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Functional forest road network planning by consideration of environmental impact assessment for wood harvesting

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Abstract Forest management today has to meet a number of objectives. Planning of multi-functional forest road networks is one essential for meeting the aims of the sustainable forest concept. Road construction damages the natural environment unless it is carefully thought out. As forest engineers we have to consider the protection of nature when designing forest roads. With this aim in mind, a new network planning approach was developed for wood-harvesting. A geographical information system (GIS) was used to evaluate the data and planning process. The new forest road network plan for Catak Forest District constituted the addition of a new 16-road segment, total length 59.067 km, to the existing road network plan, for the purpose of wood-harvesting operations. Forest road density value was determined as 22.8 m/ha: the opening-up rate of the area was increased to 77.8% and the opening-up rate of the existing stand value was increased to 94.3% after close examination. 90.2% of roads were planned for the forest areas where there is likely to be minimal negative environmental impact.

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Introduction

Forests provide many benefits for people economically, socially and environmentally and safety for countries. Each benefit can be described as a forest function. Forest functions are different for each nation and depend on culture and social life (Potocnik 1996). There can be as many as fifteen different types of forest function or planning aim (Lugoa and Gucinski 2000; Hruza 2003; Demir 2007). Determination of forest function is made by the forest owner according to its particular features.

Exploitation of forests identified functions can only be possible through an individually tailored forest roads network. A functional approach is therefore needed in forest road planning. Wood-harvesting, as the principal economic benefit of any forest, requires particular consideration when road network planning is under discussion.

Forest road network parameters change according to construction location requirements, different terrain conditions, particular technologies used and management activities. These requirements and the planning approach have to be related to management, economy and environmental ecology (Potocnik 1996).

Public awareness of environmental questions has been on the increase in the last few years. The construction of forest roads has been the main bone of contention in discussions between foresters and environmentalists. The latter's main criticism is that the construction of forest roads is destroying the environment, causing soil erosion, habitat loss, scenic impacts, etc. Public acceptance of construction work has decreased significantly. In the context of sustainable development, as stated by the UNCED (UNCED 1992), the use of natural, renewable resources is a key element of environmentally sound development. Resource use depends on the accessibility of the relevant areas: it is therefore impossible to avoid the construction of forest road networks so the forest community has to look for ways on how to improve environmental soundness and public acceptance of road construction activities (Heinimann 1996).

As the human population continues to grow, competing interests will place mounting pressures on how resources from these forest lands should be managed and used by people. To make sound decisions about the allocation of these resources, decision-makers must consider all aspects of the ecosystems in which they are found (Schumacher et al. 2000).

Effective and equitable management of our natural resources has many dimensions. Impact assessment is a process which attempts to address these dimensions and the need for more informed management. Impact assessment management and information systems recognize the complexity of natural systems and human interactions with them (Jakeman and Letcher 2003). If all choices can be presented within a spectrum of best and worst possible impacts for sustainability, decision-makers can meaningfully weigh their options. Any evaluation on this basis is presently very difficult because one needs to assess independently and integrate possibly incomplete and conflicting information from a wide variety of sources (Hepting 2007).

Sustainability of food production depends on maintaining soil quality and proper land management. Soil erosion from productive farmlands decreases soil quality and crop production, diminishes on-site land value and causes off-site environmental damage (Bhuyan et al. 2002). Mas et al. (2004) prepared deforestation maps which were overlaid with spatial variables such as proximity to roads and settlements, forest fragmentation, elevation, slope and soil type to determine the relationship between deforestation and these self-explanatory variables. A multi-layer perception was trained in order to estimate the propensity to deforestation as a function of the explanatory variables and was used to develop deforestation risk assessment maps (Mas et al. 2004). Wildlife management and conservation are problematic because of the uncertainty of popular responses to environmental factors, human disturbance and land use changes. Any plan and policy for wildlife management and habitat protection should therefore be based on detailed studies of ecosystems' status and trends, clearly stated and repeatable (Ortigosa et al. 2000).

All of these studies were separately evaluated regarding forest road impacts, since there is no comprehensive evaluation study or functional approach. Wood-harvesting needs a road network methodology based on comprehensive evaluation of road construction and functional approach.

The consequent aim has been to develop a new forest road network planning methodology for wood-production forests, use this planning approach as a case study and check results between existing road networks and new planned road segments according to opening-up rates and environmental impact assessment points.

