

A Holistic Approach for Enhancing Primary and Secondary Forest Infrastructure Used for the Development of a Forest Operations Plan - a Case Study in a Romanian Private Forest Enterprise

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Abstract:

Increasing the accessibility represents a key issue for the sustainable management of Romanian forests. Reduced productivity in timber harvesting and increased levels of residual stand damage, soil erosion and transport of sediments are the main problems when performing forest operations. A considerable emphasis is being put on technical designing of forest roads, while disregarding possible options of forest infrastructure development through integration of harvesting systems in the decision making process. Hence, this paper aims to reinforce state of the art concept of forest engineering in Romanian forestry sector, underlining the necessity for a harmonization process of road network planning with the selection of most suitable harvesting systems using GIS and sensitivity analysis, by developing a decision support tool for improving forest infrastructure in a Romanian private forest enterprise based on a holistic approach. The conceptual model has been tested in a forest area of about 903 ha and a real mean skidding distance of 735 m, from Brasov region in Romania. Scenarios containing alternative road routes and harvesting systems have been planned and assessed using GIS. Selected scenario FR1 reduced the mean skidding distance to 240.6 m. Thus, productivity in timber extraction has increased within ranges of 30 to 60%, while cost efficiency improved with 25 to 60%. However, due to increased road construction costs and low value of AAC, none of the planned road routes proved to be economically feasible and therefore, new scenarios have to be developed and assessed.

Keywords: decision making, forest infrastructure, forest engineering, forest roads planning

1 Introduction

Romanian strategy of the forestry sector (Ministry of Environment and Forests, 2011a) has the fundamental goal of developing the forestry sector for increasing its contribution to the enhancement of life quality. Implementation of sustainable forest management concept and adaptation of informational system using geographic information systems (GIS) are the guiding policies. Improvement of forests' accessibility in strict correlation with timber harvesting technologies and environmental protection requirements is a key objective which considers the following strategic actions: expansion of forest road network, developing secondary forest infrastructure and fostering the utilization of mobile cable yarding systems. However, nowadays GIS is not yet used at large scale in forest management, nor the forest road network has increased substantially, nor the cable yarding systems are being used on a regular basis in harvesting operations and neither the secondary infrastructure has been enhanced. Despite its poor density index (6,5m/ha), Romanian forest road network expands at rates way below it was foreseen (Bereziuc et al. 2003), about 30-40 km of new forest roads being built each year (Ministry of Environment and Forests, 2011b). Skidding is the main method for timber extraction, using winch tractors, skidders, gravitational hauling, ox or horse harnesses. Very few harvesters, forwarders or cable yarders are being used at national level. Mean skidding distance is about 1.2 km in accessible forests and 3.3 km in inaccessible ones, the average mean skidding distance at country level being 1.8 km (Popovici et al.

2003). Consequently, productivity of timber harvesting is very low. In addition, soil erosion, transport of sediments, residual stand damage, water pollution, damage of existing forest roads and increased risk of accidents among forest workers are also visible. Therefore, reducing mean skidding distance by a sound development of primary and secondary infrastructure represents a prerequisite condition for the sustainable development of the forest sector. Notwithstanding, enhancement of forest infrastructure is challenging, first due to the need of changing former behaviour of building valley forest roads to planning and building slope roads that fulfil multiple objectives (Enache et al. 2012). Second, due to the need of reinforcing the state of the art concept of forest engineering by harmonizing road network planning with the selection of most suitable harvesting systems adapted to local conditions.

Forest management plans provide detailed information with respect to silvicultural treatments, annual allowable cut (AAC), harvesting methods and scheduling of forest operations, but they disregard the tactical planning prior to operational phase, lacking a proper documentation for decision making with respect to which options of road routes to consider or what harvesting systems to use based on economical, environmental and social requirements. Significant emphasis is being put on technical design of forest roads, Zarojanu (2007) describing a thorough methodological approach of analyzing solutions of forest roads considering economic and environmental aspects. However, this method can be used after technical designing of different variants of roads and not in the pre-planning phase of route selection. Hence, the aim of this study is to present a holistic approach for enhancing primary and secondary forest infrastructure, considering suitable harvesting systems, economic, environmental and social constraints. The main focus is to improve decision making process in forest engineering, guiding forest managers in selecting most suitable road route option using GIS and sensitivity analysis. The concept has been developed and tested in a mountainous project area located in a private forest district from Romania. However, it could be applied for other areas with similar local conditions (i.e. topographic, climatic, forest site) or it could be used as a basis for developing other models.

2 Material and methods

Forest road network planning is a process that involves complex decision problems and conflictive objectives that need to be handled simultaneously. Technical feasibility, environmental soundness, social acceptance and economic affordability are the four main pillars on which forest infrastructure must be grounded (Stampfer 2007). Hence, the study combines approaches of problem structuring, project management, spatial modelling and sensitivity analysis for supporting the decisional process of selecting the most suitable forest road route variant and harvesting systems for local conditions.

2.1 Approaches regarding multiple functions of forest roads and decision making

Recent studies have shown that forest roads fulfil multiple functions, insisting on their strategic importance in forest operations, in accessing remote areas in case of natural hazards or for tourism and recreation activities (Popovici et al. 2003, Stampfer 2007, Kühmaier et al. 2010, Enache et al. 2011). In addition, consideration of environmental and social aspects from the early stages of planning has also been acknowledged (Popovici et al. 2003, Gumus et al. 2008, Ciobanu et al. 2011), underlining the necessity of impact assessment when developing forest infrastructure. But dealing with so many variables and constraints is not an easy task for road planner or decision maker. Thus, the complex management problem of enhancing forest infrastructure requires a good problem structuring, with clearly defined goals and objectives. This is possible using multiple criteria decision analysis tools that allow decision makers to understand and approach the problem in a participatory way (Saaty 2008, Green et al. 2010).

A sustainable development of the forest infrastructure requires harmonization of planning, designing, construction and maintenance with operational harvesting plans. Therefore, planning of forest road routes and skidding trails should be approached simultaneously (Pentek et al. 2007). In order to assess different forest road options in mountainous regions, Dürstein (1998) proposed an extensive approach system of cost-efficiency analysis, underlining the importance of participatory process in decision making. In addition, Heinimann (1998) stressed that planning phase should consider assessment of technical feasibility of alternatives, environmental impact, public involvement and decision making. Hence, in this

study, the process of enhancing the forest infrastructure has been structured in several stages, based on principles of project management (Gareis 2005).

