DOI: 10.20472/IAC.2015.017.092

STERGIOS TAMPEKIS
Department of Planning and Regional Development, University of Thessaly, Greece

FANI SAMARA
Department of Planning and Regional Development, University of Thessaly, Greece

STAVROS SAKELLARIOU
Department of Planning and Regional Development, University of Thessaly, Greece

ATHANASIOS SFOUGARIS
Department of Agriculture Crop Production and Rural Environment, University of Thessaly, Greece

OLGA CHRISTOPOULOU
Department of Planning and Regional Development, University of Thessaly, Greece

THE FOREST ROADS' ENVIRONMENTAL SUITABILITY BASED ON THE MULTI CRITERIA EVALUATION (MCE) METHOD AND THE CONTRIBUTION TO THE SUSTAINABLE DEVELOPMENT

Abstract:

The need for the "Sustainable Development" and at the same time the protection and preservation of the available natural assets has become a global concern. Forests constitute vulnerable ecosystems that change at great speed. In most of the occasions the change is downgrading. The right management of natural resources is the unique solution for the achievement of sustainable development. However, sustainable management of forests must be achieved with the respect and protection of nature and landscape. Sustainable management of forest resources can only be achieved through a well-organized road network compatible with the natural environment. This paper describes the forest roads' Environmental Suitability based on the Multi Criteria Evaluation (MCE) Method. With this method we present the spatial variability mapping for the optimal forest road network and the environmental impacts evaluation that are caused to the natural environment. With the use of the MCE method, we can assess the human impact intensity to the forest ecosystem as well as the ecosystem's absorption from the impacts that are caused from the forest roads' construction. For the human impact intensity assessment the criteria that were used are: the forest's protection percentage, the forest road density, the applied skidding means (with either the use of tractors or the cable logging systems in timber skidding), the timber skidding direction, the traffic load and truck type, the distance between forest roads and streams, the distance between forest roads and the forest boundaries and the probability that the forest roads come through unstable soils. In addition, for the ecosystem's absorption evaluation we used forestry, topographical and social criteria. The MCE method which is described in this study provides a powerful, useful and easy to use implement in order to combine the sustainable exploitation of natural resources and the environmental protection.

Keywords:

Environmental Suitability, forest roads' network, spatial variability, environmental impact, gis

JEL Classification: Q01, Q23, Q56

Introduction

Nowadays, the public awareness about the impacts of forest roads on the environment has been increased (Seiler, 2001; Cielo and Gottero, 2004; Coffin, 2007; Robinson *et al.,* 2010; Akay et al. 2012; Pellegrini, 2012). In order to achieve the sustainable management of the forests, environmental studies have to be defined based on scientific and technical studies (Makhdoum 2008). A well-organized road network is crucial for the sustainable management of forest resources (wood production, ecotourism, water supply, or soil conservation) (Calvani *et al.,* 1999; Gaodi *et al.* 2010). Furthermore, forest roads are recognized as a main source of sediment yield and pollution of off-site water and also ecological fragmentation and disturbance in forest landscapes (Laurance, 2001; Altrichter and Boaglio, 2004; Miles, 2006). Forest roads cause changes in the landscapes and losses in habitat and biodiversity (Jones *et al.,* 2000; Trombulak and Frissell, 2001; Havlick, 2002). Also, the forest road construction and maintenance operations are the most costly and destructive activities in forest operations (Liu and Sessions, 1993; Chung and Sessions, 2001). The forest road network planning for multiple objectives depends on three objective functions (life-cycle costs, adverse ecological effects, and landing attractiveness) (Stückelberger et al. 2006).

Therefore, a new method for the forest roads planning assessment that includes financial, ecological and social parameters has to be developed (Akay et al. 2008; Aruga et al. 2005; Dutton et al. 2005). Consequently, a functional approach of the forest roads planning and for the controlling of optimization of relative parameters (economic and environmental) is necessary (Eker et. al. 2013; Stückelberger, 2006).

