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CHARTING AND EVALUATION OF AN EXISTING FOREST ROAD NETWORK'S IMPACT USING DIGITAL TERRAIN MODELS AND GIS

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Abstract: *The road network is a work of infrastructure, capable in contribution substantially in the sustainable development and exploitation of mountainous regions. Given the need to improve the Greek forest road networks taking into account the environmental component and the severe constraint on the natural resources needed to plan these improvements to target these efforts based upon the available information. In sustainable managed forests, roads, their network and technical specifications have to be in accordance with natural conditions and land uses, expected logging operations and landscape aesthetics.*

The principal objective of this research is the use and contribution of the digital terrain model and GIS for the charting and evaluation of the impacts of an already existing forest road network and their accuracy.

The results of this analysis, obtained by use of Geographical Information System (GIS), help the forest manager to allocate efficiently the resources to specific forest areas. The results are based on data that are easily obtained with GIS. The Forest Road construction deals with the study of setting out data and the construction of forest roads, which present particular requirements, while simultaneously they are of essential importance for the most excellent opening up of forests, the rational exploitation of these and development of sylviculture. Generally speaking the construction of roads ought to follow criteria that are necessary and capable in order to protect the environment and the viable or better sustainable development of a region. The existence of a compatibility control of a forest road with the natural environment is necessary, particularly when the road runs an area with steep terrain. Up to now forest roads which were constructed by the forest service improved their passage areas without creating big problems in the ecosystem.

1. Introduction

The road network is a work of infrastructure, capable in contribution substantially in the sustainable development and exploitation of mountainous regions. Given the need to improve the Greek forest road networks taking into account the environmental component and the severe constraint on the natural resources needed to plan these improvements to target these efforts based upon the available information. In sustainable managed forests, roads, their network and technical specifications have to be in accordance with natural conditions and land uses, expected logging operations and landscape aesthetics. Forest roads are used by non-forestry users free of charge. Besides its traditional productive task, the forest road should also provide several non-productive tasks, which are the consequences of the modern way of life.

The layout of a forest transportation network is a decision that commits technical feasibility of off-road transport and harvesting cost for a very long time. In flat terrain ground-based technology is the predominant approach to design forest harvesting systems. On steep slopes cable-based and aircraft-based technologies are often advantageous alternatives if the productivity of the forest is big. One of the most important problems of transportation planning in mountainous terrain is where to use ground-based or the alternatives ones extraction concepts. In Greece where the productivity is usually limited we basically used ground-based concept and only in a few area with big productivity and steep terrain we used cable-based technologies.

Optimizing road spacing is a problem in forest transportation planning which dates back to the classical work of Matthews (1942). Almost all the scientific work treating road spacing was carried out for flat terrain conditions considering specific off-road transportation technologies. In steep terrain Abegg's (1988) investigation seems to be the only attempt to differentiate ground- and cable-based transportation concepts. An analytical approach formulating road spacing models for steep slope conditions is investigated by Heinimann (1998).

The results of this analysis, obtained by use of Geographical Information System (GIS), help the forest manager to allocate efficiently the resources to specific forest areas. The results are based on data that are easily obtained with GIS. The Forest Road Construction deals with the study of setting out data and the construction of forest roads, which present particular requirements, while simultaneously they are of essential importance for the most excellent opening up of forests, the rational exploitation of these and development of sylviculture.

Generally speaking the construction of roads ought to follow criteria that are necessary and capable in order to protect the environment and the viable or better sustainable development of a region. The existence of a compatibility control of a forest road with the natural environment is necessary, particularly when the road runs an area with steep terrain. Up to now forest roads which were constructed by the forest service improved their passage areas without creating big problems in the ecosystem.

Development of a forest road network usually begins with selecting the routes. Pearce in 1960 defined as route a road line such as is projected on a map or aerial photograph or a reconnaissance or grade line run in the field. The route represents a narrow belt of land within which minor variations in gradient or alignment may be made during the preliminary or final location survey. Route selection traditionally starts with available topographic maps and aerial photographs of the study area. Manual techniques for projecting gradelines onto maps have been used for years and well documented in the international literature a long year before (Holmes, 1982; Pearce, 1960; USDA Forest Service, 1984; Stergiadis, 1984).