2.2 Assessment of existing forest infrastructure

Representing a prerequisite condition for the development of future roads and skid trails networks, this stage has the main purpose quantitatively and qualitatively evaluate primary and secondary infrastructure. Existing faults, bottlenecks and cardinal points are identified in the field, while structural indexes and parameters are calculated (Bereziuc et al. 2008) providing a clear picture regarding the needs of further improvement of forest infrastructure.

For collecting field data the following instruments have been used: GPS Garmin 60 CSx GPSMAP for recording geographic coordinates and for mapping skid trails network, Meridian clinometer for slope measurements, Handheld Algiz 7 rugged Tablet PC for filling the data collection protocol and Laser LTI TruePulse 360 for distance measurements. For data processing ESRI® Arc GIS Desktop 10 and Microsoft Office Excel® software have been used.

2.2.1 Assessment of existing forest road network

This stage comprises two phases: field survey and office work. In the field, data regarding quality of existing roads has been collected (e.g. damaged road bed, damaged bridges, blocked ditches, etc.). Inspected elements of have been categorized by causing factors (e.g. lack of maintenance; timber handling in landing areas at road side; torrential flows and landslides). Geographic coordinates of starting and ending point of each identified issue have been recorded with GPS and all complementary details have been filled in the data collection protocol. Office work refers to calculation of several structural indexes of the forest road network (Bereziuc 2008, Pentek 2005, Steinmüller 2008): road density index, road distance, index of relative openness, geometric mean skidding distance and real mean skidding distance. The last two indexes have been derived both from analytic formulas and from analysis made using ESRI® Arc Toolbox. The hypothesis of work assumes that timber harvested from a forest management unit concentrates into its center of gravity. Hence, using ESRI® Analysis Tool, distance from the center of gravity of each management unit to the closest road has been determined.

The *mean skidding distance* ($\overline{S_{dr}}$) at the level of project area is calculated as weighted average of the determined shortest mean skidding distances for each management unit, using combined formulas found in literature (Ciubotaru 1998, Pentek et al. 2005, Bereziuc et al. 2008). Real mean skidding distance for each management unit, has been calculated with the following formula, using geometric mean skidding distance determined in GIS:

$$S_{dr} = S_{dg} \cdot k_g [m], \quad (1), \quad \text{where:}$$

S_{dr} – real mean skidding distance (m);

S_{dg} – horizontal distance measured on the map or established by analytical means, which is referred to as geometrical mean skidding distance on which the timber will be presumably hauled (m);

k_g – correction factor of the skidding distance, depending on local topography.

Studied literature (Amzica 1971 cited by Bereziuc et al. 2008, Staudt et al. cited by Bereziuc 2008, Segebaden 1964, 1968 and Abegg 1978 cited by Pentek 2005) stress that correction factor k_g varies according to the local topography and terrain roughness, between 1.05 and 1.7. For the purpose of this study, the correction factor k_g has been established to 1.5. The average real mean skidding distance for the entire study area was compiled in MS Office Excel® as a volume weighted average of real mean skidding distances of each management unit.

$$\overline{S_{dr}} = \frac{\sum_{i=1}^n S_{dr(i)} \cdot V_i}{\sum_{i=1}^n (V_i)} [m], \quad (2), \quad \text{where:}$$

$\overline{S_{dr}}$ – average real mean skidding distance of the study area;

- Sd_r – real mean skidding distance of the management unit (m);
- V_i – volume to be harvested and hauled from the management unit (m^3);
- i – current management unit;
- n – total number of management units in study area.

Current relative openness has been calculated with classical formulas and by GIS analysis. Hence, several statistics regarding levels of forest accessibility and ascribed forest surface and timber volume for each existing road in the project area have been elaborated.

2.2.2 Assessment of existing skidding trails

Assessment of secondary forest infrastructure follows the same principle as for previous stage. Using GPS at recording intervals of 5 seconds, all existing skidding tracks and trails from study area have been mapped. Widths of trails, stream crossings, skidding trails segments going entirely through water streams, soil erosion, average gradients and length of steep trails have been recorded and filled in the data collection protocol. Positive and negative cardinal points, including possible locations for landing areas and sensitive environmental factors have also been identified and recorded (Gumus 2008). Based on collected data, structural indexes of secondary infrastructure have been calculated. Then, relative accessibility of secondary forest infrastructure has been determined using buffer-method (Picman et al. 2011). Being given that in the project area only tractors and skidders are commonly used for timber extraction, buffer zones have been defined considering the lengths of winch ropes as follows: 30, 50 and 70 m using ESRI® Arc GIS.

2.3 Assessment of harvesting systems

The most common harvesting methodology used in Romania is *trunks and masts* (Ciubotaru 1998), a method similar to tree-length system in which trees are felled, topped and delimbed at the felling site and then are extracted either as full trunks (masts) at the road side. Extraction is usually done by Romanian manufactured tractors (U651) or skidders (TAF). One specific operation in timber extraction for Romanian harvesting conditions with low density of forest roads and long skidding distances is the *pre-skidding* (Oprea et al. 2008). This is usually done by horse or ox harnesses on distances up to 150 - 200 m (Ciubotaru 1998), and refers to the transport of timber from stump to the closest skidding track. Harnesses are used for longer distances also, commonly up to 500 m, for extracting timber in thinning operations. Currently used harvesting systems in study area are TAF skidder for final cuts and tractor or horse harness for thinnings.

2.3.1 Assessment of productivity

Productive machine hour (PMH) is a parameter used in calculation of extraction costs. Hence, assessment of productivity of harvesting machineries is an important stage in the cycle of planning primary and secondary infrastructure. For the purpose of this study, productivity of harvesting systems have been calculated based on existing time norms developed for TAF skidder and universal tractor U651 (Ciubotaru 1996) which consider the following variables: species group (i.e. coniferous, broadleaves), three classes of average tree (i.e. below $0.140 m^3$, between $0.140-0.700 m^3$ and above $0.700 m^3$ per average tree volume respectively) and real mean skidding distance. As work hypothesis, it has been considered that tractor U651 is being used for thinnings, while TAF skidder is used for final cuts. Hence, input values from the second volume class for tractor U651 and the third volume class for TAF skidder have been used. A more accurate determination of harvesting machinery productivity for the study area is envisaged in a forthcoming productivity model, which will be developed as an addendum for this study.

