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MULTICRITERIA DECISION MAKING TECHNIQUES FOR IMPROVED AND SUSTAINABLE FOREST ROAD ENGINEERING

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Abstract: *Forest roads are widely recognized as the major source of disturbance in any forest development. Most of the forest roads in Greece are in the mountain region, characterized by steep terrain, with a dense river network, creeks, glens and springs. Thus, a large volume of works, consisting mainly in the construction of retaining walls, fords and culverts, is required for the protection and stabilization of roadbeds.*
Impact is defined as any change, positive or negative, caused by the characteristics of the environment, due to a project or activity. Impact assessment is the description and evaluation of potential significant effects on the various natural and socio-economic features of the environment.
The lack of specifications for an objective environmental impact assessment and then for the development of technical projects within the forest areas, with immediately measurable criteria, led us to assess the forest road with technical (quantitative) criteria, which are also qualitative indicators of impact on the environment. Multi-criteria evaluation (MCE) analysis (the implementation of decision-making rules to identify and enable the combination of many criteria, in the form of GIS layers, into a single map) and Geographic Information Systems (GIS) are two examples of tools that aid in the development of geographic data and maps for different purposes, such as conserving land for forestry uses and the quantitative and qualitative evaluation of the impact of the forest road on the environment.
The aim of this paper was to study the forest roads in terms of how it they are designed, constructed, and maintained, as well as whether they contribute to the sustainable development of the wider area.

Key words: *Road planning, Route selection, Road layout, Road construction and maintenance.*

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1. Introduction

The first humans used forests as a source that gave them fuel, food, accommodation, water etc. As the years went the stone tools were replaced by metal ones and thus the industrial revolution begin and with it the construction of forest roads and forest works which had as a result the rise of productivity in both soil and material works. The potential that is given by the use of modern digging machines, apart from precious help, caused problems in the balance of the forest habitats [5].

The construction of a forest road must not be considered in advance from environmental point of view as negative because while being a true source of negative environmental impacts it also has many positive ones [2]. Opening assessment uses analytical and empirical methods. The analytical methods rely on theoretical models and consider quantitative opening criteria (expressed in monetary units) in relation to road density [1, 7]. Empirical methods apply knowledge of economic theory. Such methods are the dynamic methods. Among them, the method of cost-benefit analysis, takes into account only quantitative criteria and depends on road density, and the method of value - benefit analysis takes into account both quantitative and qualitative criteria (not expressed in monetary units). Both methods are applied in forest engineering [2].

For the first time, during 1977, an Environment Impact Assessment (E.I.A.) was undertaken in Greece, during the plan of dam construction in Aoos and Nestos rivers to produce electricity power. At the same year (1977), the E.I.A. was referred in the Law no. 743 [9] but without a practical use. In 1986, the E.I.A was referred in the Law no. 1650 [8] for the protection of Environment especially in articles 3-6, so that the Greek legislation can be adapted to EU directions.

In the forest road construction E.I.A. can be defined as the test if the road construction is compatible to the environment.

Forest roads are among the biggest investments that the Greek State will make in developing and managing its forests. The construction of forest roads also produces some of the biggest impacts on the forest and its associated values. These two considerations are reasons enough to explore the topic of forest roads with the specific aim of providing guidance on how to minimize both the impact and the cost of forest roads in order to ensure more sustainable forest ecology and more viable forest exploitation.

A forest is exploitable only through a good road network. Recently and following a worldwide lobbying on the degradation of the environment, countries were forced to impose laws for the protection of the environment. According to these laws, any construction work must be preceded by an environmental impact assessment to demonstrate impact during the construction as well as during the use of the work. The environmental effects to be examined are categorized as follows [3]:

- **Temporary or persisting**

Temporary effects appear during the construction, e.g. noise from the construction machinery, dust, while the persisting ones have continuous and stable influence, such as the change of the natural environment, noise, air pollution etc.