The researcher uses the map as a geometric model and attempts to select possible routes before resources are committed to costly field investigations. The researcher measures a series of coordinate points to establish a particular route on the geometric model and to calculate attributes of the route, such as grades, distances, sideslopes, cuts and fills. The attributes are used to compare alternative routes. By using a computer to convert terrain data from maps and photographs into digital form, the researcher can rapidly develop and evaluate many routes alternatives. After a DTM of the study area is produced, a researcher can superimpose any number of routes on it. The computer can automatically extract ground coordinates from the DTM and compute grades, distances, elevations and sideslopes along the routes and provide plan and profile plots of the routes in a fraction of the time needed do these tasks manually (Reutebuch, 1988). Burke (1974) was one of the earliest proponents of DTMs for harvest and transportation planning. Young and Lemkow (1976) developed several planning routines that rely on DTMs for terrain data.

The principal objective of this research is the use and contribution of the digital terrain model and GIS for the charting and evaluation of the impacts of an already existing forest road network and their accuracy.

2. Materials and method

The public forest of Kithairona located west of Athens at a distance of 60 km road from Egaleo nearby the boundaries of Boeotia prefecture. The public forest of Kithairona, extends to S - SE slopes of main ridge of the mountain Kithairona especially on the slopes of which are N, NW, W, of the town of Willis among the coordinates (Figure 1):

Latitude North 38° 11′ 30′′, South 38° 09′ 00′′
Longitude East 23° 23′ 00′′, West 23° 13′ 00′′