2.3.2 Cost analysis

Based on determined productivity, costs of timber skidding can be calculated. For the purpose of this study, the cost per machine hour has been calculated for TAF skidder, universal tractor U651, six wheeled forwarder and mobile uphill cable yarding system (tower yarder) using FAO cost calculation scheme

adapted by Holzleitner et al. (2011). The input data used for calculation resulted after discussions with representatives of Ciucas Forest District Autonomous Administration. The calculation of machine hour costs in case of forwarder and cable yarder considered second hand purchased machineries. For all harvesting systems mentioned, the machine hour costs include also operator's costs.

2.3.3 Impact assessment

It is well known that timber harvesting and road construction represent the most visible forest operations. Thus, evaluation of the impact that currently used harvesting systems have in the project area is a necessary step in the process of planning new road and skid trails routes. During field measurements damages on residual stands, as a consequence of timber skidding, areas with massive soil erosion (e.g. depths > 150 cm) and sediment transport trough water streams and on the road network have been recorded. Moreover, several segments of skid tracks have been identified going entirely trough permanent water streams. Hence, transport of sediments is a key issue in study area. Although no detailed assessment of these impacts has been made in project area, a recent study in harvesting plots with similar site conditions (Sparchez et al. 2009) showed that most of the trees located in a buffer zone of 5 m along skidding trails have been damaged at timber extraction, more than 80% when using skidders and about 40% in case of animal yarding. The study also showed that level of damage increases with terrain steepness and that values of soil dislocation index show a big variability, from 1 m³/ha to more than 140 m³/ha, depending on type of geological layer, harvesting method, average tree volume and local topography. For a more accurate assessment of the impact of timber skidding in study area, a model for soil erosion and transport of sediments should be developed in the future.

2.4 Scenario analysis

Kühmaier (2010) developed a spatial model which proved on local scale that improvement of decision making process in forest engineering requires a combined approach of road network planning with selection of most suitable harvesting systems for a given area. Thus, working scenarios in this study have been defined considering two factors: improvement of forest infrastructure by planning new road and skid trail routes on one side, and adapting current timber extraction practices to state of the art harvesting systems on the other hand.

A recent study (Oprea et al. 2008) described two types of technological lines used in Romanian forests: horses used for pre-skidding combined with TAF skidders for final skidding, and cable yarding systems used for pre-extraction in tandem with TAF skidder for final skidding to the landing area. The authors proposed an improvement of these technological lines by combining skidder with forwarder in the first case, and cable yarder with forwarder in the second case, counting on increased system productivity with 20-50% and on labour costs reduction with up to 28-34%. However, total costs of timber extraction to the road side and the option of reducing mean skidding-forwarding distance by planning new roads were disregarded. Therefore, a holistic approach is proposed in current study. Considering slope class categorization, the following harvesting systems have been taken into account for further assessments of this study: universal tractor (U651), TAF skidders (TAF), forwarders (FW) and cable yarders (CY). Hence, four technological layers (HSTL) have been established:

- ⇒ *Technological layer 0 (HSTL 0)* refers to current harvesting conditions and infrastructure conditions. Hence, it considers tractor U651 for thinnings in slopes below 20% and TAF for thinnings and final cuts in stands with slopes below 55%. In exceptional way, this hypothesis considers the use of TAF in stands with slopes steeper than 40%, provided the trails are not following the line of steepest slope, while stands located in areas with slope steeper than 55% are considered inaccessible.
- ⇒ *Technological layer 1 (HSTL 1)* considers tractor U651 for thinnings in stands with slopes below 20%, TAF for thinnings and final cuts in stands with slopes below 55% and cable yarders for stands with slopes steeper than 55%.
- ⇒ *Technological layer 2 (HSTL 2)* considers TAF skidder for slopes below 40% with forwarder technology for slopes between 40% and 55% and cable yarders for slopes steeper than 55%.

⇒ *Technological layer 3 (HSTL 3)* considers using TAF and forwarder technology in slopes below 55% in a share of 40:60, and cable yarders for slopes steeper than 55%.

The productivity and cost efficiency of state of the art forwarder technology has been determined based on previous models existent in literature (Ghaffariyan 2007, Porsinsky 2011), considering a six wheel forwarder with a maximum load capacity of 10 t used in areas with reduced bearing capacity of the soil, on moderate slope conditions, similar to the study area. Cable yarding productivity has been calculated based on a simplified version of the model developed by Ghaffariyan et al. (2010), considering the cut to length system, a yarding distance of 400 m, lateral yarding distance of 30 m, loading capacity of 1.2 m³ and an average slope of 60%.

In addition to the existing forest road network conditions (FR0) in study area, using ESRI[®] Arc GIS Editor Tool, three new variants (FR1, FR2 and FR3) of forest roads routes have been roughly planned, considering as constraints maximum slope grade of the route, terrain steepness and identified cardinal points during field data collection. The same principle was used for planning new skid trails. The reason in doing so was the necessity of testing the conceptual model of this study in a short time period. Notwithstanding, one of the goals of this concept is to automate also the process of routes planning and to provide accurate data about the planned routes, facts which will be developed at a further stage.

After locating each route, the real mean skidding distances have been derived from GIS data. The annuity of planned routes has been calculated considering discounted total road construction and maintenance costs (Aruga et al. 2005, Picman 1996), for an interest rate of 8.5% over the life span of the road of 30 years. The unitary construction cost has been estimated to approximately 50€ per linear meter, while maintenance costs have been estimated to 1 € per linear meter and year.

2.5 Conceptual model

The stakeholders involved in the decision making process are: the autonomous forest administration, local community, regional agency of environmental protection and regional water management system. Their multiple interests have been categorized based on objectives to fulfil, criteria and indicators.

The decision making process follows three stages (Fig. 1). First, the variant of new forest road route with the shortest real mean skidding distance (S_{dr}) and the lowest total costs (T_c) has been selected, using a decision matrix with normalized values (Zarojanu 2007). Based on multiple stakeholders' interests, real mean skidding distance has been established as the most representative indicator for achieving the common objectives. Because of reduced skidding distance harvesting productivity and cost efficiency will improve whilst minimizing soil erosion, transport of sediments and residual stand damage. In addition, new planned routes facilitate the access of local community to pasture lands and thus reduce the areas affected by soil compaction due to empiric cattle trails.