- **Accidental or anticipated**

The first ones include effects such as fire, environmental pollution due to accidents, while the second ones include the occupation of agricultural land leading to migration or shifting to other economic activities along with transfer of the population to urban centres.

- **Reversible or irreversible**

Reversible are the effects that can be eliminated through adequate measures or at least they can be maintained at very low levels. Irreversible are the ones that do not allow the environment to come back to its initial state. This second category may also be considered as persisting.

- **Fast developing or slowly developing**

The first ones occur during the construction or right after the completion of the work. The second ones may occur either during construction works or after their completion, but their effects appear much later e.g. effect on the flora and fauna.

The success of any activity and process depends fundamentally on the possibility of balancing (symmetry) needs and their satisfaction. That is, the ability to properly define a set of success indicators. The application of the developed new multi-criteria decision-making (MCDM) methods can be affected by decision-makers' subjectivity, which leads to consistency or symmetry in the weight values of the criteria. Many research papers from different countries explore aspects of multi-criteria modeling and optimization in crisp or uncertain environments. These papers propose new approaches and elaborate case studies in the following areas of applications: MCDM optimization in sustainable engineering, environmental sustainability in engineering processes, sustainable multi-criteria production and logistics processes planning, integrated approach for modeling processes in engineering, new trends in the multi-criteria evaluation of sustainable processes, multi-criteria decision-making in strategic management based on sustainable criteria [10].

Multi-criteria evaluation (MCE) analysis (the implementation of decision-making rules to identify and enable the combination of many criteria, in the form of GIS layers, into a single map) and Geographic Information Systems (GIS) are two examples of tools that aid in the development of geographic data and maps for different purposes, such as conserving land for forestry uses and the quantitative and qualitative evaluation of the impact of the forest road on the environment [4].

The aim of this paper was to study the forest roads in terms of how they are designed, constructed, and maintained, as well as whether they contribute to the sustainable development of wider areas. This is going to be achieved by the assessment of two alternatives of the same forest road by measurable criteria investigating the effect on the following environmental resources (components): the fauna, the flora, the water capacity (water resources, water saving), the soil, the disturbance of soil and rocky lands, the landscape-physiognomy and the acoustic environment.

2. Material and Methods

2.1. Research Area

The research area is the Public Forest of Vlastis – Emporiou in Kozani Prefecture in Greece.

Morphologically, the forest Vlastis - Emporiou has the characteristics of a mountain mass that is crossed by a large stream, Myricho. The transverse slopes range from the mildest and moderate, to strong and in some places steep, with moderate prevailing. It lies between 700 m (near the settlement of Emporio) to 1,700 m (1,703 anonymous peak of the Mouriki ridge). In general, the landscaping of the forest area is purely mountainous and as such must be treated from both an economic and a social point of view. The predominant aspects are north - northeast - east, but due to the intense relief, all the aspects are presented (Figures 1 and 2).

Fig. 1. *Research area in West Macedonia - Greece*

2.2. Methodology

The assessment method for the alternative routes are based on quantitative and qualitative criteria. Where possible, a form of benefit-value analysis [2] was used.

Stages of method application:

1. Two alternative routes were drawn (A and B). The A route has a total length of 4,600 m and the B route a total length of 3,700 m.
2. The criteria used to estimate the effects of each route were set out and the values (Z) for each criterion and alternative solution were calculated.

