COMPARING THE OUTPUT OF COST BENEFIT AND MULTI CRITERIA ANALYSIS WHEN APPLIED TO URBAN TRANSPORT INVESTMENTS

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Abstract

The aim of this work is to compare the outcome associated with the classical Cost Benefit Analysis and a Multi Criteria assessment for a transport project, when considering some aspects that were not taken into account when the economic valuation was carried out.

The Multi Criteria method applied in this case was based on the Analytic Hierarchy Process (AHP). Two methods were used to derive the weights needed for the AHP: the pairwise comparison and an approach based on utility functions combined with the Stated Preference technique. Different levels of information about the project were provided to people.

Results show that people were indeed sensitive to the information provided about the project. No major differences were obtained when using alternative methods to derive the weights. The outcome of the Multi Criteria method did not match the suggested one by the Cost Benefit analysis, but it did match the final decision by the authority.

An important conclusion has to do with the fact that decision-making process needs to incorporate formally other aspects into the assessment, apart from the economic ones. Furthermore, public opinion should be taken into account explicitly into the decision making, particularly when information regarding projects that will affect them can be provided accurately and timely.

Keywords: Cost benefit analysis; Multi criteria; Analytic hierarchy process; Stated preference; Decision making

Topic Area: E1 Assessment and Appraisal Method w.r.t. Transport Infrastructure Projects and Transport Activities

1. Introduction

Cost benefit analysis (CBA) has been widely used to support the decision making process in transport. The consideration of non-economic variables into the analysis, such as noise, accidents, air pollution and so on, has put some troubles into the application of CBA. Multi criteria decision making has appeared as an alternative to CBA to deal with these problems. One of the most used and well known multi criteria techniques is the Analytic Hierarchy Process (AHP), developed by Saaty in the late 70s (Saaty, 1977).

The AHP consists of decomposing the decision problem in a hierarchy, of criteria, sub criteria, attributes and alternatives. This hierarchy is combined with a set of weights. These weights reflect the relative importance of the hierarchy components, and it will finally allow the decision-maker to look for the best compromise solution.

The aim of this work is to compare the results associated with the application of CBA and the AHP for a transport investment decision process in a urban context, when considering some aspects that were not taken into account when carrying out the economic valuation. The CBA application was already developed by a public agency, whilst the AHP application was undertaken as part of a research project. Two methods were used to calculate the weights needed for the AHP. Different levels of information about the project and its impacts were provided to people to test for changes on weights due to this fact.

Results show that people were indeed sensitive to the available information about the project. This might affect the output of the decision process, when using public participation as an input of the decision making process. Some differences were obtained when using alternative methods to derive the weights, but they were not dramatic. The multi criteria ranking of options did not match the suggested ranking by the CBA, which was based upon economic ground alone. The ordering did match the chosen option by the authority.

A main conclusion from these results is that the decision making process needs to incorporate formally other aspects, apart from the economic ones, to support this process. Furthermore, public opinion should be taken into account explicitly into the decision making, particularly when information regarding the projects that will affect them can be provided by the authority accurately and timely.

The article has been organised as follows. The theoretical background associated with the CBA and the AHP are shown in section 2, whilst a description of the project under consideration is reported in section 3. Main results of the research are provided in section 4 whereas conclusions are given in the last section.

2. Theoretical background

The goal of social appraisal is the maximisation of social welfare. According to this, social appraisal should consider all those variables that are relevant for the welfare of a country and its society. As part of the assessment process, positive and negative benefits must be identified and valued. A period of assessment and an interest rate have to be defined, such that indicators of social profitability can be calculated. The project that satisfies certain conditions on the indicators will be the chosen one. The Cost Benefit Analysis is a perfect application of the economic assessment framework, allowing the comparison of different projects, based upon the same unit of measurement (Pearce and Nash, 1981).

The economic valuation of certain items is quite straightforward, such as the travel time and fuel consumption, and there have been developed a set of procedures for their valuation. However, this valuation process gets more complicated when there are no markets for certain items, such as noise, air pollution, visual intrusion, and so on. In many cases there are value judgements related to these valuations, making things even more complicated (Pearce and Nash, 1981).