Then, considering the selected road variant, the harvesting system technological layer with the lowest inquired costs and lowest potential impact on soil and residual stands has been chosen. For validation, the combined selected system of new forest road route with the new harvesting technological layer has been compared with the current situation (HTSL 0 and FR0).

2.6 Project area

This study has been developed in a project area of approximately 903 ha, located in the South East of Brasov County (45°55' North Latitude and 25°90' East Longitude), Romania (Fig. 2). The forest area is private property of the community of Tarlungeni and is being managed by Ciucas Autonomous Forest Administration. The project area is located at altitudes between 900 - 1600 m above sea level. According to the forest management plan, the most common forest types in this area are: mountain beech forests on shallow soils with mull flora, mixed fir-beech forests with mull flora of medium productivity and beech forests with *Festuca altissima*. The geology is represented by marly flysch - sandstones and massive conglomerates, while the rich hydrological network is composed by permanent water streams with maximum flow in spring and minimum in winter. According to Köppen classification, the study area is part of the climatic province *Dfck*, characterized by a boreal climate (*D*) with precipitation all over the

year (*f*), varying between 750 mm and 1000 mm irregularly distributed depending local relief conditions, with average temperatures for at least three months $> 10^{\circ}\text{C}$ (*c*) and for at least four months $> 7^{\circ}\text{C}$ (*k*). The average annual temperature is $7,8^{\circ}\text{C}$, the average number of days with snow layer is 71, while the average number of days without frost is 173. 20% of the studied forest area is located on gentle slopes ($<20\%$), while approximately 10% is located on steep terrain ($>55\%$). The accessibility index in the project area is approximately 13.0 m/ha. The total standing timber in the project area is 267701 m^3 , with an annual allowable cut of approximately 4025 m^3 .

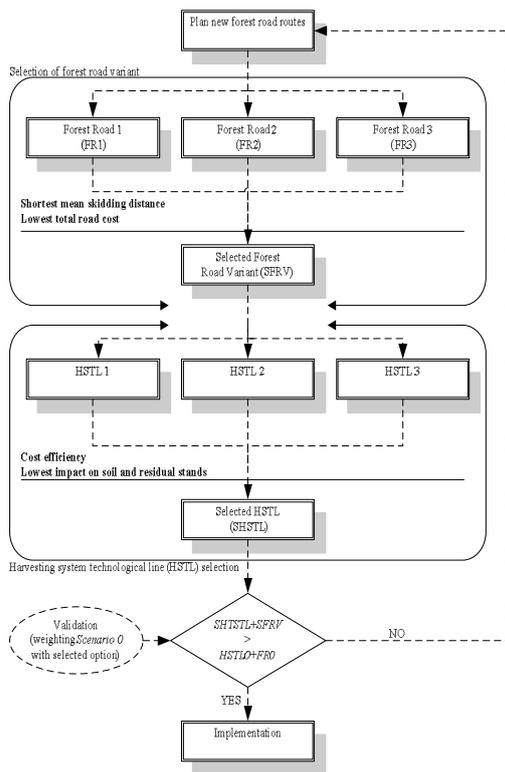


Figure 1: Flow chart of decision making process

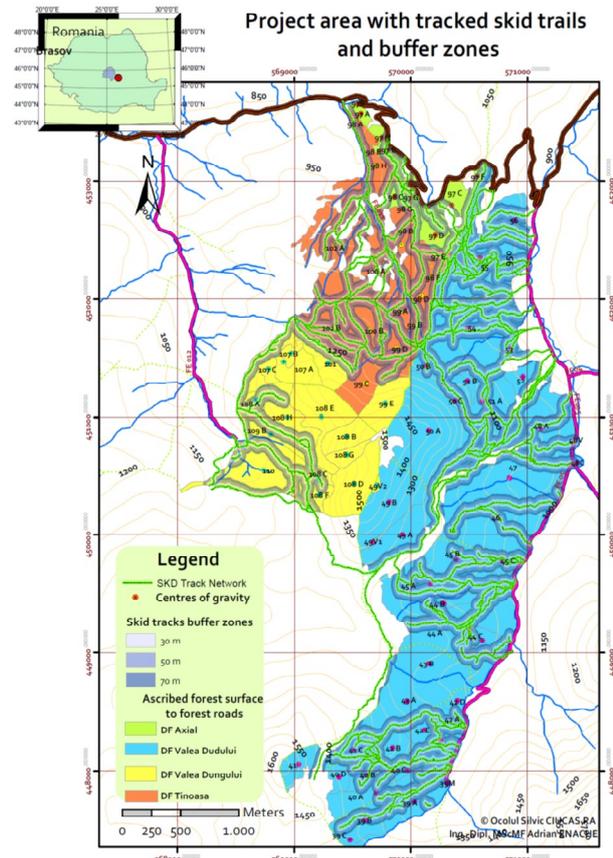


Figure 2: Project area with existing infrastructure and importance of each forest road in timber extraction

3 Results

The results of the study will be presented according to the methodological steps previously described.

3.1 Existing forest infrastructure

The access in project area is provided by three valley roads and one segment of a public road, summing up 14.64 km. Notwithstanding, considering that one of the roads only pin-points the project area and, moreover, is out of use (i.e. broken bridge), the total length of roads considered in calculations is 11.72 km. Hence, the real density index is approximately 13.0 m/ha. However, density index does not accurately characterize the road network, since the distribution of roads in the project area is not uniform, providing a more one sided opening. Several structure indexes of primary and secondary forest infrastructure have been presented in table 1. The theoretical mean skidding distance according to the geometric analytic model is 385.1 m (S_{dg}), while a more accurate determination using ESRI[®] Arc GIS refers to a geometric mean skidding distance (S_{dg}) of 490.2 m, calculated as a weighted volume average

(Tab. 1). Hence, the real mean skidding distance for the study area has been established at 735.3 m. The relevance of forest roads for timber extraction varies in the project area (Tab. 2). The most part of the timber volume (60%) gravitates on forest road FE005, while the public road has the least volume share (5%). A big variability is also noticed in case of real mean skidding distance to each forest road, the worst case (1164.5 m) being for the forests stands ascribed to road FE012 (out of use), while most of the forest stands from the project area (63%) benefit of a mean timber skidding distance of approximately 918.6 m to forest road FE005.