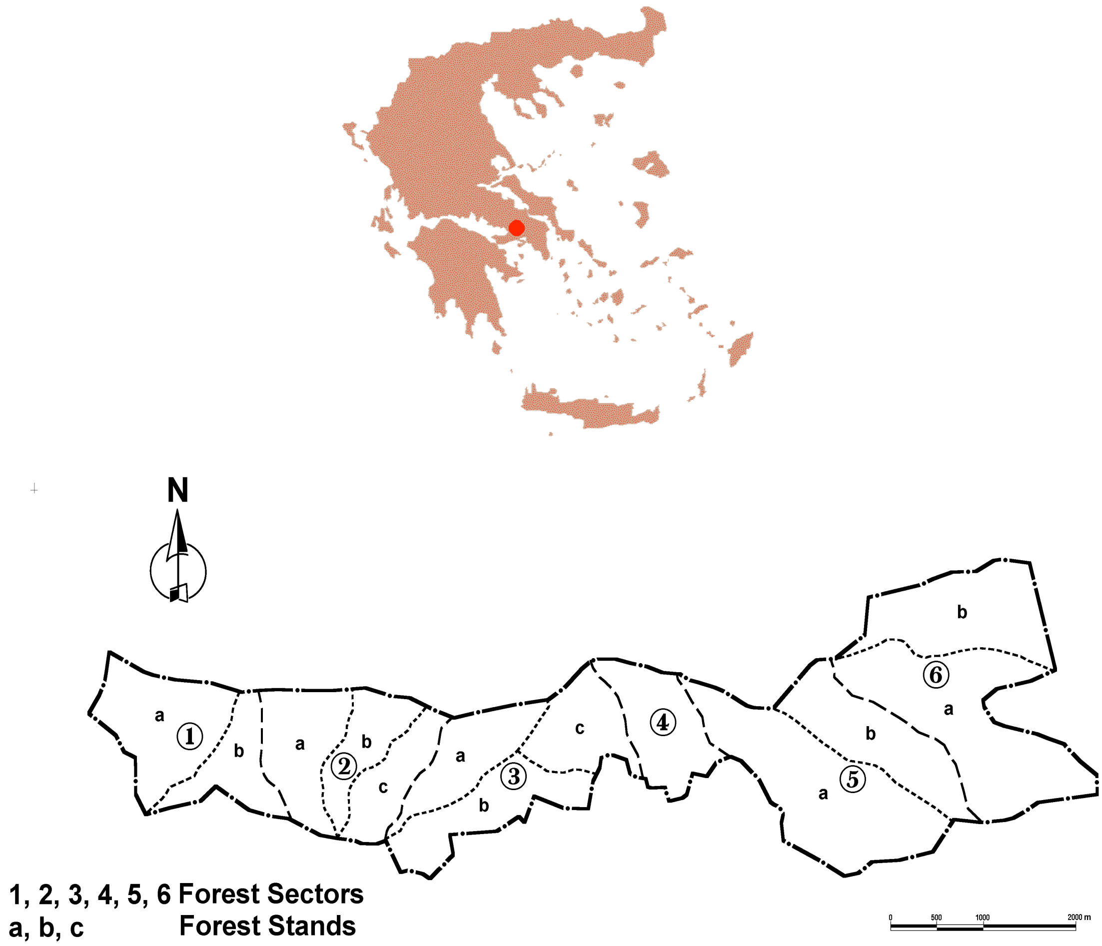

Figure 1. Reasearch area.

The work stages of the charting and evaluation of an existing forest road network are as follows:

1. Analysis of the existing forest road infrastructure by charting them on a digital map.

2. Evaluation the impacts of every forest road of the network by using digital terrain models, GIS, management plan and terrestrial measurements.

3. Checking the sustainability of the model with the evaluation of impacts on the environmental resources such as fauna, flora, water capacity (water resources, water saving), soil, disturbance of soil and rocky lands, landscape-physiognomy and acoustic environment.

4. Checking the accuracy of the digital terrain model and GIS data.

The first stage was as follows:

The topographic base map prepared by the general use map of Hellenic Geographic Service of the Army scale 1:50,000 from who has been digitized the contour lines, trigonometric and elevation points and transfers them to the HATT system.

Next was digitized the orthophotomap scale 1:20,000 and its geometrical correction in HATT system, followed by photo-interpretation, for the distinction and record of the forms of vegetation and land uses, the locating and mapping of roads and other data.

Finally, a completion and correction of the various data with an on-the-spot investigation has been done. Regarding to the soil data carried by soil maps scale 1:50,000 of the Ministry of Agriculture and the geological data from the geological maps of IGME (Institute of Geology and Mineral Exploration) scale 1:50,000.

The second stage was consisted of the evaluation of absorbency and intensity criteria as follows:

- As far as absorbency is concerned:

The ability of absorption of the forest ecosystem of the forest road construction work impacts 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.

The absorbency criteria and their weight came from a questionnaire sent to specialist scientists (Giannoulas et al., 2001). The absorbency criteria are divided into 3 categories: 1st forestry criteria, 2nd topographical criteria and 3rd social criteria. The weights of the criteria are: three (3) for the forestry criteria, two (2) for the topographical criteria and one (1) for the social criteria.

The criteria were: 1. Kind of covering; 2. Forestry species; 3. Management form; 4. Forestry form (age); 5. Height of trees; 6. Site quality; 7. Productivity; 8. Cross ground slope; 9. Aspect; 10. Relief; 11. Distance from: 11.1. Tourist resort; 11.2. National road network; 11.3. Railway; 11.4. Archaeological site; 11.5. Adjacent big city; 11.6. Adjacent village; 11.7. European path; and 11.8. Natural or artificial lake or river.

Criteria 1, 2, 8, 9 and 10 can be estimated digitally (Figure 2, 3 and 4); criteria 3, 4, 5, 6 and 7 are set based on the management plan or terrestrial measurements by stepping out the area were conducted to determine the size of criteria, while criteria from 11.1 to 11.8 are assessed with special software, displaying on the P/C screen what is observed from a different DTM point.

The absorption (A) of the forest ecosystem is multiplied by respective weight coefficient (W_A) and is divided by the sum of the weight coefficient values with a view to extract the barycentric mean:

$$C_A(\%) = \frac{\sum (A \times W_A)(\%)}{\sum W_A(\%)} \tag{2}$$

where $\sum(A \times W_A)$ and $\sum W_A$ are the sum of the absorption's estimate multiplied with the respective weight coefficient (W_A) and the sum of the weight coefficient values, respectively, for matrix as size %.