Materials and methods

Catak Forest District was selected as the investigation area of the research forest of Karadeniz Technical University's Faculty of Forestry in Trabzon, a city located on the north-east coast of Turkey. The total area under investigation was 19,553.76 ha. There are 26 forest stand types with an area of 10,241.72 ha. The remainder of the study area comprises agricultural land and rangelands which were not included in the investigation.

In this study, a new forest road network planning methodology approach was developed for wood-production forests. The methodology was based on the evaluation of the existing road network's ability to meet wood-production management goals, opening-up capacity, economical analysis of the requisite new road segments cost and, finally, environmental impact assessment of the new planned roads layout. This method can equally well be applied to roadless areas. The approach was tested by comparison results of new planned road segments and existing road network plans according to opening-up rates and environmental impact assessment points. The new network plan was designed according to the above method.

The project began with the design and building of a database. In this context, the boundary of the investigation area, available opening-up infrastructures and their conditions, road route analysis, positive and negative main points of road construction, topographical structure, water resources, forest structure, ownerships, social-economic structure and work opportunities for local people were used in the database.

An inventory of existing roads was made by GPS for examination in terms of quality and quantity. Road routes were also collected with track mode by GPS.

After determination of the existing roads (Pentek et al. 2005) new road segments were designed in accordance with the management plan. At this stage cutting areas, existing roads, stand volumes, opening-up rates and construction cost were taken into consideration.

Required road lengths were determined by cost benefit analysis (Turker 1989). The cost/benefit formula is as below (Eq. 1):

$$B/C = \frac{\left(\sum_{k=m+1}^{n} \frac{G_k}{(1+i)^k}\right) + \frac{H}{(1+i)^k}}{\sum_{j=1}^{m} \frac{I_j}{(1+i)^j}} \quad (1)$$

where

B	benefit
G_k	incomes through amortization of whole
I	Annual investment cost
H	Junk price
K	Economical life (years)
C	Cost
j	Years of cost
i	Real interest rate (3%)
m	Total investment time

Benefit as used in the economic analysis is the net present value of income from wood sales obtained through opening-up of the forest by roads during the amortization time. Expenditure includes road construction cost, maintenance and staff transportation (Erdas 1997).

Cutting compartments, which were determined in the management plan, were evaluated together in the context of new roads for the cost and benefit rate analysis. In determination of these areas topographical structure and skidding direction were evaluated. A total of 36 forest road cost compartments to be used for economic analysis was thus reached. In determination of the benefit amount the financial records of the Macka Forest Enterprise were used.

An environmental impact assessment (EIA) map was drawn up to estimate the effects of new planned roads on the environment after determination of cutting areas and required road lengths for these areas. The routes of these roads are very important in terms of impact assessment. EIA is a general term covering estimation and evaluation in environmental terms of both management operations and development proposals (OECD 1994).

An environmental impact assessment database was built to minimize the negative effect of road construction operations on the developed planning approach for wood-harvesting (Cornish 2001; Grigal and Bates 1997; Clarke and Walsh 2006; Table 1).

The layers, which are prepared separately for the components of the environment, are combined by GIS in order to prepare a layer of environmental impact assessment. In Fig. 1 the EIA coverage of the graphical and non-graphical database of the planning unit can be seen.

All points were then multiplied to form EIA points groups comprised of positive values, negative values and zero points. In the database groups were symbolized as +1 for positive areas (green), −1 for negative areas (red) and 0 for balanced areas (yellow). Red polygons described maximum negative environmental impact areas: green polygons described minimum negative environmental impact areas: yellow polygons described the second degree risk zones. An EIA coverage was thus prepared for the analysis of the whole area. While new road networks were being planned, this EIA coverage was used for optimum road layout.