Table 1: Structural indexes of forest infrastructure before and after planning new roads

Structural indexes	Current situation	Variant FR1	Variant FR2	Variant FR3
Project area (ha)		902.7 ha		
Standing volume / AAC (m ³)		267701 m ³ / 4025 m ³		
Length of road network (m)	11719.0	28085.5	27789.5	28611.9
- out of which new forest roads (m)	-	16366.5	16070.5	16892.9
Density index of road network (m/ha)	13.0	31.1	30.8	31.7
Distance between roads (m)	770.3	321.4	324.8	315.5
Theoretical geometric mean skidding distance - analytic (m)	385.1	160.7	162.4	157.7
Theoretical geometric mean skidding distance - volume weighted GIS (m)	490.2	160.4	231.7	219.2
Theoretical real mean skidding distance (m)	735.3	240.6	347.5	328.8
Length of skid trails network (m)	65377.3	75672.1	73986.0	75672.1
- out of which new skid trails (m)	-	10294.8	8608.7	10294.8
Density index of skid trails network (m/ha)	72.4	83.8	82.0	83.8
Maximum real skidding distance (m)	2139.2	1113.6	1113.6	1113.6

Although the forest management plan considers that forest stands located in project area are 100% accessible, analyses in GIS using buffer zones showed that only 44% of the area is accessible for geometric maximum skidding distance of 500 m, while approximately 95% of the area is accessible for a geometric maximum skidding distance of 1200 m (Tab. 3). Full accessibility of the project area is realized, provided a maximum real skidding distance of 2139 m (Tab. 1). Buffer zones has been defined as follows: 1200 m on the basis of former Romanian normative of forest roads designing (PD 67/80-1999), 750 m based on the new normative regarding forest roads designing (NP-003-11), 1000 m as an intermediate value between previous two ones and 500 m as an option of possible future value used for calculating the accessibility in Romanian forests.

Table 2: Relevance of forest roads in project area

Forest Roads	Length	Served area		Served volume		Mean skidding distance [m]	
	[m]	[ha]	[%]	[m ³]	[%]	geometric	real
DF FE005	5596	566.0	62.7	159354.3	59.5	612.4	918.6
DF FE011	1355	145.3	16.1	59871.4	22.4	441.4	662.0
DF FE012	2917	158.7	17.6	34867.0	13.0	776.3	1164.5
DF Axial	4768	32.7	3.6	13608.2	5.1	130.8	196.2
TOTAL	14636	902.7	100	267700.8	100	490.2	735.3

Table 3: Relative accessibility of study area - primary infrastructure

Buffer zone	Accessible forest area	
	[m]	[ha]
500	392.35	44%
750	610.70	68%
1000	769.17	85%
1200	854.42	95%

A total of 65.37 km of skid trails have been tracked during field measurements in studied area. Hence, a density index of the secondary infrastructure of 72.4 m/ha has been calculated. Surveyed skid trails have variable widths from 2.5 m to 4.5 m (sometimes even more), soil erosion and transport of sediments are present on most of the trails, especially on those located in steeper slopes (>40%), where erosion took form of ravines with deepness of often 1-1.5 m or more. Because of Romanian traditional way of building forest roads along the valleys, the skid trail network gravitates on these valley roads, the most common situation being the execution of skid tracks on the line of steepest slope alongside the stream or creek bed (Fig. 2). Only in seldom cases (i.e. especially trails of 30-40 years) they follow the contour lines. In addition, considering that skid trails are most commonly executed by forest contractors just before starting their harvesting works, without a pre-planning phase and based only on their immediate interests, empiric and random development of secondary forest infrastructure occurred. Table 4 shows that for buffer zones of 30 m along the skid trails 29% of the study area is accessible, while for a 70 m buffer zone, the accessibility increases to 54%. However, due to the lack of a strategic plan for skid trail development, overlapping of skid trail buffer zones is present phenomena at large scale. While for 30 m buffer zone, the overlapping represents only 12% of the study area, for 70 m buffer zones the share raises to 53%. This means that for the same length of existing skid trails in study area, 100% accessibility of secondary infrastructure could have been reached for 70 m buffer zones, or 72% accessibility for 50 m buffer zones. Hence, about 40% to 52% of the existing trails are in excess in the study area, if we consider buffer zones of 50 m and 70 m, respectively, with the consequent negative effects: increased soil erosion and transport of sediments, more damages to residual stands and loss of substantial productive land. All these adverse impacts are unnecessary and they could be at least minimized if not avoided¹, in the pursuit of fulfilling involved stakeholders' interests.

Table 4: Relative accessibility of study area - secondary infrastructure

Buffer Zone (BZ)	Accessible area		Overlapping BZ		Exceeding skid trails	
	[ha]	[%]	[ha]	[%]	[km]	[%]
30 m	261.2	29%	106.5	12%	17.7	27%
50 m	387.7	43%	261.6	29%	26.2	40%
70 m	486.7	54%	474.2	53%	33.9	52%
Total project area:		902.7 ha	Total length of skid trails network: 65.4 km			

3.2 Existing harvesting systems

The productivity and cost efficiency of currently existing harvesting systems at timber extraction in study area has been calculated (Tab. 5) for the average skidding distance before (735.3m) and after (240.6 m) the new variant of forest road (FR1) has been selected. The cost per machine hour is 34.46€/PMH for TAF skidder and 27.99 €/PMH for tractor U651, including operator costs. The most expensive operation is the timber extraction with tractor at thinning in broadleaves stands. Due to the long skidding distance, the current productivity is very low, varying between 1.5 - 2.4 m³/h at tractor U651 and between 3.1 - 4.6

¹ Guide to Forest Road Engineering in Mountainous Terrain - FAO, Rome, Italy, 2007

m³/h in case of TAF skidder. For the selected route FR1, productivity has increased up to 6.25 m³/h in case of TAF skidder.

Table 5: Productivity and costs of timber extraction with existing harvesting systems

Harvesting system	PMH (m ³ /h)		Cost (€/PMH)	Cost efficiency (€/m ³)		
	Coniferous	Broadleaves		Coniferous	Broadleaves	Mixed 40:60
S _d =735.3 m						
Tractor U651 - thinning	2.42	1.56	27.99	11.6	18.0	15.4
TAF skidder - thinning	3.66	2.54	34.46	9.4	13.5	11.9
TAF skidder - final cut	4.61	3.18	34.46	7.5	10.8	9.5
S _d =240.6 m						
Tractor U651 - thinning	3.53	2.48	27.99	7.9	11.3	9.9
TAF skidder - thinning	4.69	3.41	34.46	7.3	10.1	9.0
TAF skidder - final cut	6.37	4.67	34.46	5.4	7.4	6.6

Timber extraction costs with tractor U651 and TAF skidder have been calculated (Tab. 5) considering a share of coniferous and broadleaves at a ratio of 40:60, determined based on the forest management plan. Thus, current timber extraction costs vary between 9.5 - 15.4 €/m³, depending on type of machinery used and type of cut. A noticeable improve of cost efficiency is noticed after selection of variant FR1 of new forest roads. Extraction costs per m³ reduced with 36% in case of tractor U651, while for TAF skidder the costs reduced with 24% at thinnings and 30% at final cuts (Fig. 3).