- As far as intensity is concerned:

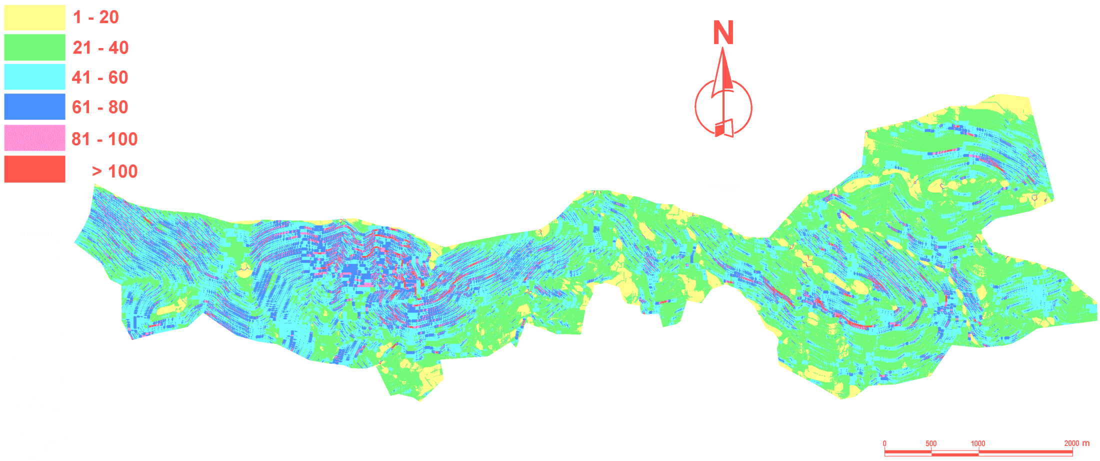

Figure 2. Slope map of the study area.

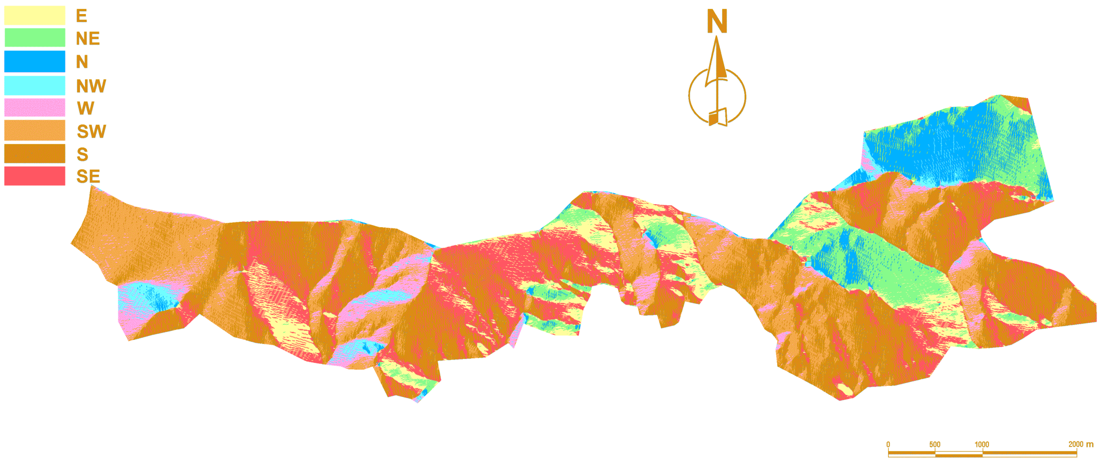

Figure 3. Aspect map of the study area.

