Forestry application of the AHP by use of MPC© software

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Abstract

We present an example of the application of the AHP decision-making approach to forest management, by use of MPC© 2.0 software. The example considered is that of a forest services company interested in buying a timber harvester. The company had preselected four different machines as possible alternatives, and established 11 different criteria involved in the decision, grouped into four categories (economic, environmental, social and technical). The decision-making process was undertaken using MPC© 2.0 software tools, which enable establishment of criteria on two levels, independent pairwise comparison of criteria (first phase) and of alternatives under each criterion (second phase), repetition of the decision-making process by the same or different users, graphical display of the results on the computer screen, and sensitivity analysis.

Key words: decision making; criteria; alternatives; multi-criteria decision analysis.

Resumen

Aplicación forestal del método AHP de toma de decisiones mediante el software MPC©

En este trabajo se presenta un ejemplo de aplicación a la gestión forestal del método AHP de toma de decisiones mediante el software MPC© 2.0. Se considera el ejemplo de una empresa de servicios forestales interesada en adquirir una procesadora para la corta de madera, habiendo preseleccionado cuatro diferentes máquinas como posibles alternativas, y estableciendo 11 diferentes criterios implicados en la decisión, agrupados a su vez en cuatro categorías: económicos, ambientales, sociales y técnicos. Se presentan con el ejemplo las utilidades del programa MPC© 2.0, entre las que destacan la posibilidad de establecer un esquema de criterios en dos niveles, la realización independiente de la comparación por pares de criterios (primera fase) y de alternativas bajo cada criterio (segunda fase), la posibilidad de incluir diferentes repeticiones de la decisión por un mismo o diferentes usuarios, un interface gráfico para la exposición de los resultados y el análisis de sensibilidad de los mismos.

Palabras clave: toma de decisiones; criterios; alternativas; análisis multicriterio.

Introduction

Nowadays the use of complex decision-making tools is essential in forestry, as many criteria must be taken into account, including economic, social, environmental and technical factors. Such criteria should comprise the basis of any pilot study, project or forest management decision for it to be considered as sustainable.

The difficult task of decision making is made even greater by the need to evaluate numerous criteria at the same time, together with different alternatives under the same aim (Altuzarra *et al*., 2000), and also taking into account the possible existence of different types of criteria (qualitative and quantitative) as well as the time and costs involved in the process (Tam *et al*., 2006).

The use of different techniques for multi-criteria analysis is justified in this context (Tam *et al*., 2006). A thorough review of different methods of multi-criteria analysis and their application to the management of natural resources is provided by Mendoza and Martins (2006). One of the most widely used of these methods in diverse fields throughout the world is the Analytic Hierarchy Process (AHP), developed by Saaty (1980).

The AHP is largely based on pairwise comparison of the criteria in a decision tree, and of comparison of each of the alternative levels of each criterion, by use of an established scale (Saaty, 1990; 1996). The method has been evaluated in numerous studies, e.g. by Schoner and Wedley (2007), Carmone *et al*. (1997), Altuzarra *et al*. (2000) and Zanazzi (2003). The widespread application of the AHP to decision making in diverse fields of knowledge throughout the world (see e.g., Oddershede *et al*., 2005) includes applications in forestry, e.g. by Gadow and Bredenkamp (1992), Schmoldt *et al*. (2001), Coulter *et al*. (2003), Kangas and Kangas (2005), Kangas *et al*. (2008), Kurtilla *et al*. (2000) and Pukkala and Kangas (1993, 1996).

The use of computer techniques is particularly important to facilitate practical application of the AHP, by automating the mathematical calculations involved. Although there are several software programmes available (e.g. Expert Choice 11.5, www.expertchoice.com), we present a new programme, denominated MPC© (*Método de Pares de Comparación*, in Spanish), which facilitates use of the AHP. We also describe an example of the practical application of version 2.0 of the programme to a real forest management case.

The MPC© software programme, version 2.0, has been designed and developed to facilitate the decision-making process in response to the need for a competitive programme that can be used for automating analysis, calculation and storage of databases, with the aim of promoting research in this type of multi-criteria analysis, the associated sensitivity analysis and the specific application of these in forest management.

