710,023.15
KOPRIVNICA	64,147,000.00	8,704,814.94	119,172,000.00	16,171,764.95
ZAGREB	178,051,500.00	24,161,774.64	152,464,000.00	20,689,524.15
SISAK	389,321,000.00	52,831,266.61	340,623,500.00	46,222,964.96
KARLOVAC	217,534,000.00	29,519,591.16	331,454,000.00	44,978,654.23
OGULIN	162,135,000.00	22,001,888.96	236,610,000.00	32,108,224.30
DELNICE	53,497,500.00	7,259,666.66	162,886,000.00	22,103,800.44
SENJ	101,655,000.00	13,794,689.75	197,183,000.00	26,757,939.19
GOSPIĆ	611,645,000.00	83,000,865.77	976,741,250.00	132,544,808.49
BUZET	16,092,000.00	2,183,701.22	97,407,000.00	13,218,231.71
Total	**3,231,211,000.00**	**438,478,709.86**	**3,684,473,750.00**	**499,986,938.77**

* Middle exchange rate of euro in the Croatian National Bank on day 13.11.2010 (1 € = 7.36914 kn).

Table 9. Construction costs of the planned network of truck forest roads in 2010 and 2020 according to the current Technical Requirements.

In order to achieve the planned primary road density in 2010, at the level of »Hrvatske Šume« Ltd. Zagreb, according to the applicable Technical Requirements, it is necessary to invest HRK 3,231,211,000, and for achieving the planned primary classical openness in 2020 it is necessary to invest HRK 3,684,473,750 (without the lowland relief area).

Fig. 7. shows the dynamics of the construction of lower and upper truck forest road structure for the period from 2004 - 2009 by Forest Administration Units. During the six

observed years, a total of 1,295.86 km of lower structure and 1,438.64 km of upper structure were built, or on average 215.98 km of lower structure and 239.77 km of upper structure of truck forest roads per year. The greatest amount of lower and upper structure were built in 2006 (246.69 km and 307.49 km), and the least in 2009. The difference between the constructed lengths of lower and upper structures indicate that truck forest roads are not always constructed all at once, but the construction procedure extends over two or more years. Most often the reasons are the following: lack of financial means, unfavourable weather conditions at the end of the year, construction technology or simply, because that is how it was conceived by the construction plan.

Fig. 6. Construction of the lower and upper structure of the TFR for the period from 2004 to 2009 by the FAU-s.

6. Discussion

A significant diversity of Croatian forestry from the point of view of terrain orthography (lowland, hilly, mountainous and karst), site and stand characteristics, as well as the way of forest management (regular, selection), but also the ways of forest opening in certain orthographic areas, or the degree of forest road density, indicates the need of good planning in the entire forestry department, as well as in timber harvesting works, or forest opening. Quality and reliable planning, in this case of forest roads, guarantees rationalization (a collection of procedures for achieving savings in business) in a part of forestry production.

Planning forest roads is a starting, unavoidable and very important stage of establishing an optimal forest road network in the field. Planning may be strategic, tactical and operative. On the level of strategic planning, we use the so called descriptive (primary) classification of

terrains, which describes a terrain according to measurable characteristics and divides it into categories, independently of the applied timber harvesting systems.

Planned values of primary road density in 2010 and 2020 on the level of relief categories represent only guidelines which should be followed, but should not (and must not) be strictly adhered to in the final design of primary forest transportation system network. It is recommended to re-examine and, if necessary, redefine the values of planned primary road density by relief areas (Table 1), at the same time recognizing all the factors which have an influence on the calculation of planned primary forest transportation system density.

At the lower, also more accurate, planning stage (tactical planning), it is possible to deviate from the values defined at the strategic level, both in positive and negative, but acceptable intervals. Target (optimal/best possible) primary road density is defined on the level of a Management Unit; Studies of Primary Forest Opening are made at this level.

The accuracy of planning is the greatest and suits the best to the actual condition at the lowest planning level, but it also requires the most precise and the most complete data and information. In operative planning, sometimes even the division into Management Units is not accurate enough, because within the same Management Unit there may be two or more (very rarely) relief categories. This planning level presupposes a purposeful (functional or secondary) terrain classification, which associates the possibility of application of potential and suitable harvesting systems with classes of terrain factors. The harvesting system is determined by procedures, method of timber processing (cut-to-length, half-tree, full-tree, tree-length), as well as machines and tools used in the harvesting of a cut-block. The selection (use) of a timber extraction device (skidder, forwarder, adapted farm tractor – AFT, AFT with semitrailer, cable yarder) in the light of the influence of terrain (relief categories) and stand factors, as well as the level of primary and secondary forest openness is the most important determinant of the entire harvesting system.