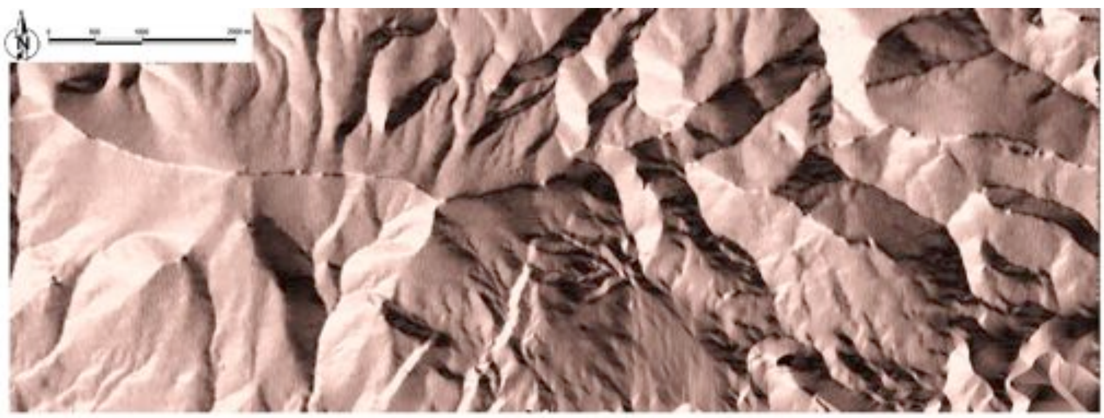

Figure 4. Relief map of the study area.

The intensity criteria have been set based on literature and the questionnaire. The questionnaire was drafted with the help of experts and literature and includes the impact intensity criteria. It was asked from the employees of forestry technical offices in Greece to evaluate the criteria and express their views and observations (Kotoulas, 1985, 1987; Ntafis, 1986; Mader, 1990; Zundel, 1990; Doukas, 1993; Sedlak, 1993; Becker, 1995; Doukas and Akca, 1999). This gradation depends on many parameters such as

(Koutsopoulos and Kophitsas, 1984): The effect period, the influence area, people's sensitivity and social and political desire.

The intensity criteria were divided in laying out criteria and construction criteria. The laying out criteria are the following:

1. Earthwork allocation.

1.1. The curve radius (the more it exceeds 25 meters the lowest the grading).

1.2. The laying out of the gradient (the highest the height discrepancy between the ground and the gradient over 0.5m, the lowest the grading).

1.3. The cross section (the largest the distance of the centre line and the section point of the road with the ground over 0.5m, the lower the grading depending on the discrepancy in meters).

2. The road gradient (the percentage of the road where the road gradient is not 3-12%, reduces the grading on a scale of 100).

3. The width of the road (the percentage of the road where the road width is different than 3.5m with widening every 250m, reduces the grading on a scale of 100).

4. The distance of serpentines (the less the distance between serpentines from 500m, the less the grading).

5. The distance of the forest road from a stream, from the forest boundary and from dangerous sites.

The percentage of the forest road that is located on a valley less than 10m from a stream bank reduces the grading on a scale of 100.

The percentage of the forest road that is located less than 10m outside the forest borders or less than 20m inside the forest borders, for aesthetic reasons, reduces the grading on a scale of 100.

The percentage of the road passing by a clay ground, large opening streams, unstable grounds, reduces the grading on a scale of 100.

6. The view of the forest road to morphological formations, vegetation, space projection, compatible constructions and water areas.

The percentage of the road where there are no morphological formations (no need to prevail), reduces the grading on a scale of 100.

The percentage of the road, where the visual field is not consisted of vegetation forms providing even a limited variety; uniform cultivation in the form of geographical shapes reduces the grading on a scale of 100.

The percentage of the road, where the visual field include no water flows and streams, even with limited visual interest and clarity (provided that they exist), is graded with a lower percentage on a scale of 100.
The percentage of the road, where the visual view does not focus on the forest and the assiduous forestry interventions, is graded with a lower percentage on a scale of 100.

7. The adaptation of the forest road in the environment. The percentage of the road, which is not visually concealed when observed from the opposite slope from a spot of the same altitude, is graded with a lower percentage on a scale of 100.

The construction criteria are the following: construction machinery, construction materials, the seeding and mulching of side slopes, technical works, drainage, supply (Becker, 1995).

8. Construction of forest road (only for existing road).

8.1. Machinery of earth works. The percentage of the road, where a hydraulic excavator has not been used on earthy grounds with ground slope over 60%, is graded with a lower percentage on a scale of 100.