Over the last decade, there has been an important development on techniques that might allow the decision-maker the valuation of those goods without an explicit market. Examples of these developments are the contingent valuation method and the stated preference technique (Tinch, 1995; Bateman and Willis, 1999; Bateman et al., 2002; Rizzi and Ortuzar, 2003). These developments have allowed the measurement of the willingness to pay for preserving and visiting recreation sites, the reduction of air pollutants, and the reduction of accident risk. The results of these estimations might be incorporated later into the classical CBA since they would be measured in a common monetary unit

All previous measures correspond to subjective valuations, implying that some adjustments might necessary for their incorporation into the social appraisal framework. It is well known that subjective valuation might differ from social one (Tinch, 1995). An issue not always considered into CBA emerges due to this fact, and has to do with public participation into the decision making process. Multi criteria assessment appears appropriate in this case, since it might allow the decision-maker an explicit consideration of people's opinion about certain aspects, such as the social importance of visual intrusion, for instance.

2.1. Multi criteria assessment

In real life, it is not easy to find a decision-making problem with only one goal. When there are several goals and there is a trade-off between them, then multi criteria techniques are appropriate. According to Zionts (quoted in Tudela (1998)), multi criteria methods can be classified depending on the nature of the decision problem restrictions: implicit or explicit, and the nature of the results: deterministic or random.

When there are implicit constraints, the multi criteria analysis will consist of choosing an alternative among a set of finite and known options. The analysis will be based on the attributes that describe the options, and the importance of the criteria involved into de decision process. There are several methods that might be applied to this type of discrete multi criteria problems: the Multi Attribute Utility theory, the Electre and Promethee procedures and the Analytic Hierarchy Process. This article will focus on the Analytic Hierarchy Process (AHP).

2.2. The analytic hierarchy process (AHP)

The AHP was developed by Saaty (1977) and consists of decomposing a complex decision making process into a hierarchical structure, similar to a probability tree, with nests, levels and links between levels. At the top of the hierarchy will be the main goal. Hanging from this goal will be the secondary criteria. From these criteria might be hanging other sub criteria. This decomposition procedure goes until the penultimate level of the hierarchy. At this level will be the attributes that will describe better and in detail the decision process. The bottom level of the hierarchy contains the discrete options under consideration (see figure 1). The construction of this hierarchy might require the involvement of experts, decision-makers and takers, and general public.

A set of weights is required to proceed with the analysis. These weights represent the relative importance of the criteria, sub criteria and attributes belonging to a specific nest in the hierarchy. According to the original procedure developed by Saaty, these weights are obtained from pairwise comparison matrices, for each nest in the hierarchy.

Once weights are available, the hierarchical structure is collapsed, following a folding back procedure. For each option under study, there will be a final weight. These final weights are used to rank the options.

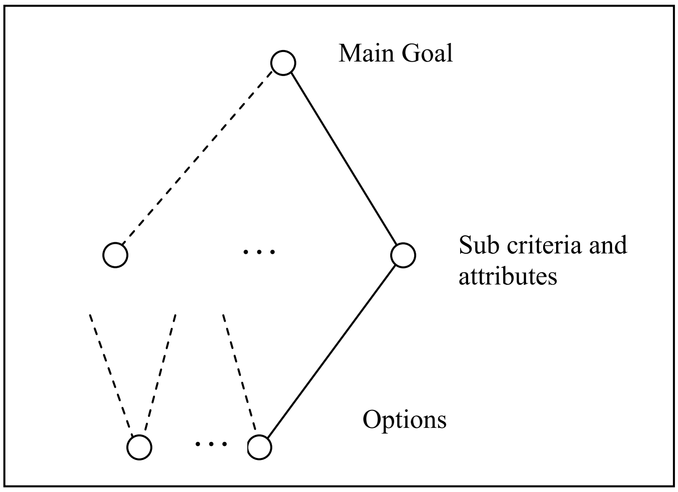

Figure 1: Hierarchy of criteria, attributes and alternatives

2.3. Weights calculation

Saaty's original method to calculate the weights was based on the pairwise comparison matrix. This comparison gives the relative importance of the elements belonging to the same nest in the hierarchy. These comparisons between elements can be represented through a squared matrix, A, whose structure is as follows