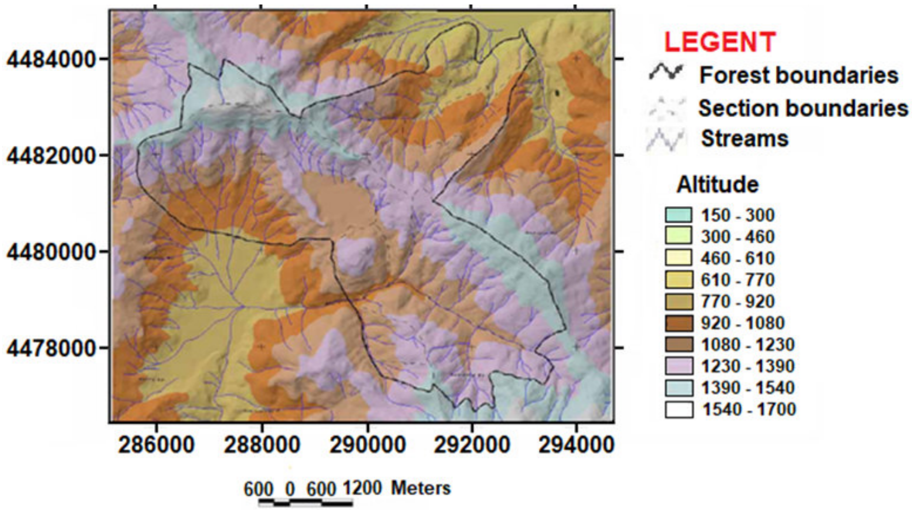

Fig. 2. *The digital terrain model of the research area*

Estimation criteria: Total costs of construction in €, the forest landscape in m^2/ha, the water saving in m^3/ha and the approximation of the area in running meters of forest road.

The forest landscape and the water saving (quality criteria) were estimated for the groups of environmental resources.

Prerequisites of grouping of environmental resources were: the ability to measure with one quantity (expression of quantity, Z), with an indicator (expression indicator) and with a unit, to be independent among each other but not to cover each other in respect to the estimation methodology.

The area's approximation criterion (quality criterion) was estimated based on the demand of the stakeholders for immediate access to the area in case of fire and was expressed with a length indicator of forest road and with units in running meters.

3. The importance of estimation criteria (weight, G) was calculated from a questionnaire sent to respondents.

4. The fulfillment degree or transformation coefficient (E) was calculated using the following formula (1):
- For a decreasing direction of estimation (when the quantity (Z) increases then the benefit is decreased) and
- For an increasing direction of estimation (when the quantity (Z) decreases then the benefit is increased):

$$Z = \frac{B}{Z} \quad (1)$$

where:

Z is the expression of quantity (effect) of criterion;

B – the comparison size = average value of expression quantities of all criteria for each alternative solution;

E – a transformation coefficient.

Constraint:

$$E_{\min} \rangle 0 \text{ and } E_{\max} \leq 3.2$$

When the quantity (Z) increases then the benefit is decreased in a decreasing direction of estimation.

When the quantity (Z) decreases then the benefit is increased in an increasing direction of estimation.

The quantities of criteria are expressed in different units. For the estimation and shaping into comparable numbers of benefit value to be possible, it is required to transform them into a non-dimensional scale. The transformed size is called fulfillment degree and is a non-dimensional number.

The partial values (G × E) were calculated for each criterion and alternative solution. The total has provided the total benefit value for each alternative solution. The alternative solution with the biggest benefit value is the most advantageous.

Materials: The data have resulted from a map with a scale 1:20,000, and field measurements such as the length of the forest roads, the average hill slope (45%), the occupation zone in m^2/ha, the amounts of earth fills in m^3/ha for a road 6 m wide, the construction cost and the questionnaire.

Afterwards, the absorptive capacity of the forest ecosystem of the effects from the forest road construction projects was studied. Specifically, the term absorption is defined by whether the impact effect will be absorbed from the forest ecosystem as time passes, as well as the number of impact receivers.

In order to determine the absorbency criteria and their weights the following steps were used:

i. The absorbency criteria were specified based on the related Greek and international literature [6];
ii. Their weights came from a questionnaire sent to scientists such as foresters of forest services and employees of the Private Forest Technical offices;
iii. The absorbency criteria were divided into 3 categories: 1st forestry criteria, 2nd topographic criteria and 3rd social criteria. The first two categories are related to the terrain conditions and for the third one with the distance.

The weights of the ***forestry criteria*** are three (3) and these are: the kind of coverage, the forestry species, the forest management form, age (forestry form), the height of the trees, the site quality and the productivity of the forest, and these are analyzed extensively below.