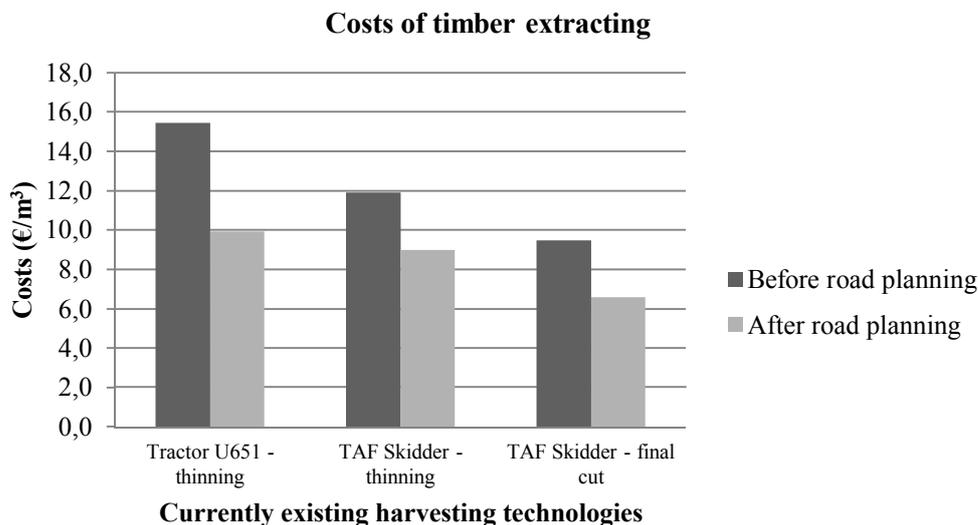


Figure 3: Costs of timber extraction with currently existing harvesting systems

3.3 Selection of new forest roads

For the purpose of this study, three variants (FR1, FR2 and FR3) of new road routes have been planned in GIS (Fig. 4) based on the following principles: locating low volume slope roads following natural contour

lines, facilitating access to good landing areas for installing cable yarders and for using forwarders, reducing mean skidding distance, connecting the new roads to existing road network in minimum two points. The structural indexes and characteristics of the road network after planning each variant are presented in table 1. It has to be underlined that route location has a relevant importance in reducing the real mean skidding distance because the closer the route is located to the centres of gravity of each management unit, the shorter real mean skidding results.

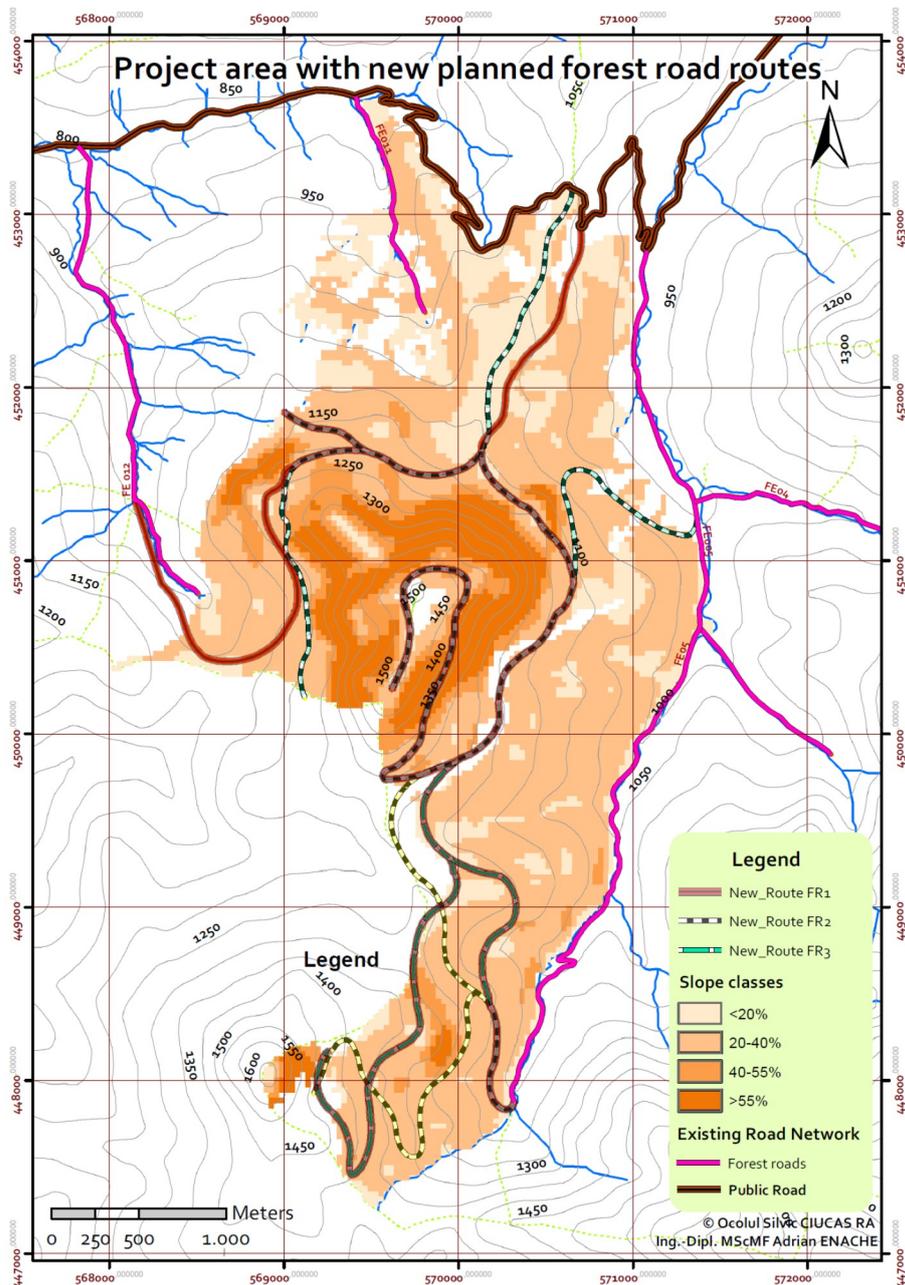


Figure 4: Project area with new planned variants of forest road routes

Since variant FR1 (16366.5 m) provides the best ratio annuity (77668.5€) to shortest real mean skidding distance (240.6 m), it has been selected as the most suitable road route for further proceedings (Tab. 7). Buffer zones classes (maximum geometric skidding distance) have been defined around the existing roads and planned routes. Hence, a greater accessibility level for the same buffer zone class can be achieved in case of selected variant FR1, when compared with existing infrastructure. For example, 100%