An expert-based approach to the forest road network planning can be achieved by combining the Delphi method and the spatial multi-criteria evaluation. This methodology is useful in forest road planning because it takes under consideration environmental and cost parameters (Hayati et al. 2012). Additionally, the Application of Sensitivity Analysis is also a significant method in forest roads network planning and environmental impacts' assessment (Hayati et al. 2013). Likewise, the GIS-Based Multiple-Criteria Decision Analysis (MCDA) and the GIS-MCE based model for forest road planning are also methods in forest roads planning.

The MCE method is a fundamental approach for screening and selecting spatially differentiated decision variants (Beinat and Nijkamp 1998). In the MCE technique, an attempt is made in order to combine a set of criteria to achieve a decision according to a specific objective (Eastman et al. 1995). In the last fifteen years, much work has been directed toward integrating Geographic Information Systems (GIS) and MCE methods in the context of spatial decision support systems for planning, retail and services locations, land-based project selection, and environmental management (Eastman et al. 1993; Jankowski 1995; Malczewski 1999). Nevertheless, over the last 20 years spatial MCE has come to be recognized as an inextricable component of Spatial Decision Support System (SDSS) (Malczewski 2006). Integrating GIS-based data processing and analysis techniques and Multi-Criteria Decision analysis we move into the concept of Multi-Criteria Spatial Decision Support System (MC-SDSS) (Malczewski 1999). The advantage of MCE is that provides a flexible way of dealing with qualitative multidimensional environmental effects of decisions (Munda et al. 1995).

In order to assess the Environmental Suitability for forest roads' the intensity and the absorption criteria method could be used.

Materials and Methods

The MCE technique includes the evaluation of the intensity and absorption criteria in order to achieve the spatial variability for the optimal forest road network. We agreed on the optimal ecosystem forest protection status to be the 100%.

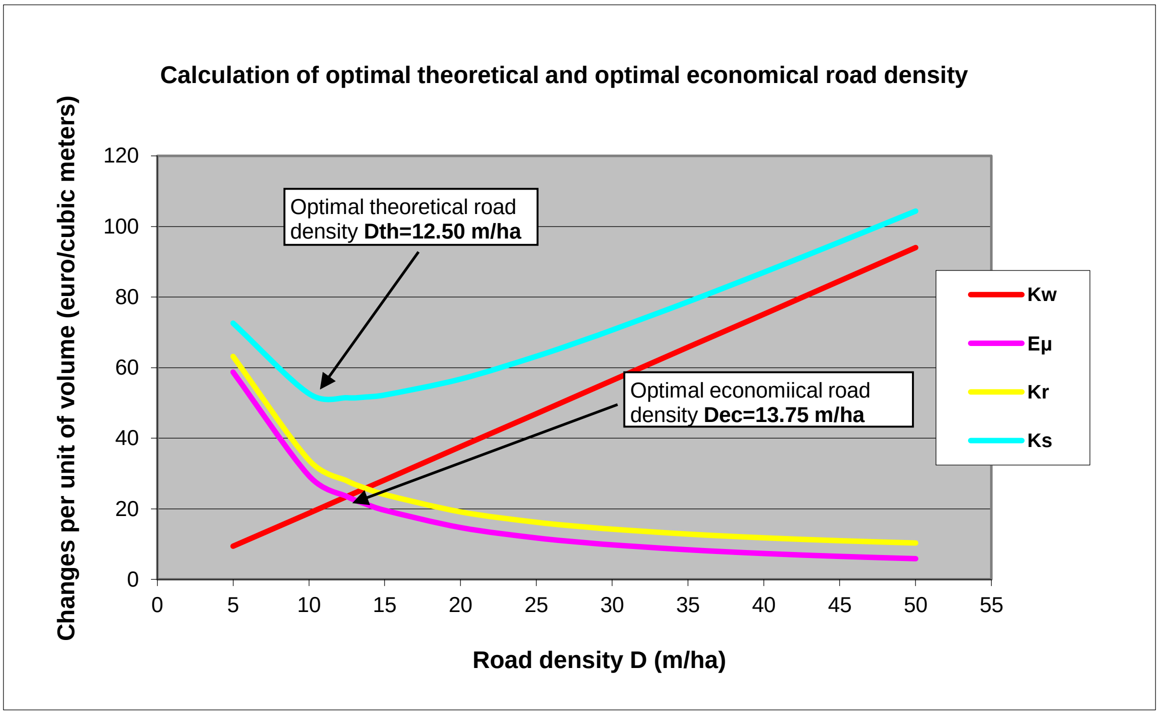
For the assessment of the intensity of the environmental impacts we used the criteria below (Doukas, 2004; Gianoulas, 2001). Each criterion is rated with a Weighting factor (based on experts' agreements) that represents the intensity value.

a) Intensity criteria in productive forests.