Results and discussion

Potential cutting volume was determined by input of volume and incremental information into the database of digital stand type map of whole planning unit. A total of 102 compartments was planned for cutting in the 10-year management period of the investigation

Table 1 Environmental impact assessment (EIA) indicator groups point system

Element of the environment	Risk	Indicator	Indicator groups	EIA points
Soil	Loss of productive soil	Side slope groups	S < % 45	+3
			% 45< S < % 75	0
			S > % 75	−3
		Rocky areas	Roads on rocky areas	−3
Water	Damaging water sources	Destruction of water source area	30 m zone around of stream bed	−3
Biosphere	Habitat loss	Destroyed area of valuable habitats	Seed stands	−3
			Picea sitcensis, orgin test areas	−3
			Aforestation areas	−3
Atmosphere	Road maintenance cost	Aspect groups	North aspects	−3
			East and West aspect	0
			South aspects	+3
Socio-economic conditions	Change of household characteristics	Nationalization costs	Private ownerships areas	−3
Cultural heritages	Destruction of archaeological and historic resources	Resources areas		−3

area. The total area is 5,064.6 ha. The total stand volume of the planned compartment is 565,962.9 m^3. Annual increment of this stand volume is 13,275.1 m^3. A 20-year period increment, which is the amortization time for the forest roads, was calculated to be 265,501.6 m^3.

The economic value, reduced net present value for 2006, of 81,861.2 m^3 of wood raw material, calculated for a 20-year management period, is 3,017,926.3 USD. The economic value of the total increment occurring is 9,788,083.6 USD as net present value for 2006.

A road network length of 248.815 km is required for the Catak study area. The total forest road length is 232.209 km in the plan.

The 43.412 km of the existing roads' longitudinal slope is more than 10%, and that of 15.505 km of roads is over 12%.

Total cutting area is 5,064.6 ha according to the management plan. Including that for the years 2000–2009, 3,108.1 ha (61.4%) of this area was opened up by existing road networks. There is 388,812.5 m^3 stand volume in this area and the opening-up rate of total stand volume is 68.7%. The opening-up of annual increment rate has been, however, calculated as 9,046.4 m^3.

86.4% of areas opened up by existing roads was done by only one road segment. 7.2% was opened-up twice by different road segments. Additionally, 1.4% of the total area was opened up by three or more road segments.

The existing road network plan is not capable of activating all management plan activities according to the calculations. If the management activities were carried out within the existing roads network, the planned works would only be successful at a rate of 68.7%.

Existing road routes were accepted as a 20 m wide corridor and overlaid with EIA coverage to find the effect of their environmental impact. It was calculated that 32.3% of existing roads were located in maximum negative environmental impact areas. 46.6% of existing roads were planned for the minimum environmental impact areas. 21.1% of roads were located in second degree risk zones.

More than half of the existing roads constructed according to the previous network plan are located in maximum negative environmental impact areas.

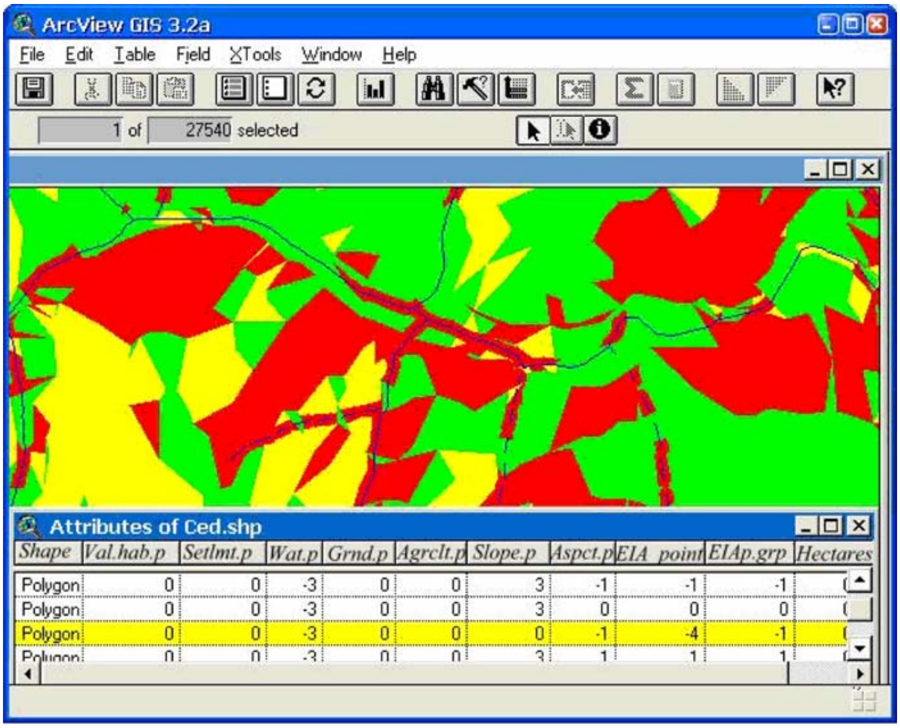

Fig. 1 EIA graphical and non-graphical database

Val.hab.p : Valuable habitat points
Setlmt.p : Settlement area points
Wat.p : Watery ground points
Grnd.p : Ground points
Agrclt.p : Agriculture area points
Slope.p : side slope points
Aspct.p : Aspect points
EIA points : EIA total points
EIAp.grp : EIA groups

Evaluation of the existing network plan allowed the new road segments to be successfully designed to realize forestry activities for the years between 2000 and 2009.