Methods

The AHP

The Analytic Hierarchy Process developed by Saaty (1980; 1990) briefly consists of the following steps: (i) Hierarchical representation or decomposition of a problem separated into three levels, with the objective in level 1, the criteria involved in the decision making (structured, or not, into different hierarchical levels) in level 2, and all of the possible alternatives in level 3. (ii) Estimation of priorities (weights) amongst criteria (level 2) using pairwise comparisons with the aid of a scale. (iii) Estimating the weights of the alternatives (level 3) for each criterion, also in pairs and using the same scale. And (iv) Selection of the best alternative.

The degree of consistency (*CR* or Consistency Ratio) in the pairwise comparisons (steps ii and iii) can be established mathematically, and according to Saaty (1990), Zeshui and Cuiping (1999) and Raharjo *et al*. (2001), if $CR > 0.1$ then results are inconsistent, and if $CR \leq 0.1$ it will be consistent or logical.

MPC© software

Although there are numerous software programmes on the market that facilitate the application of the AHP, a relatively new programme, MPC© version 2.0 (Pérez-Rodríguez and Rojo, 2010), was applied in the present study. This software was developed by the authors of the present study so that the cost of application was zero and control over the calculations was total, as in this case all elements of the software were accessible at all times, and could be adapted to the needs of the study.

MPC© 2.0 includes the following characteristics:

a) Automated AHP methodology, including the possibilities of dividing the criteria into two hierarchical levels, and independent comparison of each pair, which facilitates automation of the comparisons and focuses attention on the pair being compared.

b) Own database or capacity to create independent databases, which involved feedback of the weights under a temporal factor.

c) Possibility of participation of up to 40 users: facilitates comparison of the results obtained by several users for the same decision.

d) The possibility of carrying out up to 100 repetitions per user.

e) Simple user interface: easy to learn and apply so that decision makers can dedicate their time and effort to the pairwise comparisons, without distraction from other elements. To minimize the cognitive bias in the pairwise comparisons, several studies have been taken into account, such as those by Biederman and Cooper (1992), Chun and Cavanagh (1997), Treisman and Kanwisher (1998), Henderson and Hollingworth (2003) and Hollingworth (2007).

f) To use the software, the user simply selects an already created decision or introduces a new decision in a local programme database or in another independent database that can be created with the software. Once the decision has been loaded or created, the user can proceed to compare the criteria or the alternative levels of each criterion. Once the evaluations have been made,

the user can access the graphical display of the weights. The user also has the option of adding repetitions that they think are useful, as well as adding other decision makers. The general results are obtained after all the evaluations of the criteria are made to interact with all the evaluations of the alternatives, or the repetitions that the user has selected. It is also possible to obtain the mean weights for the criteria.

g) Once the overall results are obtained, the user can carry out a sensitivity analysis, varying the weights obtained for the criteria, in accordance with the results reported by Triantaphyllou and Sánchez (1997) and by Wijnmalen and Wedley (2009), and can observe the variation produced in the graph of the overall results.

Application to an example concerning selection of forestry machinery

As a practical example of the application of the method, we have chosen a specific decision in a forestry context. The case is that of a small-medium sized forestry management business that wishes to acquire a timber processing machine. Such machines are generally expensive, so that the decision can be classified as complex because of the initial and posterior costs involved.

The objective of the decision making process was to evaluate all possible alternatives under certain criteria, so that selection of the machine would be optimal

and take into account relevant factors in addition to the initial cost of the item. In others words the decision would also take into account other costs, manageability, contamination, safety, etc.

The set of criteria taken into account in selecting one type of machine or another in the example was as shown in Table 1, divided into two levels (with principal criteria and other sub-criteria associated with these).

Furthermore, the alternatives proposed for a case such as this should be the alternatives that are available in the working area (to buy). The following four machines were considered in the example:

1) Sampo Rosenlew 1066 (distributed by Forestal Soft S.L., technical information available at www.forestalsoft.com).

2) Komatsu Forest/ Valmet 911.3 (distributed by Hitraf S.L., technical information available at www.hitraf.com).

3) Excavator + processing head (distributed by Forestal Soft S.L., technical information available at www.forestalsoft.com).

4)) Adapted agricultural tractor + processing head (distributed by Hitraf S.L., www.hitraf.com).