The intensity criteria that were used are:

I. Road Density. Logging means: Tractors. The excess percentage of Dec and Dmax is rated as the reduction of the optimum 100. The comparison of the existing road density Dex with the optimum theoretical Dth and the optimum economical road density Dec is based on their calculation applying the Kroth method (Bernetti, 1965; Kroth, 1973; Tan, 1992; Olsson, 2004; FESA, 2005; Tampekis, 2009; Pellegrini, 2012). Weighting factor: 3.

Figure 1. Equations of costs and road density. $K_W = K_B + K_R + K_{SU}$ is for the forest roads' total construction and maintenance (K_{SU}) costs. The construction costs are from the loss of territorial annuity (K_B) and the depreciation and capital interest that is invested for forest roads' construction (K_R). Kr is for the wood skidding costs and $K_S = K_W +$ Kr is for the total construction, maintenance and wood skidding costs.



Source: Tampekis, 2009

II. Use of tractors in skidding. The percentage of the use of tractors for skidding is rated as the reduction of the optimum 100. Weighting factor: 2.

III. Opening-up percentage. The reduction percentage of the forest opening-up from forest roads and tractor roads which is <70%, is rated as the reduction of the optimum 100. Weighting factor: 3.

IV. Skidding direction (horses, tractors, cable winches). The skidding direction percentage which is <45° comparing to the vertical to the road skidding, is rated as the reduction of the optimum 100. Weighting factor: 1.

V. Traffic load and truck type.

- The excess percentage of the traffic load, in comparison to the one that is justified from harvesting, is rated as the reduction of the optimum 100. Weighting factor: 2.
- The excess percentage due to truck overloading of the uniform truck loading according to the rules is rated as the reduction of the optimum 100. Weighting factor: 2.

VI. *Forest Roads' Location.*

- The forest roads' distance from the streams should be enough not to affect the forest ecosystem. The percentage of forest roads that pass through the valley and the distance from the margins of the stream is less than 10 m, is rated as the percentage reduction of optimum the 100 as given in the table below:

Table 1. Intensity evaluation rating due to the forest roads' distance from the streams.

Distance from streams (m)	Rate (%)
>10	100
5-10	50-100
0-5	0-50

Weighting factor: 3

- The percentage of the roads that pass through in less than 10 meters outside the forests' boundaries or 20 meters within the forests' boundaries is rated as the percentage reduction of the optimum 100. Weighting factor: 3
- Forest roads shall not be going through unstable soils where they may be slipping, sliding or have failures in the construction of embankments. The layout design rate of

forest road, passing through a clay soil, large exposures streams, unstable soils, is rated as a percentage reduction of the optimum 100. Weighting factor: 3

b) Intensity criteria in non-productive forests.

The intensity criteria that were used are:

I. ***Road Density and Forest Protection Percentage***. The percentage of the excess or the reduction of the values D=12.5-15m/ha, forest roads' spacing S=800m and the forest protection percentage which is < 85%, is rated totally as the reduction of the optimum 100. Weighting factor: 3

II. ***Applied Skidding Means.*** The percentage of the trees' skidding that aren't carried out with the use of cable logging systems or with draught animals or with the combination of them, is rated as the reduction of the optimum 100. Weighting factor: 2

III. ***Skidding direction (draught animals, cable logging systems).*** The skidding direction percentage which isn't achieved in diagonal or in parallel layout, comparing to the vertical road skidding (theoretical skidding distance), is rated as the reduction of the optimum 100. Weighting factor: 1