$$A = \begin{pmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ . & . & \dots & . \\ . & . & \dots & . \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{pmatrix} \qquad (1)$$

where

$$a_{ij} = \frac{1}{a_{ji}} \quad , \quad \forall i, j = 1, 2, \ \dots, n$$

$$\text{and} \quad a_{ii} = 1, \quad \forall i = 1, 2, \ \dots, n$$

Saaty (1990) recommends the use of a 9 points scale to assess the relative importance between elements. For this scale, 1 implies that both elements are equally important, whilst 9 would imply that one of the elements would be extremely more important than the other one.

Once the matrix has been obtained, through an interview to people or decision-makers, corresponds the calculation of a normalised vector of weights. There would a vector of weights for each nest in the hierarchy. The dimension of the vector would be n, which is the number of elements in the nest. These weights, wi, can be calculated through a normalisation process of any of the columns in matrix A, as shown in equation 2 (Saaty, 1990)

$$wi = \frac{aij}{\sum_{k=1}^{n} akj} \quad , \quad \forall\, i = 1, 2, \dots, n. \qquad (2)$$

After all weights for all nests have been estimated, corresponds to collapse the hierarchy tree, using a folding back procedure for every option under study. This collapsing procedure is similar to the one used to collapse probability trees.

There are many critiques to the original Saaty AHP. One of them is associated with the use of a 9 point scale (Murphy, 1993; Dood, 1997), whereas another issue is related to the axiom that states that there is independence between the attribute weights and the information that people posses about the alternatives under study (Weber, 1997).

Tudela (1998) proposed a method to cope with the last critique. The method rests on the assignment of a utility function to every nest in the hierarchy, using revealed or stated preference techniques to assess these utilities.

2.4. The utility function approach to derive the weight vector

Tudela (1998) proposed an alternative method to the pair wise comparison to assess the weight vector to use with the AHP. This method consists of assigning a utility function to every nest in the hierarchy. This function will be dependent on the elements belonging to the nest. These functions can be estimated using revealed or stated preference information.

Given a nest, a marginal change in the nest utility can be expressed as a weighed sum of marginal changes on the attributes belonging to the nest. From this can be derived a general expression of the weight for every attribute. These weights will be dependent on the attribute marginal utilities and its magnitudes. It is worth noticing that people's perceptions are made explicit when considering the attribute marginal utility. For a linear utility expression, the weight of the i-th element, ωi, will be:

$$\omega_i = \frac{\alpha_i \quad x_i}{\sum_i \alpha_i x_i} \qquad (3)$$

α_i is the coefficient associated with the variable x_i in the utility function. Notice that the denominator corresponds to the total utility of the nest. Coefficients can be estimated using revealed or stated preference information, depending on the situation under analysis.

3. Case study and application

3.1. Project description

The project under study consists of the improvement of part of the road system in the Chiguayante district, Concepcion, Chile. When the Cost Benefit Analysis was developed, the district had just one main road, known as the O'Higgins – Manuel Rodriguez axis (thicker line in figure 2). This fact generated high levels of congestion at the peak hours.

Several options were considered during the social economic appraisal of the axis improvement (Mideplan, 1997). In this work, the focus will be on two of them.

Alternative 1 corresponded to the widening of the O'Higgins and Manuel Rodriguez streets, to two lanes per direction (to Concepcion and to Hualqui). Between La Alhambra and Cruce EFE (railways crossing) a three lane per direction improvement was suggested. The railway crossing would be solved building an overpass.

Alternative 2 considered a widening and prolongation of Manuel Rodriguez street (thinner line in figure 2), improving the pavement in the O'Higgins street as well. The railway crossing would be solved building an overpass further west (Concepcion direction, La Alhambra area), out of the urban area.