Once the criteria and alternatives were established, the decision structure was loaded into the MPC© 2.0 programme. An expert then carried out the pairwise comparisons of the criteria and then the pairwise comparison of the alternatives under each criterion. To

Table 1. Weights and inconsistencies (in parenthesis) obtained in the pairwise comparison, in four repetitions of the criteria and subcriteria. Std dev: Standard deviation for the weights

| Criteria | Repetitions | | | | Std dev. |
	1	2	3	4	
Economic	0.27 (0.092)	0.26 (0.106)	0.30 (0.108)	0.24 (0.069)	0.029
Initial cost	0.14 (0.014)	0.15 (0.056)	0.10 (0.105)	0.10 (0.105)	0.021
Maintenance costs	0.24 (0.014)	0.27 (0.056)	0.21 (0.105)	0.21 (0.105)	0.026
Consumption	0.62 (0.014)	0.61 (0.056)	0.68 (0.105)	0.69 (0.105)	0.031
Social	0.05 (0.092)	0.05 (0.106)	0.12 (0.108)	0.14 (0.069)	0.035
Contamination	0.14 (–)	0.17 (–)	0.25 (–)	0.25 (–)	0.056
Safety	0.86 (–)	0.83 (–)	0.75 (–)	0.75 (–)	0.056
Environmental	0.11 (0.092)	0.09 (0.106)	0.07 (0.108)	0.08 (0.069)	0.017
Mineral erosion	0.75 (–)	0.75 (–)	0.75 (–)	0.75 (–)	0.040
Effects on plant substrate	0.25 (–)	0.25 (–)	0.25 (–)	0.25 (–)	0.040
Technical	0.56 (0.092)	0.59 (0.106)	0.51 (0.108)	0.54 (0.069)	0.074
Yield	0.40 (0.156)	0.26 (0.271)	0.46 (0.106)	0.46 (0.106)	0.098
Manageability	0.19 (0.156)	0.36 (0.271)	0.17 (0.106)	0.17 (0.106)	0.092
Size	0.11 (0.156)	0.09 (0.271)	0.10 (0.106)	0.10 (0.106)	0.008
Mobility	0.30 (0.156)	0.30 (0.271)	0.27 (0.106)	0.27 (0.106)	0.086

increase the accuracy of the results, the evaluation of the criteria was repeated four times and of the alternatives, three times.

Results

The results obtained for the criteria weights and the inconsistencies in the pairwise comparisons are shown in Table 1. The values were determined by a single expert with a wide knowledge of forest machinery, in four repetitions.

For the decision maker, the main criterion was the *technical* criterion, although there were inconsistencies (values > 0.1) in the sub-criteria into which this criterion was divided. However, the results obtained in this case were not highly dispersed, so that it can be assumed that although inconsistent, the combination of

results is homogeneous. With respect to the other criteria, all were consistent, or very close to being so.

The comparisons for each criterion with respect to the alternatives, weights and inconsistency values obtained in the three repetitions are shown in Table 2.

It can be seen, for example, that for the criterion *Initial cost*, the decision maker generally preferred the first alternative, the Sampo Rosenlew 1066 forest harvester, followed by the adapted agricultural tractor + processing head.

The result of the matrix calculation (i.e. multiplying the weights of the alternatives by the weights of the criteria) is the matrix of weights in each of the alternatives (Table 3). This table includes the results provided by MPC© 2.0, i.e. the different possible combinations of the weights of the criteria and of the alternatives, obtained in the different repetitions, as well as the mean

Table 2. Weights and inconsistencies (in parenthesis) of each of the four alternatives (machines) under each criterion in three repetitions