IV. ***Traffic load and truck type.***

- The excess percentage of the visitors' number, in comparison to the reception capacity of the space, is rated as the reduction of the optimum 100. Weighting factor: 2.
- The percentage of vehicles with a uniform load on the wheels largest than the permitted by the regulations is rated as the reduction of the optimum 100. Weighting factor: 2

V. ***Forest Roads' Location.***

- The forest roads' distance from the streams should be enough not to affect the forest ecosystem. The percentage of forest roads that pass through the valley and the distance from the margins of the stream is less than 10 m, is rated as the percentage reduction of optimum the 100 as given in the table below:

Table 2. Intensity evaluation rating due to the forest roads' distance from the streams.

Distance from streams (m)	Rate (%)
>10	100
5-10	50-100
0-5	0-50

Weighting factor: 3

- The percentage of the roads that pass through in less than 10 meters outside the forests' boundaries or 20 meters within the forests' boundaries is rated as the percentage reduction of the optimum 100. Weighting factor: 3
- Forest roads shall not be going through unstable soils where they may be slipping, sliding or have failures in the construction of embankments. The layout design rate of forest road, passing through a clay soil, large exposures streams, unstable soils, is rated as a percentage reduction of the optimum 100. Weighting factor: 3

The weighted average of the environmental impact intensity evaluation (ΣI), is equal to the sum of the products $\Sigma(I \times W_I)$ divided by the sum of the weighting factors (ΣW_I).

$$\Sigma I = \Sigma(I \times W_I) / \Sigma W_I \quad (1)$$

Where:

I= the criterion value assessment (%) that evaluates the impact intensity which is not negative,

W_I= the weighting factor of each intensity criterion

ΣW_I= the sum of the Weighting values of each intensity criterion

c) Absorption criteria.

The ability of the forest ecosystem absorption of the forest roads' impacts was also 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 evaluation criteria of absorption that were studied and the respective Weighting factors are:

I. ***Forestry Criteria***. Weighting factor: 3

- Land uses: Woodlands: 100%, Forest area: 25-50%, Barren: 15%.
- Forest species: Coniferous: 65%, Broad-leaved: 75%, Mixed 100%.
- Forest management form: High forest: 100%, Coppice forest 50%, Composite forest: 75-100%.

- Forest age: Even aged forest: 50%, Group-selective forest: 100%, Gardening forest: 75%.
- Tree height: High >20m: 100%, Medium 10-20m: 75%, Low <10m: 25-50%.
- Soil quality: I-II: 100%, III-IV: 50%, V-VI: 25%.
- Forest productivity (Harvesting): High >3 m^3/year×ha: 100%, Medium 1-3 m^3/year×ha: 50%, Low <1 m^3/year×ha: 25%.

II. *Topographical criteria.* Weighting factor: 2

- Slopes: High >20%: 5-25%, Medium 8-20%: 50%, Low <8%: 100%.
- Aspects:

- Elevations <1000m; Northern: 100%, Eastern: 75%, Western: 75%, Southern: 50%,

- Elevations ≥1000m; Northern: 70%, Eastern: 100%, Western: 100%, Southern: 70%,

- Terrain relief: Mild: 100%, Various: 50%, Intense (divided into many parts): 15%.

III. *Social Criteria (number of receivers).* Weighting factor: 1

- The tourist resort.
- The national road network.
- The railway network.
- The archaeological area.
- The neighboring city.
- The neighboring village.
- The European pathway.
- The natural or artificial lake or river.

The rating of the criteria above, depends on the number of people that accept the effect and is rated 25% if the receivers are many, 50% if the receivers are a few and 100% if there aren’t any.