accessibility to forest stands is achieved at a maximum geometric skidding distance of 500 m in case of FR1, while only 95% accessibility is achieved for buffer zone of 1200 m in case of existing road network (Fig. 5). In addition, more than 85% of the forest stands are located in a maximum range of 300 m from the roads in case of FR1, while only approximately 30% in case of existing infrastructure (Fig. 6). Secondary infrastructure has also been improved, by planning 10295 m of new main skid tracks (Tab. 1) following natural contour lines, aiming for better connecting secondary skid trails, while reducing the soil erosion by closing unnecessary existing trails built on the line of steepest slope. Besides the opened access to forest stands, selected variant FR1 facilitates the access also to pasture lands and touristic points of interest (i.e. climbing areas, hiking trails, landscape observation points), thus fulfilling multiple functions.

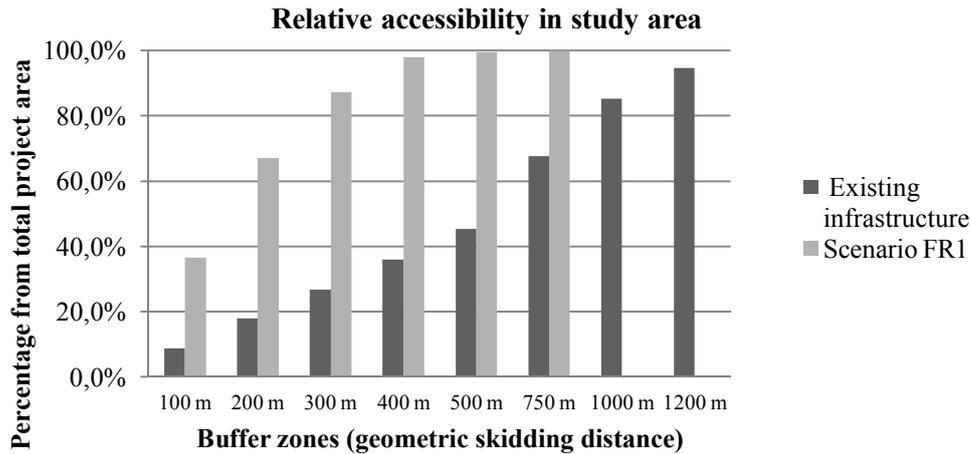


Figure 3: Relative accessibility in study area before and after planning the selected route FR1

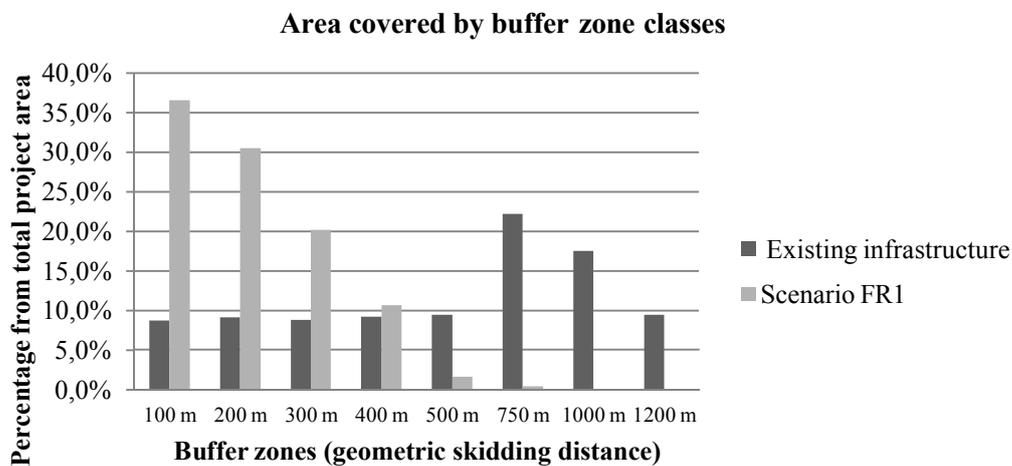


Figure 4: Accesible forest stands by buffer zone classes (before and after planning route FR1)

3.4 Evaluation of new harvesting systems

Productivity and cost of timber extraction have been calculated for all working scenarios, considering the mean skidding distance for route FR1. Forwarder productivity of 15 m³/h and machine costs of 45.49 €/PMH were calculated, while for cable yarder resulted a productivity of 9.33 m³/ha and hour machine costs of 51.20 €/PMH. Hence, cost efficiency of harvesting system technological layers scenarios (HSTL) has been calculated for each HSTL (Tab. 6). Due to newly adopted road route FR1 with its real mean

skidding distance reduced with approximately 300% and due to increased productivity of newly adopted harvesting systems, important savings in timber extracting are possible for each scenario. Notwithstanding, it has to be mentioned that even in these circumstances, the depreciation costs of the new road cannot be covered from these savings (Tab. 7). Hence, we considered also the savings that Ciucas Autonomous Forest Administration (CAFA) can make by changing the practice of selling timber on stump. Currently, CAFA sells approximately 74% (mostly final cuts) of its timber on stump, while for the rest of 26% (thinnings) the used practice is to harvest with contractors and to sell the timber at road side. Under the improved infrastructure conditions of FR1 this practice could be changed by adopting the system of contracting all harvesting operations and selling all timber at the road side. This practice would lead to extra savings, but only for scenarios HSTL 2 and HSTL 3 (Tab. 7). The total earnings from the road bed clearance sums 221333.9 € and the corresponding discounted annual value (20595.3 €) at a rate of 8.5% for the life span of the road have been also considered in the cost efficiency evaluation as extra savings.