The wood-harvesting road network approach designed by this study used functional forest road network design, opening-up rates of areas and stand volumes as planning criteria.

There was no previous acceptance of limitation for the value of road density. Local information was therefore of greater importance and road density value was determined after the design of a road network plan suitable for all wood-harvesting operations.

The total length of the new roads planned is 59.067 km. The total road length by reaches 307.882 km with the addition of the newly-designed road segments. Total forest road length is 291.276 km. Total forest roads length for serving wood-production areas is 155.885 km. These figures give an approximate road density value of 22.8 m/ha. Forest roads on a digital terrain model can be seen in Fig. 2.

Cost and benefit rate calculation was used for the economic investment evaluation of new roads to be constructed. Income from wood sales over the 20 year-period is 3,017,926.3 USD which is the reduced net present value for 2006.

Costs of new road construction and a 20-year maintenance plan (0.005% of construction cost) are evaluated as the cost of road network. Reduced cost is thereby calculated as 692898 USD overall.

Cost/benefit rate works out at 4.5 according to these calculations. If the cost/benefit rate is over 1 in the evaluation of the investment project, the project will be accepted as economical (Turker 1989). The roads agreed to be built are found to be economical in the results of planning studies.

EIA coverage was taken into consideration while new road routes were planned. Attention was duly paid to the location of new roads in risk-free zones but in some limited conditions negative environmental impact areas were used as well. While 63.5% of new roads were located in minimum negative envi-

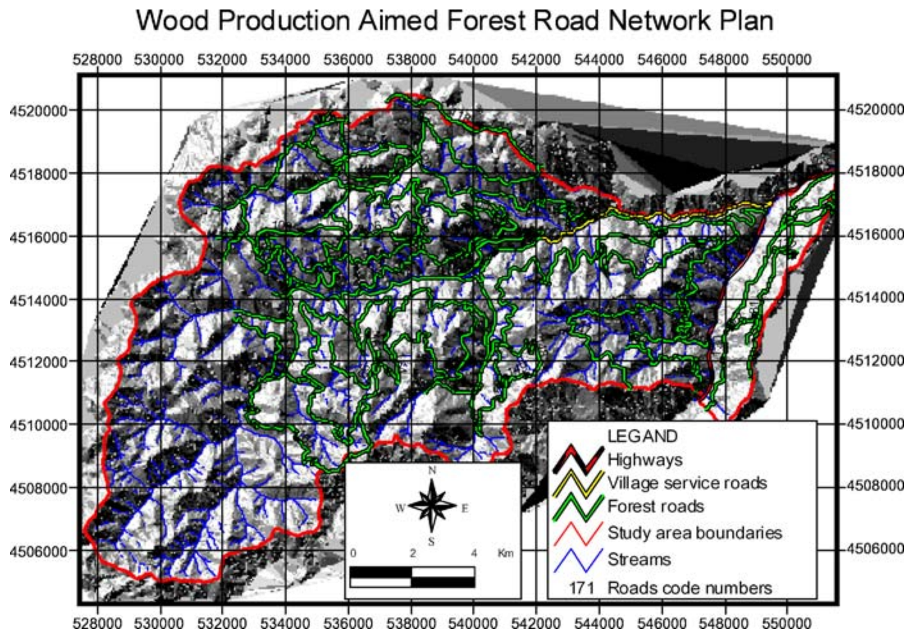

Fig. 2 Catak forest district new road network map

ronmental impact risk zones, only 9.8% were located in maximum negative environmental impact zones. Of all designed roads, 26.7% were located in second-degree risk zones.

Total opening-up areas were increased to 3,941.4 ha by the new roads: the opening-up area rate was also increased to 77.8% (Fig. 3). In this area, there is a 533,697.5 m^3 (94.3%) volume.