Criteria	Sampo Rosenlew 1066			Komatsu Valmet 911.3			Excavator + head			Adapted agricultural tractor + head		
	Repetitions			Repetitions			Repetitions			Repetitions		
	1ª	2ª	3ª	1ª	2ª	3ª	1ª	2ª	3ª	1ª	2ª	3ª
Economics												
Initial cost	0.519	0.555	0.473	0.201	0.079	0.122	0.079	0.097	0.122	0.201	0.252	0.283
	(0.015)	(0.015)	(0.052)	(0.015)	(0.015)	(0.052)	(0.015)	(0.015)	(0.052)	(0.015)	(0.015)	(0.052)
Maintenance	0.463	0.375	0.473	0.096	0.125	0.122	0.169	0.125	0.122	0.273	0.375	0.283
	(0.106)	(0)	(0.052)	(0.106)	(0)	(0.052)	(0.106)	(0)	(0.052)	(0.106)	(0)	(0.052)
Consumption	0.439	0.543	0.365	0.124	0.076	0.099	0.124	0.136	0.172	0.313	0.245	0.365
	(0.020)	(0.069)	(0.053)	(0.020)	(0.069)	(0.053)	(0.020)	(0.069)	(0.053)	(0.002)	(0.069)	(0.053)
Social												
Contamination	0.473	0.365	0.375	0.122	0.099	0.125	0.122	0.172	0.125	0.283	0.365	0.375
	(0.052)	(0.053)	(0)	(0.052)	(0.053)	(0)	(0.052)	(0.053)	(0)	(0.052)	(0.053)	(0)
Safety	0.081	0.067	0.097	0.418	0.426	0.384	0.283	0.372	0.291	0.217	0.134	0.228
	(0.039)	(0.040)	(0.052)	(0.039)	(0.040)	(0.052)	(0.039)	(0.040)	(0.052)	(0.039)	(0.040)	(0.052)
Environmental												
Mineral erosion	0.312	0.300	0.365	0.062	0.100	0.099	0.312	0.300	0.172	0.312	0.300	0.365
	(0)	(0)	(0.053)	(0)	(0)	(0.053)	(0)	(0)	(0.053)	(0)	(0)	(0.053)
Effects on plant substrate	0.300	0.300	0.300	0.100	0.100	0.100	0.300	0.300	0.300	0.300	0.300	0.300
	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Technical												
Yield	0.097	0.099	0.099	0.291	0.365	0.365	0.384	0.365	0.365	0.228	0.172	0.172
	(0.052)	(0.053)	(0.053)	(0.052)	(0.053)	(0.053)	(0.052)	(0.053)	(0.053)	(0.052)	(0.053)	(0.053)
Manageability	0.375	0.375	0.397	0.125	0.125	0.103	0.125	0.125	0.103	0.375	0.375	0.397
	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Size	0.375	0.375	0.375	0.125	0.125	0.125	0.125	0.125	0.125	0.375	0.375	0.375
	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Mobility	0.300	0.389	0.357	0.100	0.069	0.083	0.300	0.153	0.161	0.300	0.389	0.399
	(0)	(0.015)	(0.039)	(0)	(0.015)	(0.039)	(0)	(0.015)	(0.039)	(0)	(0.015)	(0.039)

Table 3. Final results (weights) for the combination of the repetitions of evaluation of the criteria and the repetitions of the evaluation of the alternatives

Combinations of weights for the criteria and for the alternatives		Alternatives			
Repetition Criteria	Repetition Alternatives	Sampo Rosenlew 1066	Komatsu Valmet 911.3	Excavator + head	Adapted tractor + head
1	1	0.27	0.23	0.17	0.31
1	2	0.28	0.21	0.17	0.33
1	3	0.30	0.20	0.17	0.32
2	1	0.30	0.18	0.16	0.33
2	2	0.27	0.21	0.16	0.31
2	3	0.32	0.23	0.16	0.35
3	1	0.29	0.19	0.20	0.34
3	2	0.26	0.21	0.19	0.32
3	3	0.29	0.24	0.19	0.29
4	1	0.27	0.22	0.20	0.31
4	2	0.27	0.23	0.20	0.30
4	3	0.29	0.21	0.20	0.30
Mean:		29%	21%	18%	32%
Standard deviation:		2.02%	1.83%	1.64%	1.96%

values and standard deviations, which in this case indicate the preference for alternative 4 (adapted agricultural tractor + processing head), followed by alternative 1 (Sampo Rosenlew 1066 forest harvester).

As well as selecting the best alternative, the results of the final matrix calculation also help to hierarchize the criteria according to the relative degree of importance in the decision, as shown in Table 4. In this case, the most important criteria were *technical*, followed by *economic*.