By analyzing the existing primary road density by FAUs and by relief categories conclusively with 31st December 2009 at the researched area, it is concluded that the planned primary road density has not been achieved on the greatest part of state-owned forests. Moreover, in the better part of the forests, not even the minimal necessary primary road density has been reached, specifically, in the lowland area in 4 out of 11 FAUs, in the hilly area in 5 out of 9 FAUs, in the mountainous area in 6 out of 12 FAUs, which has a significant negative influence on the quality, efficiency and rationality of management in these insufficiently opened forests.

With the average annual intensity of truck forest road construction, based on the data from 2004 – 2009 (taking into consideration the average constructed length of the lower truck forest road structure of about 216 km/y), it would take 47 years to achieve the planned openness in 2010, and 63 years to achieve the same for 2020 (without the construction of truck forest roads in lowland area).

It should be considered to extend the time period for the attempt to achieve the planned values of primary forest transportation system density. At the same time, the construction of truck forest roads should be intensified, and raised from the present 216 km/y to at least 600-800 km/y. Thus, the planned values of primary road density for 2010 (counting with the construction of 700 km/y of truck forest roads) might be achieved in about 15 years, and for

2020 in about 20 years (without the construction of truck forest roads in the lowland area). Because of that, the objective financial, expert and infrastructural capacities of the company »Hrvatske Šume« Ltd. should be acknowledged. Besides the existing sources of financing, the means from current business operations and the means from the fund for generally beneficial forest functions, it is necessary to search for other sources of financing of all the stages for establishing an optimal primary forest transportation system network, e.g. EU funds, etc.

There is a significant gap among the primary road density of forest areas which belong to the same relief category. In the future, while planning investments into the rebuilding and development of primary forest transportation system, the priority orientation of financial means into the less opened forest areas should be taken into consideration, all until there is a balance of primary road density on the level of the overall relief area.

The values of primary road density (existing, as well as planned for 2010 and 2020) will be compared with the average values of the existing primary road density in the forests of the Republic of Austria (*Stampfer 2011* according to *Austrian Forest Inventory 1992/96*). In order to make the comparison complete, the basic characteristics of Austrian forests and harvesting works are provided:

- forest ownership (48.3% are private forests with the surface of less than 200 ha, 22.4% are private forests with the surface of more than 200 ha, 15.7% are state-owned forests, and 15,6% are forests owned by other forest owners – community forests, communal forests and provincial forests),
- inclination of the terrain where forests grow (more than 22% of the forests grow on inclined terrains with an inclination of more than 60%, and 39% of forests on terrains inclined 30-60%; other forests are situated on inclinations up to 30%),
- particularities (way) of forest management,
- generally useful forest functions,
- harvesting systems (procedures, method of timber processing, machines and tools used):
  - applied device for timber cutting and processing (82.41% of harvesting volume is cut and processed with a chainsaw, and 17.59% with a harvester),
  - means used for timber extraction (skidder extracts 53.1%, forwarder 26.8, cable yarder 14.2%, manually 4.6%, horse-power 0.4% and other ways – e.g. helicopter 0.9% of the overall annual allowable cut).

Forest ovners	Road density km/1000 ha
Smale scale forest owners (< 200 ha)	49.1
Private Companies (> 200 ha)	41.8
Federal Austrian Forests	33.7
Average	**45.0**

Table 10. The existing primary road density in the Republic of Austria (*Stampfer 2011* according to *Austrian Forest Inventory 1992/96*).

In smaller forest properties, where less modern machinery is used for timber extraction (mostly AFTs and AFTs with semitrailers); there is a denser primary forest transportation system network owing to the rationalization of overall timber harvesting costs.

The existing primary road density in the Republic of Austria (in Austrian state forests) is far greater than the planned openness in the hilly area of the Republic of Croatia for 2020; of course, there is an even greater difference when comparing with the planned openness for 2010, while the greatest differences exist when comparing with the existing primary road density. There are Management Units in Croatian state forests whose primary road density is on the level of those in Austrian state forests, but these are rare. As an example, there are three Management Units situated in selection forests of Gorski Kotar, owned by the state but managed by the University of Zagreb Faculty of Forestry. The primary road density in those units amounts to between 32 and 36 km/1000 ha, with the average values of mean timber extraction distance of 150 m.

Habsburg (1970), *Sanktjohanser* (1971) and *Piest* (1974) agree that the optimal primary road density for the needs of forest exploitation varies between 17 and 30 m/ha, depending on the terrain and site characteristics, while the optimal primary road density for rational overall forest management is a bit greater. The suggested values correspond very well to the planned primary road density in Croatia for 2010 and 2020, while there are slight deviations in lowland forests and karst area forests. Considering the time distance and the development of the entire timber harvesting system, as well as the total forest ecosystem management that has been established in the meantime, the recommended primary forest transportation system density by the three above mentioned authors should be taken with a grain of salt.