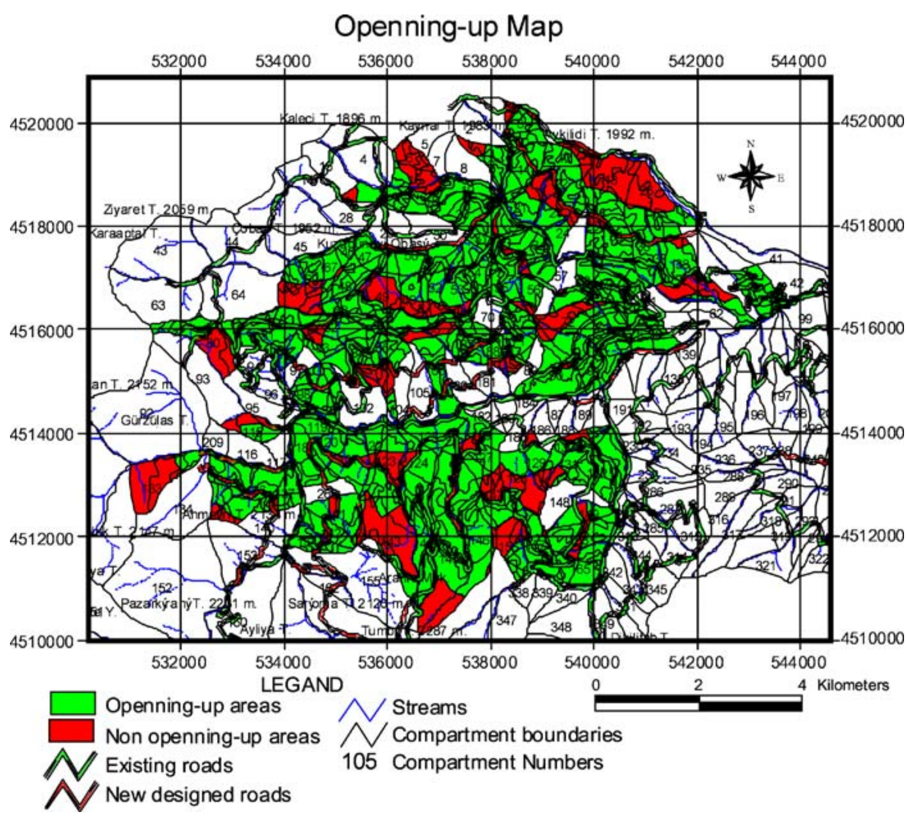

Fig. 3 Opening-up areas map in forest road network plan

Table 2 A comparison between existing roads and new planned roads objectives

Elements/roads	Existing roads	New roads
Lengths (km)	155885	59067
Opening up rate (%)		
Area (ha)	3108.1 (61.4%)	3941.4 (77.8%)
Volume (m^3)	388812.5 (68.7%)	533697.5 (94.3%)
EIA risk area (%)		
Risk free zones	45.5	90.2
Maximum risk zones	54.5	9.8

The developed method's gaining is shown at Table 2. Table 2 summarizes comparisons of planning objectives between existing roads and new planned roads.

According to Table 2 new roads are more functional and more environmentally friendly. These results were obtained from the wood-harvesting road network planning method.

Conclusions

The new forest road network plan was achieved by the addition of a total of 59.067 km forest roads designed as 16 additional segments for successful wood-production.

New planned forest roads network cost/benefit rate is 4.5. Roads planned for construction have been shown to be economical by the planning studies undertaken.

Catak Forest District wood-production/ forest road density value was calculated as 22.8 m/ha after planning studies.

Opening-up rate of volume is increased to 94.3% but only 68.7% of total potential income can be opened up to use by the existing road network plan.

While the increased rate of opening-up of wood volume by newly-designed forest roads is 25.6%. Comprehensive GIS database and research led to this success.

The 90.2% of designed roads were planned in minimum negative impact risk and second-degree risk zones. Only 9.8% of designed roads were planned in maximum risk zones, necessitated by difficult terrain conditions.

New forest road network plans must be redesigned taking into consideration the functions of forests in Turkey.

Forest road networks aimed at enhancing wood-production must be implemented to meet the targets of the management plan. 20 m/ha road density, which is a conservative measure, need not be a criterion for forest network plans. Opening-up area and stand volume rates should be the main criteria in planning operations.

A geographical information system should be used as a tool for functionally based forest road network plans by reason of its geographical data storage, updating, and number of possible analyses.

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