The decision maker may or may not agree with the result obtained, and hierarchization of the criteria serves as a basis for a sensitivity analysis. With the MPC© 2.0 software, the decision maker can vary the weight of each of the criteria, adjusting them to (in their opinion) more appropriate values, and graphically observing (in real time) how the results vary with the change. The sensitivity analysis enables the decision maker to test whether the result obtained is consistent (i.e. if there is little variation in the results) or flexible (i.e. if the hierarchy varies greatly on modifying the weights of the criteria), which helps the decision maker to justify the decision taken, or to emphasize those criteria that may be critical to the decision.

An example of sensitivity analysis that can be carried out with MPC© 2.0 software is shown in Figure 1, in which the weights originally obtained for each alternative are compared with the weights obtained by increasing the weight of the *economic* criterion by 10%.

Tabla 4. Relative ranking of criteria

Criteria:	
Technical	55.00%
Economic	26.75%
Social	9.50%
Environmental	8.75%

Subcriteria	
Yield	21.73%
Consumption	17.39%
Mobility	15.68%
Manageability	12.24%
Safety	7.18%
Mineral erosion	6.56%
Maintenance costs	6.22%
Size	5.50%
Initial Cost	3.28%
Effects on plant substrate	2.19%
Contamination	1.82%

In this case the initial differences between alternatives 4 and 1 would be reduced, thus complicating the selection of one or the other.

Conclusions and recomendations

The AHP is applicable to the field of forestry in which multiple criteria for different types of alternatives often must be taken into account. It is therefore
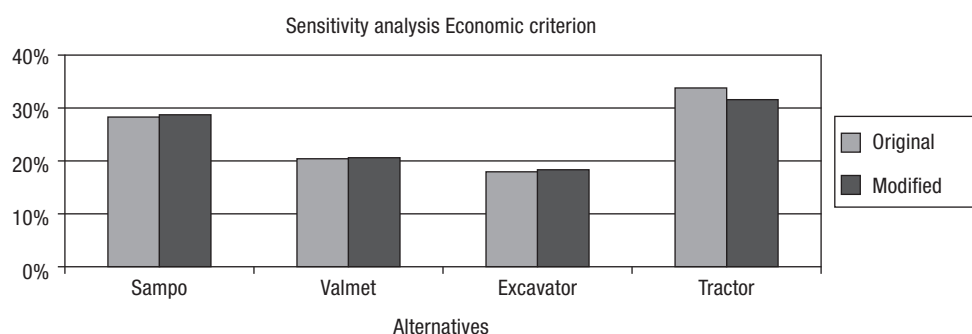
Figure 1. Example of sensitivity analysis. Result of increasing the weight of the economic criterion by 10%.

possible to evaluate the weight or importance of the alternatives and the criteria in a more or less simple way, particularly when the criteria are difficult to quantify mathematically, thus providing a much greater analytical capacity than a simple questionnaire.

However, the functioning of this method must be understood, as wrong application may lead to an erroneous decision. It is therefore essential to take into account the number of criteria so that the evaluation is as brief as possible, considering the importance of the criteria in previous evaluations and defining the number of participants and repetitions so that the result obtained is as objective as possible. In addition, the environment where the evaluation is carried out should be controlled, as this will affect development of the process and the validity of the results.

The different computer programmes available are essential for applying the AHP, as the method involves multiple calculations and a large amount of data handling. MPC© version 2.0 is a tool with a great analytical power, and includes all of the elements required for the user to reach the most appropriate decision in terms of the purposes and objectives of the decision. In addition, this software serves as an analytical tool for the study of this method, with the aim of incorporating new functions, particularly in terms of skewed judgements, or even in the search for relationships between criteria, between alternatives and between both of these to improve the sensitivity analysis.

The results obtained in this example are derived from very few repetitions, as the objective of applying the method was to demonstrate and test the capacities of the software in a real case. Detailed analysis of the entire process, from the start until obtaining the final weights, allows separate recommendations of each of the various aspects involved, as below.

Number of repetitions analyzed

Successive repetitions of the same evaluation of criteria and alternatives are very useful, especially when the decision maker is not experienced in using the Saaty scale (Saaty, 1980). In general, and from the experience acquired in this and other applications, the inconsistency decreases gradually from the first evaluation, because the decision maker becomes better at adapting the scale to his/her opinion. Moreover, the behaviour of each criterion can be observed and recorded in successive repetitions, as the dispersion of the weights of each one can be analyzed. MPC© 2.0 uses databases, so that a decision may be evaluated successively by the same decision maker, so that each of the evaluations represents a repetition.