Both alternatives considered also an improvement of the public transport management system. Public transport moves the 80% of trips in the study area.

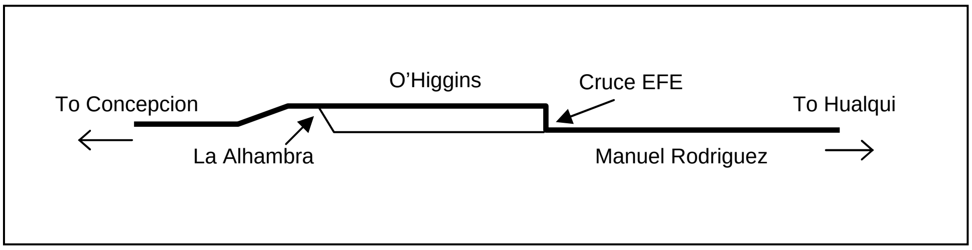

Figure 2: Present situation

3.2. Social economic appraisal

The economic appraisal of the project was developed by a private company for the public agency, following the methodology stated in SECTRA (1997). Investment levels, travel time savings, fuel consumption and maintenance costs were the main items considered in the assessment. The short and long run main indicators are as follows (Mideplan, 1997):

Table 1: Short run indicators (Ch$, December 1996)

Alternative	NPV 1 (M Ch$)	TRI (%)
1	1.030	39.0
2	993	34.7

Table 2: Long run indicators (Ch$, December 1996)

Alternative	NPV (M Ch$)	TIR (%)
1	19.829	58.4
2	19.525	53.1

NPV stands for net present value, NPV 1 is the NPV for the first year, TIR corresponds to the interest rate that makes the NPV equal to zero, and TRI is the ratio between benefits and costs (including investment) for the first year of the project.

From previous figures can be seen that alternative 1 would be the one to be implemented, since it has the best economic indicators. Figures are not too different though.

3.3. Multi criteria application

Since the economic appraisal did not consider any environmental aspect, and given that fact that final economic figures were not too different, then the AHP was applied to determine whether there would be any difference in the multi criteria appraisal output with respect to the economic one.

Hierarchies definition

The application of the AHP requires the definition of hierarchies, for both benefits and costs. They are shown in figures 3 and 4, and were defined by Asenjo (2001).