The weighted average of the environmental impact absorption evaluation (ΣA), is equal to the sum of the products $\Sigma(A \times W_A)$ divided by the sum of the weighting factors (ΣW_A).

$$\Sigma A = \Sigma(A \times W_A) / \Sigma W_A \qquad (2)$$

Where:

A= the criterion value assessment (%) that evaluates the absorption,

W_A= the weighting factor of each absorption criterion,

ΣW_A= the sum of the Weighting values of each absorption criterion

Conclusions

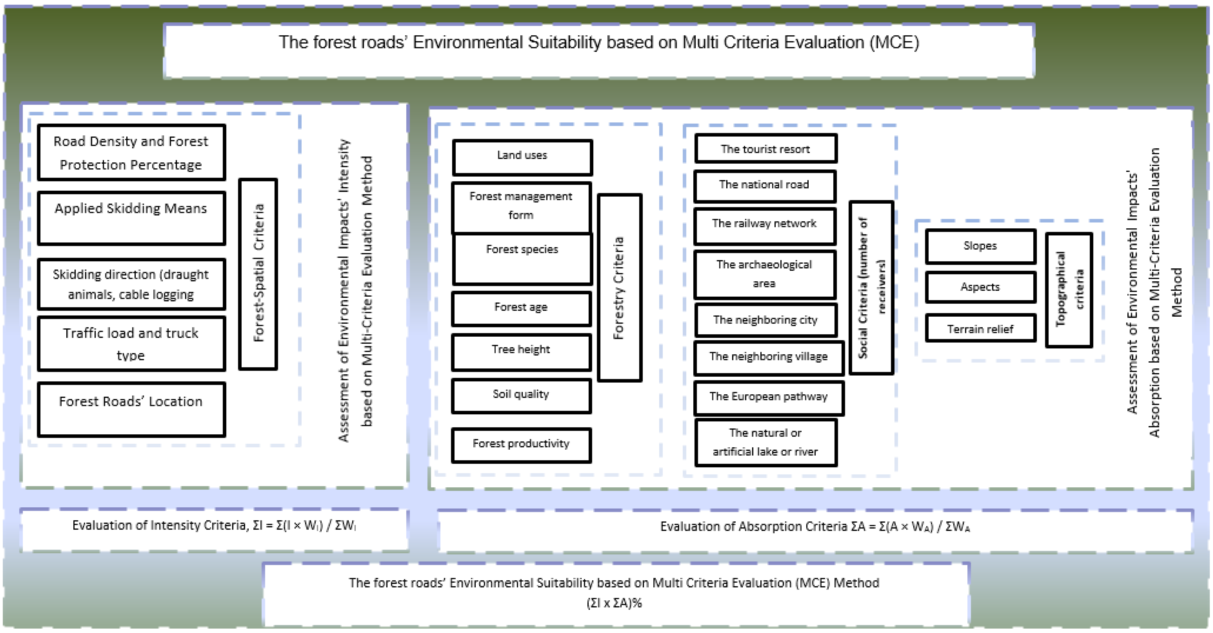
The development and the application of the mapping of the Environmental Suitability for the optimum forest roads’ network as well as the environmental impacts evaluation that are caused to the natural environment based on the MCE technique, with the use of the intensity and the absorption criteria evaluation is an innovative tool.

Consequently, with this method we will ensure the best protection and at the same time the sustainable exploitation of the forest resources.

Additionally, it will be valued if there are any impacts to the natural environment and if some of the forest roads had been constructed legally or not according to the guidelines.

This method plays a crucial role in the optimum solution selection (spatial, financial, forest, topographical, social and environmental) for the forest roads’ planning. It can also be customized to each areas’ particularities and to be applied for the creation of a new integrated decision support system (DSS).

Figure 2. Workflow of the forest roads’ Environmental Suitability based on the Multi Criteria Evaluation (MCE) for non-productive forests.



Acknowledgements

This research has been co-financed by the European Union (European Social Fund-ESF) and Greek national funds through the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF) - Research Funding Program: Thales. Investing in knowledge society through the European Social Fund.

References

AKAY, A. E., ERDAS, O., REIS, M. AND YUKSE, A. (2008). Estimating Sediment Yield from a Forest Road Network by Using a Sediment Prediction Model and GIS Techniques. Build. Environ., 43: 687–695.

AKAY, A. E., WING, M. G., SIVRIKAYA, F. AND SAKAR, D. (2012). A GIS-based Decision Support System for Determining the Shortest and Safest Route to Forest Fires: A Case Study in Mediterranean Region of Turkey. Environ. Monit. Assess., 184(3): 1391-1407.