7. Concluding remarks

The planned values of primary road density in 2010 and 2020 on the level of various relief categories of the Republic of Croatia, besides being the guidelines for strategic planning in the Republic of Croatia, may also be used as landmarks in primary forest road planning on a strategic level in countries of similar orographic, site and stand conditions, as well as the ways of forest management. The existing primary road density should certainly be taken into consideration, and in accordance with the financial, professional and infrastructural resources of a certain country and its forestry, the deadlines for achieving the planned values of primary road density, annual intensity and construction priorities should be defined.

The more developed countries and countries with a long forestry tradition, which could have invested significant financial means permanently and systematically into the primary openness of their forests during the last few decades, are expected to have a better primary road density than the Republic of Croatia (which could have started with a more systematic and more intensive forest opening only after being proclaimed independent in the 1990s), and therefore, less need for primary classical openness in the future (with the purpose of achieving planned primary road density) and probably less differences in the existing primary road density of equal or similar (comparable) forest areas, that is, they have a uniform existing primary road density of the same relief categories. A multiple use of truck

forest roads, by first of all users outside forestry (e.g. tourism), contributes to greater density and better quality of truck forest roads.

Operative planning, as the lowest and the most accurate level of forest road planning, requires a purposeful analysis of the terrain, connecting the possibility of applying potential and suitable timber harvesting systems with terrain factor analysis. At this planning level, timber harvesting systems have a significant influence on the shape and density of the truck forest roads, but even more on the on the shape and density (and existence, in general) of the secondary forest road network. The application of certain timber harvesting systems is, besides the terrain factors, conditioned by the degree of technological growth (technological awareness), resulting in utilization (the possibility of using) the most up-to-date means of timber extraction, and connected with that, the procedures and methods of timber processing. The selection of a timber extraction system is often under the influence of traditional forestry values of a certain country.

This paper describes and applies the methodology, but it can serve as a starting point for making a case study in any European and non-European country. Individual differences (specific qualities) of a certain country should be recognized and integrated into the modified methodology in a proper way to make the research results achieve an expected high level.

The data about the primary road density does not say much about the quality of spatial distribution of primary forest transportation system components. For better understanding of the real value of primary road density, it is always necessary to present primary classical openness coupled with the average timber extraction distance, or the mean distance of access to the endangered forest area, in the case of forest fire-prevention roads in the karst area. A clear insight into the real, quantitative (amount of primary forest roads) and qualitative (spatial coverage with primary forest roads) parameters of primary forest transportation system may only be achieved by a parallel consideration of primary road density and mean timber extraction distance.

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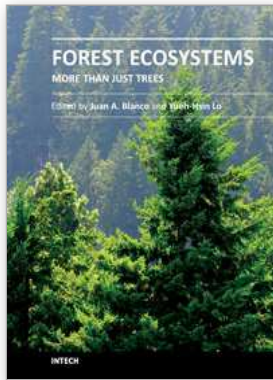
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Forest Ecosystems - More than Just Trees

Edited by Dr Juan A. Blanco

The common idea for many people is that forests are just a collection of trees. However, they are much more than that. They are a complex, functional system of interacting and often interdependent biological, physical, and chemical components, the biological part of which has evolved to perpetuate itself. This complexity produces combinations of climate, soils, trees and plant species unique to each site, resulting in hundreds of different forest types around the world. Logically, trees are an important component for the research in forest ecosystems, but the wide variety of other life forms and abiotic components in most forests means that other elements, such as wildlife or soil nutrients, should also be the focal point in ecological studies and management plans to be carried out in forest ecosystems. In this book, the readers can find the latest research related to forest ecosystems but with a different twist. The research described here is not just on trees and is focused on the other components, structures and functions that are usually overshadowed by the focus on trees, but are equally important to maintain the diversity, function and services provided by forests. The first section of this book explores the structure and biodiversity of forest ecosystems, whereas the second section reviews the research done on ecosystem structure and functioning. The third and last section explores the issues related to forest management as an ecosystem-level activity, all of them from the perspective of the �other� parts of a forest.

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Tibor Pentek and Tomislav Poršinsky (2012). Forest Transportation Systems as a Key Factor in Quality Management of Forest Ecosystems, Forest Ecosystems - More than Just Trees, Dr Juan A. Blanco (Ed.), ISBN: 978-953-51-0202-1, InTech, Available from: http://www.intechopen.com/books/forest-ecosystems-more-than-just-trees/forest-transportation-systems-as-a-key-factor-in-quality-management-of-forest-ecosystems

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