The percentage of the road, where a hydraulic excavator has not been used on rocky grounds for fragment management, is graded with a lower percentage on a scale of 100.

The percentage of the road that has not been stabilized on a road gradient > 10%, is graded with a lower percentage on a scale of 100.

8.2. Material. The percentage of the road where the material of road surfacing is not taken from the site or does not consist of environmental-friendly recycled materials is graded with a lower percentage on a scale of 100.

Depending on the construction materials, if the road is gravel-paved, it is graded with a lower percentage on a scale of 100. If it is asphalted or if it bears other construction materials, it is graded with 50.

8.3. Seeding and mulching of side slope. The percentage of the road's side slopes, where on the embankments with slope near the corner of the natural side slope and ground slope of about 60 – 70%, natural or technical seeding and mulching has not been carried out, is graded with a lower percentage on a scale of 100.

8.4. Road drainage system. The percentage of road culverts that is not: a. Slab-roofed culverts in openings 3-4 meters wide b. Drain boxes on soil of poor bearing, 3-4 meter wide. C. Concrete pipes with embankment twice as large as the pipe's diameter, depending on the type and corner of bearing d. Stabilized stream beds with concrete (passages), is graded with a lower percentage on a scale of 100.

The percentage of the road retaining walls exceeding 3 meters in height is grade with a lower percentage on a scale of 100.

The percentage of exceeding the bridge's opening over 8 m. is graded with a lower percentage on a scale of 100.

The lack of drain dips (rills) across the surface at road gradient > 10% and length > 100 m., is graded with a lower percentage on a scale of 100.

The percentage of the main forest road where ditches on the road surface and the necessary sloping for its drainage lack is graded with a lower percentage on a scale of 100.

$$C_{\mathrm{I}}(\%)=\frac{\sum(\mathrm{I}\times W_{\mathrm{I}})(\%)}{\sum W_{\mathrm{I}}(\%)} \tag{1}$$

where $\sum(\mathrm{I} \times \mathrm{W}_{\mathrm{I}})$ and $\sum \mathrm{W}_{\mathrm{I}}$ are the sum of the estimate impact intensity multiplied with the respective weight coefficient (W_{I}) and the sum of the weight coefficient values, respectively, for matrix as size %.

The evaluation of all these parameters of absorbency and intensity will be difficult and therefore the description of an E.I.A. in a profile form will be a necessary addition.

The evaluation of impacts on the environmental resources such as fauna, flora, water capacity (water resources, water saving), soil, disturbance of soil and rocky lands, landscape-physiognomy and acoustic environment was taken place with on-the-spot observations.

The accuracy check of the digital terrain model and GIS data can only be carried out by checking the primary data that they have been derived.

3. Results

In figure 5 we can see the digital terrain model with the two forest roads.

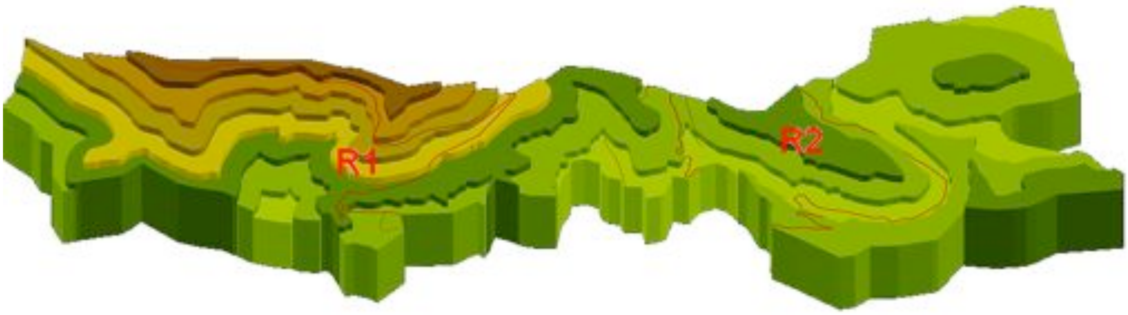

Figure 5. DTM of the study area with roads.