ALTRICHTER, M., BOAGLIO, G.I., (2004). Distribution and relative abundance of peccaries in the Argentine Chaco: associations with human factors. Biological Conservation 116, 217–225.

ARUGA, K., SESSIONS, J., & AKAY, A. E. (2005). Heuristic planning techniques applied to forest road profiles. Journal of Forest Research-JPN, 10, 83–92.

BEINAT E. AND NIJKAMP P. (1998). Multicriteria analysis for land-use management. In. Beinat E. and Nijkamp P. (Eds). Multiple Criteria Decision Making: An Integrated Approach. Dordrecht, Kluwer. Academic publishers. pp. 253–270.

BERNETTI G. (1965). La rete stradale forestale come problema di assestamento. L'Italia Forestale e Montana, 20 (6): 261-267.

CALVANI, G. MARCHI, E. PIEGAI, F. TESI, E. (1999). Funzioni, classificazione, caratteristiche e pianificazione della viabilità forestale per l'attività di antincendio boschivo. L'Italia Forestale e Montana 54 (3):109-125.

CHUNG, W., & SESSIONS, J. (2001). Designing a Forest Road Network using Heuristic Optimization Techniques, Council on Forest Engineering (COFE) Conference Proceedings: "Appalachian Hardwoods: Managing Change" Snowshoe, July 15-18, 2001.

CIELO P., AND GOTTERO F. (2004). Piano della viabilità. Finalità, analisi ed elaborati. Sherwood, 10 (10): 33-38.

COFFIN, A.W. (2007). From roadkill to road ecology: a review of the ecological effects of roads. Journal of Transport Geography, 15, 396-406.

DOUKAS, K., (2004) Forest Works and Natural Environment. Publications Giahoudi, Thessaloniki, 227-310.

DUTTON, A. L., LOAGUE, K. AND WEMPLE, B. C. (2005). Road Sediment Production and Delivery: Processes and Management. Earth. Surf. Proc. Land, 30: 325-338.

EASTMAN J. R., KYEM P.A.K., TOLEDANO J., AND JIN W., (1993). GIS and Decision Making. Vol. 4, Explorations in Geographic Information System Technology Geneva, UNITAR Faber B, Watts.

EASTMAN J.R., JIN W., KYEM P.A.K., TOLEDANO J., (1995). Raster Procedures for Multi-Criteria / Multi-Objective Decisions. Photogrammetric Engineering & Remote Sensing vol. 61 (5): 539-547.

Eker, M.,& Coban, H.O. (2010). Impact of road network on the structure of a multifunctional forest landscape unit in southern Turkey, Journal of Environmental Biology, ©Triveni Enterprises, Lucknow (India) January 2010, 31, 157-168.

FESA. (2005). South African Forest Road Handbook. http://www.icfr.ukzn.ac.za/collaboration/forest-engineeringsouthern-africa/fesa-publications/

GAODI, X., WENHUA, L., YU, X., BIAO, Z., CHUNXIA, L., KAI, A., JIXING, W., KANG, X., & JINZENG, W. (2010). Forest ecosystem services and their values in Beijing. Chinese Geographical Science. 20(1), 51–58.

GIANOULAS, V. (2001). Forest opening-up with modern machinery. Technico-econmic, environmental effects. Ph.D. Thesis, Aristotle University of Thessaloniki.

HAVLICK, D.G. (2002). No place distant: roads and motorized recreation on America's public lands. Island Press, Washington, DC. 297 p.

HAYATI E, MAJNOUNIAN B, ABDI E, SESSIONS J, MAKHDOUM M. (2012). An expert-based approach to forest road network planning by combining Delphi and spatial multi-criteria evaluation. Environmental Monitoring and Assessment, Volume 185, Issue 2, pp 1767-1776, Springer Publications.

HAYATI E, MAJNOUNIAN B, ABDI E, SESSIONS J, MAKHDOUM M. (2013). An expert-based approach to forest road network planning by combining Delphi and spatial multi-criteria evaluation. Environmental Monitoring and Assessment, February 2013, Volume 185, Issue 2, pp 1767-1776, Springer Publications.