Number of decision makers participating in the decision

When faced with a complex decision, for added validity, a group of experts should participate in making the decision, so that different points of view are taken into account in evaluating the decision under the same objective. In the example shown, the results obtained were derived from the evaluations made by only one expert, so that it would be useful to extend the procedure to other experts to determine any common points, or on the other hand, any discrepancies. MPC© 2.0 can include up to 40 decision makers for each decision, and these individuals can join the process at any time they choose.

However, when several people are involved in making a decision, each of the criteria under evaluation must be defined in detail, so that there are no errors in interpretation, which may results in differences in the weights obtained.

Control of the evaluation conditions

It is recommended that any factors affecting the decision maker should be taken into account, such as the time of starting and finishing the evaluation, the existence or otherwise of causes of distraction (telephone calls, noise, etc.), as well as the degree of stress, anxiety, tiredness, boredom, amongst others. This information will complement the results obtained, and can be used as the basis for establishing the reliability of a series of weights determined by a particular decision maker.

Number of criteria/alternatives

The AHP is very sensitive to the number of criteria and alternatives relative to the number of pairs that must be evaluated, and this is directly related to the time that the decision maker must invest in finishing a repetition. It has been found in some practical applications of this method that very long processes lead to loss of concentration by the decision maker, and therefore to high levels of inconsistency and notable dispersion of the weights. Therefore, in developing the latest version of the MPC© software, the stages of qualifying the criteria and alternatives have been separated, so that they can be carried out independently.

Rejecting criteria/alternatives from an already evaluated scheme

Once a set of criteria has been evaluated, a high degree of dispersion in the weights of one or more of the criteria may be observed, or the inconsistencies in successive repetitions may not decrease until becoming consistent. In such cases, MPC© 2.0 allows these criteria to be omitted from the proposed set. Mathematically, this operation is carried out by setting the value of such criteria to zero and distributing the initial weights among the others. However, in some cases, this may not be appropriate as decision makers may vary their opinions in regard to a particular criterion, depending on what it is compared with, so that in such cases we recommend repeating the entire decision. We therefore recommend carrying out some initial qualification tests to determine a useful set of criteria, as it would be impractical to handle criteria that display inconsistency. All of the above, regarding the possibility of omitting criteria from a decision that has already been evaluated, also applies to the alternatives.

Introducing criteria/alternatives in the structure already evaluated

Unlike in the previous case, introducing a new criterion in a decision that has already been evaluated is very complicated because of the irreversibility of the pairwise comparisons. It may be feasible to include the new criterion in the non-normalized comparison matrix, although it would then be necessary to determine whether evaluation of the weights of the other criteria would vary proportionally on inclusion of another new criterion. Moreover, in terms of the software, as little information as possible should be stored in the databases, to favour the rapidity of the process, so that saving the data in the comparison matrix is rather impractical. As in the previous case, we recommend carrying out an initial evaluation to determine whether the proposed criteria and alternatives are consistent with the decision in question.

Finally, the version 1.0 of the MPC© software can be downloaded free of charge from the following website http://www.usc.es/uxfs/ of the "*Unidade de Xestión Forestal Sostible*" (UXFS) research group, University of Santiago de Compostela.

Acknowledgements

References

Altuzarra A, Moreno JM, Salvador M. 2000. Medidas de influencia para los juicios en el proceso analítico jerárquico (AHP). Proc XIV Reunión ASEPELT-España, Oviedo (Spain), June 22-23.

Biederman I, Cooper EE. 1992. Size invariance in visual object priming. Journal of Experimental Psychology: Human Perception and Performance 18, 121-133.

Carmone FJ, Kara A, Zanakis S. 1997. A Monte Carlo investigation of incomplete pairwise comparison matrices in AHP. European Journal of Operational Research 102, 538-553.

Chun MM, Cavanagh P. 1997. Seeing two as one: Linking apparent motion and repetition blindness. Psychological Science 8, 74-79.

Coulter ED, Sessions J, Wing MG. 2003. An exploration of the Analytic Hierarchy Process and its potential for use in forest engineering. Proc Council on Forest Engineering, Bar Harbor, Maine (USA), September 7-10.