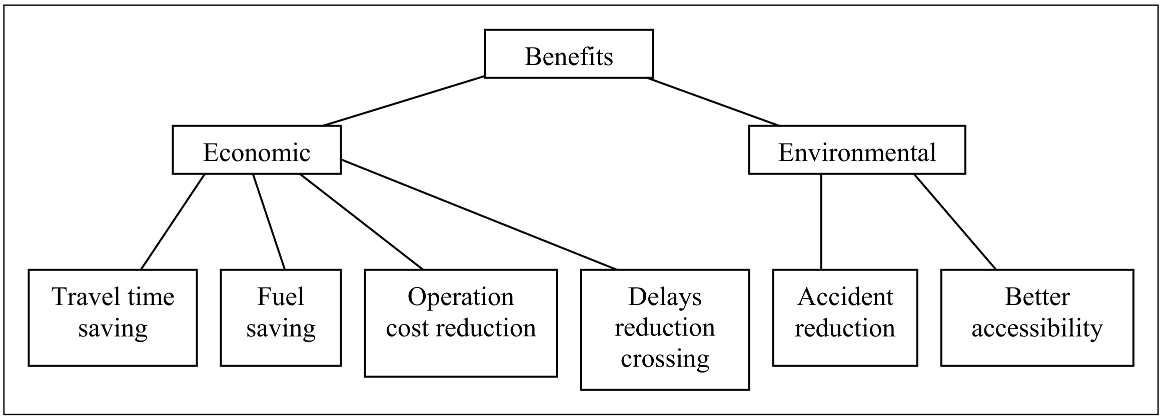

Figure 3: Hierarchy of benefits

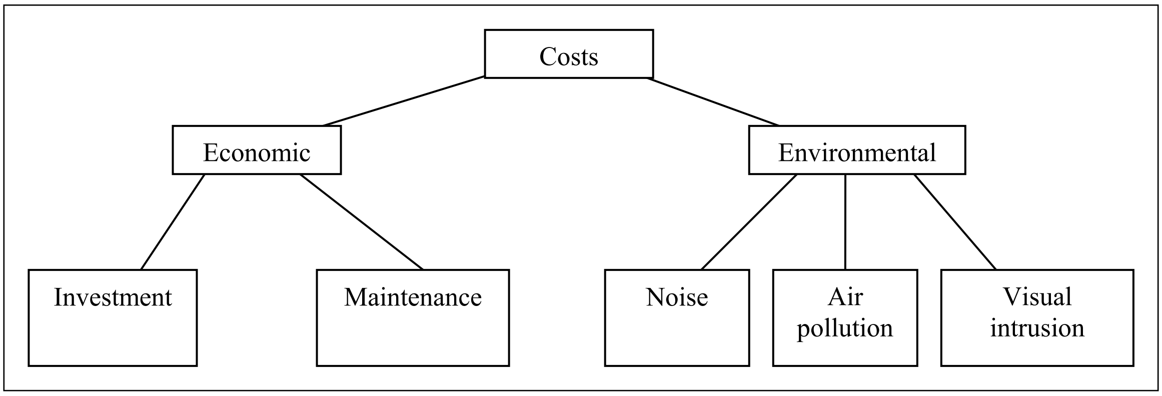

Figure 4: Hierarchy of costs

Both hierarchies considered the inclusion of attributes that were not taken into account when applying the social appraisal. All of them are related to environmental aspects.

For the calculation of weights, both approaches indicated in section 2 were used: pairwise comparison (Saaty, 1990) and utility function (Tudela, 1998).

Pairwise comparison weights

The pairwise comparison experiments were developed by Asenjo (2001) and Cisternas (2002). Experiments were applied to people that lived in the area where the project was deemed to be implemented. The 9 points scale suggested by Saaty was used to collect the comparison responses. Since it was of interest to find out whether the level information that people had about the project and its impacts were relevant for the weights, then several experiments were carried out. Information had to do with the project itself, and the effect of impacts upon people's health and the environment.

Table 3 contains the final weights for the top level of hierarchies (see figures 3 and 4), whilst tables 4 and 5 show the final weights for the lower levels. Columns I, II and III refer to the level of information people had. Column I corresponds to basic information about the project, column II considers the provision of some information about impacts, whereas column III consider full information about them, in terms of quality and quantity.

Table 3: Economic and environmental weights

Attribute	I	II	III
Environmental	0.410	0.272	0.272
Economic	0.590	0.728	0.728

Source: Cisternas (2002)

Table 4: Benefits hierarchy. Attribute weights

Attribute	I	II	III
Travel time	0.458	0.458	0.458
Fuel	0.176	0.176	0.176
Other operation cost	0.128	0.128	0.128
Crossing improvement	0.238	0.238	0.238
Accidents reduction	0.633	0.663	0.663
Accessibility	0.367	0.367	0.367

Source: Cisternas (2002)

Table 5: Costs hierarchy. Attribute weights

Attribute	I	II	III
Investment	0.718	0.718	0.718
Maintenance	0.282	0.282	0.282
Noise	0.373	0.387	0.386
Visual intrusion	0.227	0.194	0.190
Air pollution	0.400	0.419	0.424

Source: Cisternas (2002)

The interpretation of the previous weights will depend upon whether they belong to the benefit or cost hierarchy. If a weight related to the benefit hierarchy is close to 1, then the attribute associated with the weight is more attractive to people. For example, travel time savings have a higher importance than fuel savings. For the weights associated with the cost hierarchy, the interpretation is the opposite. When the weight is close to 1, then the attribute is less attractive to people. For instance, investment levels are less attractive to people than maintenance costs.

Table 6 contains the final weights after collapsing the tree structures.