Table 6: Cost efficiency of harvesting scenarios after selecting road route variant FR1

	HSTL 0		HSTL 1		HSTL 2		HSTL 3	
	Volume [m ³]	Cost [€]						
U651	897.8	13846.5	897.8	8921.1	-	-	-	-
TAF thinning	148.9	1770.2	148.9	1339.2	1046.7	9414.2	1046.7	9414.2
TAF final cut	2513.7	23838.3	2513.7	16562.1	2170.5	14300.9	377.4	2486.9
FW	-	-	-	-	343.2	1039.8	2136.2	6472.8
CY	-	-	465.4	2559.8	465.4	2559.8	465.4	2559.8
Inaccessible	465.4	11635.3	-	-	-	-	-	-
Total	4025.8	51090.3	4025.8	29382.1	4025.8	27314.7	4025.8	20933.7
Yearly savings (€)		0		21708.2		23775.6		30156.6
Yearly savings (%)		0%		42%		47%		59%

Productivity of timber extraction has improved after selecting variant FR1 of roads, from the currently existing average of 2.88 m³/h (HSTL 0) to 5.21 m³/h (HSTL 1), 6.26 m³/h (HSTL 2) and 10.56 m³/h (HSTL 3) respectively. The environmental and social benefits of variant FR1 are also noticeable, first due to reduction of mean skidding distance and the opportunity of employment for local people at road construction, and second because the increase in productivity is strictly correlated with potential reduction of soil erosion, residual stand damage and rate of accidents among forest workers due to gradual increase of full suspension timber extraction from scenario HSTL 0 (0%) to scenario HSTL 3 (64.6%).

Table 7: Profit and loss statement for the implementation of variant FR1

Scenario	HSTL 0	HSTL1	HSTL2	HSTL3
Cost efficiency of timber extraction (€)	51090.3	29382.1	27314.7	20933.7
Yearly Savings 1 - timber extraction		21708.2	23775.6	30156.6
Yearly Savings 2 - selling at road side		18283.49	20350.88	26731.93
Yearly Savings 2 - selling at road side		-838.34	2450.35	15212.4
Annuity (€)			-77668.5	
Yearly Savings 3 - from road clearance			20595.3	
Net profit/loss for implementing FR1		-36203.4	-30847.3	-11704.1

Despite all mentioned benefits of enhancing forest infrastructure from environmental and social points of view, and all counted savings possibilities due to introduction of new harvesting systems with increased productivity, the selected variant FR1 is not viable from an economical point of view, no matter which harvesting scenario will be selected (Tab. 7). The best case scenario (HSTL 3) results in an annual loss statement of -11401.3 €, which is not acceptable. Hence, according to decision making flow chart (Fig. 1), this means the evaluation process has to restart all over again, by planning new road routes with a lower density index.

4 Discussion

The significant reduction of mean skidding distance from 735.3 m to 240.6 m was possible through the location of road route FR1 closer to the centres of gravity of the forest management units than the other two routes. As a result, the productivity and cost efficiency of harvesting machineries at timber extraction notably improved, while reducing the potential of soil erosion and residual stand damages. However, selected variant FR1 and hence, both the other planned routes (FR2, FR3), are not economically feasible. The negative financial results of the assessed scenarios could be the result of several combined factors. First, the financial investment effort for building variant FR1 of roads cannot be sustained by the current annual allowable cut values. Current annual growth per year and hectare in the study area is of approximately 7.5 m³, while the AAC established through the forest management plan is approximately 4.5 m³. This means that only about 60% of the annual forest growth is allowed for harvesting. Second, construction costs per running meter are high. Despite the fact that the unitary construction costs (50 €/m) considered in this assessment are below Romanian national average as a result of planning road routes using several existing segments of skid tracks as road base, this value is still high enough and cannot be covered by timber harvesting at the existing levels of AAC. Third, social and environmental benefits of forest roads cannot be considered in monetary units, or if they were, the willingness to pay for such services is commonly very low. Hence, the multiple functions of roads cannot be shared in terms of recovering investment costs from the beneficiary of these services (i.e. tourists, local people), timber harvesting remaining the only activity to sustain the investment. Under these circumstances, one can draw the conclusion that reduction of mean skidding distance at 240.6 m with a consequent road density index of 31.1 m/ha in study area still represent very optimistic values that cannot be achieved from an economical point of view, unless subsidies are provided (i.e. European funds for rural development). Hence, evaluation of other scenarios of road routes is necessary in order to find the acceptable solutions from environmental and social points of view which are technically feasible and economically viable.

5 Conclusion

The aim of this study was to develop a decision support tool for enhancing forest infrastructure using a holistic approach, including multiple assessments of forest infrastructure and harvesting systems, before and after planning new road routes, and thus underlining the importance of preliminary planning phase prior to technical designing. The conceptual model has been tested in a forest area of approximately 903 ha from Brasov region, Romania with an AAC of 4025 m³, which is irregularly opened by existing forest infrastructure (valley roads and empirically developed skid trails) and characterized by a real mean skidding distance of 735 m and a maximum real skidding distance of about 2140 m. Reduced productivity in timber harvesting and increased levels of residual stand damage, soil erosion and transport of sediments are the main problems when performing forest operations. New development options (road routes and harvesting systems) have been planned and assessed using GIS, selected scenario FR1 improving accessibility up to a mean skidding distance of 240.6 m. Productivity in timber extraction has increased within ranges of 30 to 60%, while cost efficiency improved with 25 to 60%, depending on harvesting scenarios. The increase of productivity is strictly correlated with potential reduction of soil erosion, residual stand damage and rate of accidents among forest workers due to gradual increase of full suspension timber extraction up to 65% from AAC, depending on scenarios. However, due to increased road construction costs and low value of AAC, none of the planned road routes proved to be economically feasible. Hence, the process of planning and assessing new road routes and harvesting systems has to be started all over again, in order to find those solutions which solve both environmental and social issues, while being technically feasible and economically viable. The conceptual model

presented in this study provides sound information regarding evaluation of different development options of forest infrastructure, including location of new roads, productivity and cost efficiency of harvesting systems through multiple assessments. Hence, this tool proved to be useful for supporting decision making in forest engineering and for elaboration of forest operations plans. This holistic conceptual approach can be further improved by developing local productivity models for existing harvesting machineries in timber extraction, for establishing the impact of harvesting on soil erosion and for determination of real mean skidding distance and correction factor k_g based on GIS analysis. Automation of processes in the model is also envisaged.

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