The weights of each of the ***topographic criteria,*** as was calculated from the questionnaire, are two (2) and these criteria are: the cross slope of the ground, the aspect and the relief. They are analyzed extensively below.

The weights of the ***social criteria*** are one (1) and this is the distance from: a tourist resort, from the national and country road network, from a railway, from an archaeological site, from an adjacent big city, from an adjacent village, from a European path and from a natural or artificial lake or river. All these are analyzed in detail below.

The grading of these criteria depends on the following principle:

We accepted a situation as ideal (=100%) for the forest protection by road construction. The percentage of deviation from this ideal situation will be subtracted from 100%. The result will be the grading of the criteria.

To grade the criteria, aerial photographs and digital orthophotos of the area were used as well as the management plan, the forest map of the complex and the geological map. For the onsite measurements modern surveying instruments were used.

In detail ***the forestry criteria*** are the following:

1. *The kind of coverage* – the percentage of the road that crosses: a forest is graded with excellent 100; a wooded area, depending on the density, with 25-50; and a bare land with 15;
2. *The forestry species* – the percentage of the road that crosses: a mixed forest is graded with excellent 100; a conifer forest with 70; and a broadleaf forest with 50-80 depending on the season when measurements are carried out, that is if trees have leaves or not;
3. *The forest management form* – the percentage of the road that crosses: a seedling (high) forest is graded with excellent 100; a coppice forest is graded with 50 and a composited or middle form forest is graded with 75 to 100 depending on the seedling-coppice forest rate;
4. *Age (forestry form)* – the percentage of the road that crosses: a group-selective forest is graded with excellent 100, a selection forest with 75 and an even-aged forest with 50.
5. *The height of the trees – the* percentage of the road that passes among large trees >20m is graded with excellent 100; medium size trees 10-20m with 75 and small trees <10m with 25 to 50 depending on their height.
6. *The site quality* – good (first and second site quality), medium (third and fourth site quality) and poor (fifth and sixth site quality). The percentage of the road that crosses good site quality is graded with excellent 100, medium with 50 and poor with 25.
7. *The productivity of the forest:*
   - Category I: over $3m^3$/year/ha;
   - Category II: 1-$3m^3$/year/ha;
   - Category III: less than $1m^3$/year/ha.

The percentage of the road that crosses through forest of category I productivity is graded with excellent 100, forest of category II productivity with 50 and forest of category III productivity with 25.

In detail ***the topographic criteria*** are the following:

1. *The cross (transverse) slope of the ground* – the percentage of the road that crosses from gentle slopes <8% is graded with excellent 100, from moderate slopes 8%-20% with 50 and strong (intense) slopes >20% with 25 to 5, depending on the slope;
2. *The aspect* – the percentage of the road that crosses from an altitude less than 1000m with northerly aspect is graded with excellent 100, southerly with 50 and easterly aspect - westerly aspect with 75; the percentage of the road that crosses from an altitude over 1000m, with easterly or westerly aspect is graded with excellent 100, and northerly or southerly aspect with 70;

3. *The relief* – the percentage of the road that crosses through a mild relief is graded with excellent 100, a multifarious relief is a rich relief with continuous mountain ranges and deep ravines.

Social criteria depend on the number of people affected by the road. Distance plays a major role in impact, via:

1. *Distance from a tourist resort* – since tourism is seasonal and is very intense during the peak season, each kilometer of the distance from the resort increases grading e.g. distance 0-1 km is graded with 0, 1-2 km with 10, 2-3 km with 30 etc.;
2. *Distance from the national and provincial road network* (the same as with the resort);
3. *Distance from a railway line* - it has no direct impact but if one sees the road from the train, he/she might want to visit the forest soon by car. However, it has impact due to noise;
4. *Distance from an archaeological site* – the same grading as with the resort;
5. *Distance from an adjacent big city* – the same grading as with the resort;
6. *Distance from an adjacent village* – the same grading as with the resort;
7. *Distance from a European path every time the road crosses the path, its grading is reduced* – e.g. if it crosses the path once it is graded with 80, if twice with 60, 3 times with 40 etc.;
8. *Distance from a natural or artificial lake or river* - the same grading as with the resort).