Table 6: Alternative final weights. Pairwise comparison approach

		Weights		
Alternative		**I**	**II**	**III**
1	Benefits	0,395	0,342	0,342
	Costs	0,591	0,679	0,683
	Ratio	**0,668**	**0,503**	**0,500**
2	Benefits	0,605	0,658	0,658
	Costs	0,409	0,321	0,317
	Ratio	**1,480**	**2,051**	**2,077**

Source: Cisternas (2002)

Ratio corresponds to the benefit weight divided by the cost weight. Higher the ratio, more preferred will be the alternative. This is consistent with the fact that the best alternative will be the one with the higher benefit weight and the lower cost weight. According to the ratio values, alternative two should be the preferred one. This preference increases when information is provided to people. This can be seen when comparing the first and third columns.

Utility function weights

Weights were obtained using the information collected using Stated Preference (SP) experiments during October 2001 (Akiki, 2002) and January 2002 (Cisternas, 2002). Stated Preference experiments rather than revealed experiments were used due to the nature of the attributes and the non existence of real markets. People interviewed lived in the project area.

Experiments were designed using standard SP methodology (Kocur et al., 1982; Ortuzar, 2000). Several pilot experiments had to be carried out until the definitive designs were available. SP experiments were of the choice type, using a five point semantic scale to collect responses, such that people were not forced to choose between alternatives. Graphical information had to be used to support the field work such that people might understand clearly the trade-off between attributes they were offered. People were asked to respond up to 9 choice games (Akiki, 2002; Cisternas, 2002). In some cases, the same people were asked to respond the pairwise comparison and the SP experiments.

Responses were modelled using binary Logit models, collapsing the semantic scale responses into binary answers. The maximum likelihood method was used to estimate the coefficients. Linear and non linear specifications were estimated. Box-Cox transformations were used to model the non linear utilities. Weights expressions were function of marginal utilities (people's perceptions) and the magnitude of attributes, as expected (see equation 3).

Weights reported in tables 7 and 8 are based on the best estimates and assessed in the mean value of attributes. In this case, just two levels of information were considered, I and II, since the application of the SP technique required the provision of certain information before applying the experiments. Table 7 contains the attribute weights for the cost hierarchy.

Table 7: Costs hierarchy. Attribute weights

Attribute	I	II
Investment	0.721	0.721
Maintenance	0.279	0.279
Noise	0	0.516
Visual intrusion	0	0.395
Air pollution	1	0.089

Source: Akiki (2002)

It can be observed the null importance that people assigned to the noise and visual intrusion for the first level of information (basic information about the project and the impacts). This fact changed when more qualitative and quantitative information was provided to people.

Final weights can be seen in table 8 when using the alternative approach to calculate the importance of attributes. Weights for the top level of the hierarchy and the benefits hierarchy were obtained from tables 3 and 4.

Table 8: Final weights. Utility function approach

		Weights	
Alternative		**I**	**II**
1	Benefits	0,395	0,342
	Costs	0,582	0,669
	Ratio	**0,679**	**0,511**
2	Benefits	0,605	0,658
	Costs	0,418	0,331
	Ratio	**1,448**	**1,986**

Source: Cisternas (2002)

It can be observed that when providing more information to people, then alternative two gets more attractive.

When comparing the results from both weight estimation methods, it can be seen that the output was the same. Alternative two should be preferred to alternative 1. The inclusion of other aspects, apart from the economic ones produced this difference with the respect to the outcome of CBA. Besides, the provision of information did affect the weights and might have affected the ranking of alternatives. In fact, the advantages of alternative two got stronger when more information was available for people.

Sensitivity analysis

To test for changes in the ranking of the options, a sensitivity analysis was performed. Weights were modified a 20% up and down, for both hierarchies and all levels.

No major changes in the ranking were observed when introducing changes in the weights. The ratio index varied between 0.105 and 0.308 points with respect to the present values.

4. Conclusions

CBA suggested that the best alternative was alternative 1. When the authority had to take the final decision, it chose alternative 2. Further analysis showed that the authority took into account other aspects that were not included in the economic analysis. The authority kept in mind the urban impact of building an overpass crossing in the central area of the district, and the accessibility and the environmental impacts of this action.