Table 1 shows the estimated environmental impact of the two roads. The absorption coefficient (C_A) 65.71% of the road (R1) is bigger than (R2) that is 48.43%. The intensity coefficient (C_I) 84.265% of the road R1 is bigger too, than R2 which is 76.54%. The compatibility coefficient for the R1 is 55.37% and for the R2 37.065%.

Evaluation of impacts on the environmental resources:

Fauna: No mentionable impacts are expected. Local temporary disturbances are expected during spring and summer where there are many passing drivers. Moreover, on the passage points and along the forest roads axis there are no indications of nest making or wildlife hibernation sites (birds or mammals). The sites estimated to fulfil the nesting conditions for some predators are far enough, on the rocky slopes, in the area. Consequently, there is no question of particular nuisance for the fauna and especially bird fauna.

Flora: A permanent impact on the flora is done during the construction phase due to loss of vegetation. The impact is reduced over time due to the natural or artificial regreasing of the slopes on the forest roads but we have a small degree of vegetation loss during the phase of the working operation of forest roads.

Water capacity (water resource): During the operational phase, the effect is considered as reversible with appropriate shaping of the pavement and the construction of draining works.

Table 1. Evaluation of forest roads R1 and R2

		R1		**R2**	
Criteria	**Weights**	**Grade %**	**Sum**	**Grade %**	**Sum**
a. Criteria of absorption (A)					
Terrain conditions					
1. Kind of covering	3	70	210	40	120
2. Forestry species	3	70	210	50	150
3. Management form	3	100	300	50	150
4. Forestry form (Age)	3	90	270	50	150
5. Tree height	3	75	225	35	105
6. Site quality	3	25	75	25	75
7. Forest productivity	3	25	75	25	75
8. Slope of ground	2	10	20	15	30
9. Aspect	2	75	150	55	110
10. Relief	2	15	30	15	30

11. Distance from					
11.1 Tourist resort	1	100	100	100	100
11.2. Highway	1	75	75	50	50
11.3. Railway	1	100	100	100	100
11.4. Archaeological sites	1	100	100	100	100
11.5. Town	1	100	100	100	100
11.6. Village	1	80	80	70	70
11.7. European path	1	80	80	80	80
11.8. Lake or river	1	100	100	100	100
b. Criteria of intensity (I)					
Laying out					
1. Earthwork allocation					
1.1. Curve radius	2.10	80	168	70	147
1.2. Gradient	2.01	60	120.6	80	160.8
1.3. Gross section	2.25	60	135	80	180
2. Road width	2.04	80	163.2	80	163.2
3. Road gradient	2.52	100	252	100	252
4. Serpentine	2.13	100	213	60	127.8
5. Position of road					
5.1. Distance of water flows	1.83	100	183	90	164.7
5.2. Distance of forest boundary	1.65	80	132	70	115.5
5.3. Area with construction problems	2.40	100	240	100	240
6. Picture of landscape					
6.1. Form of terrain	1.83	100	183	70	128.1
6.2. Vegetation	1.80	50	90	60	108
6.3. View effect	1.70	100	170	60	102
6.4. Compatible constructions	1.60	90	144	90	144
6.5. View of water flows	1.65	100	165	80	132
7. Visual absorption capability	1.77	100	177	60	106.2
Construction					
8. Construction of forest road (only for existing road)					
8.1. Machinery of earth works	2.16	50	108	50	108
8.2. Material	2.08	90	187.2	90	187.2
8.3. Seeding and mulching of side slope	1.38	70	96.6	70	96.6
8.4. Road drainage system	2.31	90	207.9	80	184.8

Soil: The impact on the ground during the phase of operation is focused on the erosion of the body of the forest road which is supported by the big lengthwise axial gradients and the surface of the slopes on the forest road. The impact is decreased over time and it will be of limited extent as long as the appropriate measures are taken.

Balance of soil and rocky lands: It is expected that, during the operation phase, rocks may become temporarily unstable in the earth fill; the slopes. This will be of limited importance.

Acoustic environment: During the phase of operation no impact is expected except from the noise of the passing cars.