The forestry and topographic criteria can be estimated digitally; while criteria 3, 4, 5, 6 and 7 from the forestry ones can be estimated from the management plan or by the terrestrial measurements. The social criteria are assessed with special software, displaying on the P/C screen what is observed from a different DTM point.

First, in order to calculate the mean absorbency value (C_A), we multiply the grading of each criterion (A) with its weight (W_A) and in the end we divide the sum of the products with the total sum of weights. This value is the mean absorbency value on a scale of 100 (%).

$$C_A = \frac{\sum (A \cdot W_A)}{\sum W_A} \qquad (1)$$

where:

C_A is the mean absorbency value, for matrix as size %.

A – the grading of each criterion, for matrix as size [%];

W_A – the respective weight coefficient, absolute number;

$\sum (A \cdot W_A)$ – the sum of the estimate absorbency multiplied with the respective weight coefficient, for matrix as size [%];

$\sum W_A$ – the sum of the weight coefficient values, absolute number.

3. Results and Discussion

From the assessment of the two alternatives of the same forest road by setting up measurable criteria the effect on the following environmental resources (components) were investigated: the fauna, the flora, the water capacity (water resources, water saving), the soil, the disturbance of soil and rocky lands, the landscape-physiognomy and the acoustic environment.

Fauna: Local temporary disturbances are expected during the construction phase while during the working operation phase; no impacts on the forest's roads are expected. Expression indicator is the occupation zone of forest roads in m^2/ha.

Flora: A permanent impact on the flora is expected during the construction phase due to loss of vegetation. The impact is expected to reduce over time due to the natural or artificial regeneration of the slopes on the forest roads, but a small degree of vegetation loss is expected during the phase of the working operation of forest roads. Expression indicator is the occupation zone of forest roads in m^2/ha.

Water capacity (water resource): The construction of forest roads is not expected to have large effects on the aquatic environment. Expression indicator is the volume of earth fills in m^3/ha.

Soil: A permanent loss of the soil layer is expected. The impact is expected to decrease over time, and it will be of limited extent during the operation phase as long as the appropriate measures are taken. Expression indicator is the occupation zone of forest road in m^2/ha.

Balance of soil and rocky lands: It is expected that, during the construction phase, rocks may become temporarily unstable in the earth fill; the slopes will be of limited importance during this phase. Expression indicator is the volume of earth fills in m^3/ha in combination with the height and the gradient of slopes.

Acoustic environment: Noise from the explosions and from machinery will temporarily affect the local fauna during construction. Expression indicator is the volume of rocky masses and the type and number of machines used for the implementation of the works.

Landscape-physiognomy: The physiognomy and the harmony of the micro-landscape will be adversely affected during construction due to the removal of vegetation which will take place during the phase of construction of the forest road and the surface layout. The impact is expected to continue beyond the phase of construction into the operational phase of the forest road but is expected to be limited. Expression indicator is the occupation zone in m^3/ha in combination with the created earth fills.

Table 1

Estimation and hierarchy of alternative solutions

Estimation Criteria	Z		Expression		Weight	E = B / Z		G × E	
	A	B	Indicator	Unit	(G)	A	B	A	B
Costs of construction	160	113	Cost	€	30	3	3.2	90	96
Forest landscape	140	104	Occupation zone	m^2/ha	20	2	2.5	40	50
Water Saving	35	28	Volume of earth fills	m^3/ha	15	2.1	3	31.5	45
Approximation	4600	3700	Length	m	35	0.2408	0.3610	8.43	12.6
Total Benefit Value								169.9	203.6
Hierarchy								2	1