JANKOWSKI, P. (1995). Integrating geographical information systems and multiple criteria decision making methods. International Journal of Geographical Information Systems 9: 251–73.

JANKOWSKI, P., LIGMANN-ZIELINSKA, A., SWOBODZINSKI, M. (2008). Choice Modeler: A Web-based Spatial Multiple Criteria Evaluation Tool. Transaction in GIS. 12(4), 541-561.

JONES, J.A., SWANSON, F.J., WEMPLE, B.C., SNYDER, K.U., (2000). Effects of roads on hydrology, geomorphology, and disturbance patches in stream networks. Conservation Biology 14, 76–85.

LAURANCE, W.F., (2001). Tropical logging and human invasions. Conservation Biology 15, 4–5.

KROTH, W. (1973). Entscheidungsgrundlagen bei Walderschlieflungsinvestitionen. Forstwissenschaftliches Centralblatt December 1973, Volume 92, Issue 1, pp 132-151.

LIU, K., & SESSIONS, J. (1993). Preliminary planning of roads using digital terrain models. Journal of Forest Engineering, 4, 27–32.

MAKHDOUM, M.F. (2008). Landscape ecology or environmental studies (Land Ecology). Journal of International Environmental Application & Science. 3(3), 147–160.

MALCZEWSKI, J. (1999). GIS and Multicriteria Decision Analysis. New York, John Wiley and Sons.

MALCZEWSKI, J. (2006). GIS-based multicriteria decision analysis: a survey of the literature. International Journal of Geographical Information Science 20 (7), pp. 703–726.

MILES, M. (2006) Deer Counts 2003–2005. Email communication with attached spreadsheet sent 7/25/06. State Farm Insurance, USA.

MUNDA, G., NIJKAMP, P., RIETVELD, P. (1995). Qualitative multi-criteria methods for fuzzy evaluation. European Journal of Operational Research. 82(1), 79–97.

OLSSON, L., (2004). Optimisation of forest road investments and the roundwood supply chain. Department of Forest Economics Umea, Doctoral thesis, Swedish University of Agricultural Sciences Umea, 2004, Acta Universitatis agriculturae Sueciae. Silvestria, 1401-6230; 310. ISBN 91-576-6544-3, Doctoral thesis.

PELLEGRINI, M. (2012). Support tools for planning and management of a forest road network. (Tesi di dottorato), http://paduaresearch.cab.unipd.it/4454/1/TESI_PhD_PELLEGRINI.pdf, ttp://paduaresearch.cab.unipd.it/4454/.

ROBINSON, C., DUINKER, P.N., AND BEAZLEY. K.F. (2010). A conceptual framework for understanding, assessing, and mitigating ecological effects of forest roads. Environmental Reviews, 2010, Vol. 18, No. NA : pp. 61-86.

SEILER, A. (2001) Ecological Effects of Roads, A Review. Introductory Research Essay, Volume 9, Department of Conservation Biology, SLU Uppsala.

STÜCKELBERGER, J.A. (2006): GIS-gestützte Erschliessungsplanung [GIS-based road network planning]. In: Bündnerwald [Journal of Forest Service, Canton of Grisons, Switzerland], (3), pp. 19–24.

STÜCKELBERGER, J.A., HEINIMANN, H.R., CHUNG, W. AND ULBER, M. (2006). Automatic road-network planning for multiple objectives. In: Chung, W. and Han, H.S. (Eds.). The 29th Council on Forest Engineering, 233–248.

TAMPEKIS, S., (2009). The compatibility of the forest opening-up works with the natural environment, for the development of the mountainous region of Metsovo," Ph.D. dissertation, Dept. Forestry and Natural Environment, Aristotle University of Thessaloniki, Greece.

TAN, J., (1992). Planning a forest road network by spatial data handling-network routing system, Soc. of Forestry in Finland, 1992, Vol. 227, Acta forestalia Fennica, ISSN 0001-5636.

TROMBULAK, S.C., AND FRISSELL, C.A. (2001). Review of ecological effects of roads on terrestrial and aquatic communities. Conserv. Biol. 14(1): 18–30. doi:10.1046/j.1523-1739.2000.99084.x.