Gadow KV, Bredenkamp B. 1992. Forest management. Academica, Pretoria, South Africa. 151 pp.

Henderson JM, Hollingworth A. 2003. Eye movements and visual memory: Detecting changes to saccade targets in scenes. Perception & Psychophysics 65(1), 58-71.

Hollingworth A. 2007. Object-position binding in visual memory for natural scenes and object arrays. Journal of Experimental Psychology: Human Perception and Performance 33, 21-47.

Kangas J, Kangas A. 2005. Multiple criteria decision support in forest management. The approach, methods applied, and experiences gained. For Ecol Manage 207, 133-143.

Kangas A, Kangas J, Kurttila M. 2008. Decision Support for Forest Management. Springer Science. 221 pp.

Kurtilla M, Pesonen M, Kangas J, Kajanus M. 2000. Utilizing the analytic hierarchic process (AHP) in SWOT analysis - a hybrid method and its application to forest-certification case. Forest Policy and Economics 1, 41-52.

Mendoza GA, Martins H. 2006 Multi-criteria decision analysis in natural resource management: A critical review of methods and new modelling paradigms. For Ecol Manage 230, 1-22.

Oddershede A, Arias A, Cancino H. 2005. Rural development decision support using analytic hierarchy process. Proc ISAHP 2005, Honolulu, Hawaii (USA), July 8-10.

Pérez-Rodríguez F, Rojo A. 2010. Apply the AHP by new free software called MPC for take decisions in forest Management. Proc XXIII IUFRO World Congress, Seoul (Korea), August 23-28.

Pukkala T, Kangas J. 1993. A heuristic optimization method for forest planning and decision-making. Scand J For Res 8, 560-570.

Pukkala T, Kangas J. 1996. A method for incorporating risk and risk attitude into forest planning. Forest Science 42, 198-205.

Raharjo J, Halim S, Wanto S. 2001. Evaluating comparison between consistency improving method and resurvey in AHP. Proc ISAHP 2001, Berne (Switzerland), August 2-4.

Saaty TL. 1980. The Analytic Hierarchy Process. Planning priority setting, resource allocation. McGraw-Hill, New York (USA). 287 pp.

Saaty TL. 1990. Decision making for leaders. The Analytic Hierarchy Process for decision in a complex World. University of Pittsburgh. RWS Publications, Pittsburgh (USA). 292 pp.

Saaty TL. 1996. Ratio scales are fundamental in decision making. Proc ISAHP 1996, Vancouver (Canada), July 12-15. pp. 146-156.

Schmoldt DL, Kangas J, Mendoza GA, Pesonen M (eds.). 2001. The Analytic Hierarchy Process in natural resource and environmental decision making. Kluwer Academic Publishers, Dortrecht (Netherlands). 335 pp.

Schoner B, Wedley W. 2007. Ambiguous criteria weights in AHP: Consequences and solutions. Faculty of Business Administration, Simon Fraser University, Burnaby, B.C. (Canada), VSA IS6.

Tam CM, Tong TKL, Chiu GWC. 2006. Comparing non-structural fuzzy decision support system and analytical hierarchy process in decision-making for construction problems. European Journal of Operational Research 174, 1317-1324.

Treisman AM, Kanwisher NG. 1998. Perceiving visually presented objects: recognition, awareness and modularity. Current Opinion in Neurobiology 8, 218-226.

Triantaphyllou E, Sánchez A. 1997. A sensitivity analysis approach for some deterministic multi-criteria decision making methods. Decision Sciences 28(1), 151-194.

Wijnmalen DJD, Wedley WC. 2009. Correcting illegitimate rank reversals. Proper adjustment of criteria weights prevent alleged AHP intransitivity. Journal of Multi-Criteria Decision Analysis 15, 135-141.

Zanazzi JL. 2003. Anomalías y supervivencia en el método de toma de decisiones de Saaty. In: Problemas del Conocimiento en Ingeniería y Geología (Godoy LA, ed), Vol. I. Editorial Universitas, Córdoba (Spain). pp. 148-170. [In Spanish].

Zeshui XM, Cuiping W. 1999. A consistency improving method in the Analytic Hierarchy Process. European Journal of Operational Research 116, 443-449.