Table 2

Absorbency criteria of the forest roads A and B in the forest area

	Absorbency Criteria	Weights	A [%]		B [%]	
			Grade	Sum	Grade	Sum
1	2	3	4	5 = 3 × 4	6	7 = 3 × 6
Terrain conditions						
	Forestry criteria					
1.	Kind of coverage	3	100	300	80	240
2.	Forestry species	3	100	300	100	300
3.	Forest management form	3	100	300	100	300
4.	Forestry form (age)	3	80	240	70	210
5.	Tree height	3	40	120	75	225
6.	Site quality	3	50	150	50	150
7.	Forest productivity (harvesting)	3	50	150	50	150
	Topographic criteria					
8.	Slope of ground	2	20	40	60	120
9.	Aspect	2	70	140	70	140
10.	Relief	2	100	200	80	160
Social criteria						
	Distance from					
11.	Tourist recreation area	1	90	90	90	90
12.	National or provincial road network	1	100	100	90	90
13.	Railway	1	100	100	100	100
14.	Archaeological site	1	100	100	100	100
15.	Adjacent big city	1	100	100	100	100
16.	Adjacent village	1	50	50	70	70
17.	European path	1	100	100	100	100
18.	Natural or artificial lake or river	1	40	40	100	100
Total		35		2620.00		2745.00
Absorption coefficient value: $C_A = \frac{\sum(A \cdot W_A)}{\sum W_A}$				74.86%		78.43%

Based on the expression indicators, the environmental resources were classified in two groups; those that are expressed by the occupation zone and with the criterion of the forest landscape, and those with the volumes of earth fills and with the criterion of water saving.

The following Tables 1 and 2 presents the estimation and hierarchy of alternative solutions and the absorbency criteria for the roads in the research area.

Table 1 shows the results of estimation and hierarchy of the alternative solutions (A and B). Solution (B) has the biggest benefit value (203.6) and is considered more advantageous than (A) with total benefit value (169.9). The selection of (B) is mainly due to its degree of fulfillment (transformation coefficient) (0.3610) which is bigger than (A).

Table 2 shows the estimated environmental impact of the two routes. The absorption coefficient (78.43%) of the solution (B) is bigger than (A) 3.5 unit about. This difference is due to kind of coverage, tree height, slope and adjacent village. So, because these differences and with regard to the differences in benefit-value analysis shown in Table 2 we consider solution (B) more advantageous.

4. Conclusions and Suggestions

The results of the alternative solutions and the selection of the B are in harmony with the willingness of the respondents (questionnaire) for a better approach to the area, with smaller costs and effects on the forest landscape. A small difference on the potential of absorption from the natural environment is shown by alternative A.

The impacts from the forest road are not considered significant. The most significant effect is upon the forest landscape-physiognomy of the area, as a result of the removal of flora and the surface of slopes.

Taking suitable measures such as the avoidance of unnecessary earth fills and large axial gradients, the construction of ditches and draining gutters as well as the use of machines friendly to the environment (e.g. excavators) will reduce the impacts on the natural resources and will increase the absorption of the proposed alternative solution.

It is very useful to have alternative road construction solutions clearly mapped out for comparison before road construction begins. These solutions should be based on the newest planning technique and according to the aims of forest infrastructure development, the terrain conditions and the protection of the forest ecosystem.

In sensitive ecological systems such as Mediterranean forest areas it is very important, from a technical and an economic design perspective, to have a realistic concept, within the framework of an environmental impact assessment (E.I.A.) or better ESCs (Environmental Standard Commitments).

It will very practical and useful for the assessment by the ESCs to have a list of serviceable criteria, and their weights to evaluate the absorption of road construction in order to make a profile for each forest road.

Multi-criteria evaluation (MCE) analysis (the implementation of decision-making rules to identify and enable the combination of many criteria, in the form of GIS layers, into a single map) and Geographic Information Systems (GIS) are two examples of tools that aid in the development of geographic data and maps for different purposes, such as conserving land for forestry uses and the quantitative and qualitative evaluation of the impact of the forest road on the environment.

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