Landscape-physiognomy: The physiognomy and the harmony of the micro-landscape will be adversely affected. This is due to a number of factors, inadequate organization and the implementation of restoration works, the regreasing of slopes, the gradual absorption of alterations by the broader landscape and the activity of natural processes.

The accuracy of the data is very good. As we investigate this in the paper entitled “Reliability control of digital images that are used in forest inventory and management in Greece” in the same Formec Symposium, we combine and check the results with on-the-spot observations and measurements.

Indicative data is that the mean square error is about 8.9 m in an orthophotomap scale 1:20,000 with dense foliage which is quiet well for the investigation goals.

4. Discussion – Conclusions

Based on the results, we notice that the road R1 under study is classified as acceptable, since its compatibility coefficient is 55.37%. But one other hand the road R2 under study is not acceptable, since its compatibility coefficient is 37.065%. As we can see for R1: C_I>50% and C_A>50%, the construction is accepted under no special conditions.

Regard to R2: C_I>50% and C_A<50%, the construction is accepted under conditions. As absorbency is the problem we can only improve the management and the forestry form where we can do it or to improve the covering and the forestry species with plantations through low-height shrubby vegetation.

Both forest roads are category C. Considering that the forest area is very small, the actual condition of the forest that is degraded with very low wood stoke and proposed management which does not look forward to wood production, but the protection, preservation and improvement of the forest.

General account of that torrent control-protective nature of the forest healthy, aesthetic, etc. effects, no specific restrictions on the management, beyond the need for a durable existence of forests, improvement and rational management, by cluster, according to the forestry and biological requirements of species that exist.

Apart from the torrent control-protective role of forests this very valuable and growing is the assessment of healthy, aesthetic character of the forest, both local residents and from the tourists who flock during the summer months in the region and in transit to Porto Germeno.

The area is a resort for Athenians and those who originate from there. The forest offers the beauty of the fir in the wider area covered with pine trees. Finally at the top of Kithairona provide remarkable views in every direction.

The view from the top of Kithairona is amazing. Can anyone see the Boeotia plain and Evia, Parnes and other mountains of Attica, the Saronic islands, the mountains of the Peloponnese, much of the Corinthian Gulf and Parnassus.
The existence road density is:

D_{ex} = 18,848 m / 1,582.5 ha = 11.91 m / ha
which is quiet well for a forest with torrent control-protective role according to the literature.

Forest stands 1a, 1b, 2a, 2b, 2c are not adequately served by the existing roads. One forest road may be started from the serpentine at the stands 2c and 3a with western direction to the western boundary of the studied forest would meet this need. The opening of the road under the prevailing local conditions will negatively affect the environment and cause damage on an already degraded forest.

The construction of another forest road a little bit lower outside of the fir forests in Aleppo pine (*Pinus Halepensis*) forest may be covering some needs of fir forest, while it would serve and the Aleppo pine forest.

Following the above does not suggest the construction of any road, but we believe that the opening in the area of a road should be considered in the reasoning developed above; the service of Aleppo pine and fir forests.

During the assessment of the consequences on the natural environment are presented failings, are due to the determination whole of the direct consequences, in expectation of future consequences and in objective assessment of the size of direct consequences.

It could be very useful to have alternative road construction solutions for comparison based on the new planning technique according to the aims of forest opening up, terrain conditions and the protection of the forest ecosystem, before the forest road constructed.

In sensitive ecological systems such as Mediterranean forest areas it is very important, from a technical and an economical design view, to have a realistic concept, within the framework of an Environmental Impact Assessment (E.I.A.)

The presence of an integrated and adequate road network ought to serve:
- Rational exploitation of forest.
- The transfer of personnel and equipment for operations at the forest.
- The transfer of materials for the exploitation of forests and construction of the Forest technical works.
- The immediate and rapid movement of the wood to local consumption or processing.
- Improving the protection of the forest and the performance of health, aesthetic and other effects of the forest, which concern all citizens.
- The needs of local residents in fuel, various rods, technical wood, etc.
- General coverage of the country's technical wood and fuel.
- The maintenance of pasture for livestock of the surrounding residents.

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