When applying the AHP, that did consider non economic attributes, the final output matched the authority decision. Indeed, an AHP based only on economic attributes matched the CBA outcome.

From this is clear the importance of considering other aspects into the decision making process. Valuation of environmental aspects is required if the CBA framework will be used to support the decision making process. Another option is to try with a different framework appraisal, such as multi criteria analysis (MCDA), or a combination of CBA and MCDA.

Consideration of the level of information that people have and how this might affect people's decisions is also of importance. Indeed, the authority should provide clear information such that people make right decisions from an individual and social point of view. When changes on people's attitudes are desirable, then might be needed to make evident and clear to people the effect of their actions.

The use of the utility function approach to calculate the weights showed the role that might have people's perceptions and attributes magnitude, in clear contrast with one of the original AHP axioms. Indeed, people's perceptions are based on their past experience and what they are going through at the present, implying that weights should be sensitive to these facts.

Results show that people were sensitive to the available information about the project. This might affect the output of the decision process, when using public participation as an input of the decision making process. Some differences were obtained for the alternative methods to derive the weights, but they were not drastic.

A main conclusion from these results is that the decision making process needs to incorporate formally other aspects, apart from the economic ones. Furthermore, public opinion should be taken into account explicitly into the decision making, particularly when information regarding the projects that will affect them can be provided by the authority accurately and timely.

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References

Akiki, N., 2002. Analisis y calculo de los pesos a usar en la AHP usando un enfoque de funciones de utilidad. Civil Engineer Final Dissertation. Civil Engineering Department. Universidad de Concepcion. Concepcion. Chile. (in Spanish).

Asenjo, R., 2001. Analisis del papel de la informacion en la Evaluacion de Proyectos Utilizando Tecnicas Multicriterio. Industrial Engineer Final Dissertation. Industrial Engineering Department. Universidad de Concepcion. Concepcion. Chile. (in Spanish).

Bateman, I., Carson, R., Day, B., Hanemann, W., Hanley, N., Hett, T., Jones-Lee, M., Loomes, G., Mourato, S., Özdemiroglu, E., Pearce, D.W., Sugden, R. and Swanson, J., 2002. Economic Valuation with Stated Preference Techniques: A Manual. Edward Elgar. Cheltenham.

Bateman, I., and Willis, K., 1999. Valuing environmental preferences: theory and practice of the contingent valuation method in the US, EU and Developing countries. Oxford University Press. New York.

Cisternas, R., 2002. Estudio Comparativo de los Resultados de Evaluacion Economica versus Multicriterio para un Proyecto de Transporte. Civil Engineer Final Dissertation. Civil Engineering Department. Universidad de Concepcion. Concepcion. Chile. (in Spanish).

Dood, F., 1995. Scale Horizons in Analytic Hierarchies. Journal of Multicriteria Decision Analysis. 4. 177-188.

Kocur, G., Adler, T., Hyman, W., and Aunet, B., 1982. Guide to forecasting travel demand with direct utility assessment. Report UMTA NH 11-0001-82. Urban Mass Transportation Administration. US. Department of Transportation. Washington, DC.

Mideplan, 1997. Informe Final de Estudio Mejoramiento Eje O'Higgins de Chiguayante. Santiago. Made by Testing Ltd. for the Chilean Planning Ministry (in Spanish).

Murphy, C. K., 1993. Limits on the Analytic Hierarchy Process from its consistency index. European Journal of Operational Research. 65. 138-139.

Ortuzar, J., 2000. Stated Preference Modelling Techniques. PTRC. London.

Pearce, D., and Nash, C., 1981. The Social Appraisal of Projects. A Text in Cost benefit Analysis. MacMillan. London.

Rizzi, L., and Ortuzar, J. de D., 2003. Stated Preferences in the Valuation of Interurban Road Safety. Accident Analysis and Prevention, 35, 9-22.

Saaty, T. L., 1977. A scaling method for priorities in Hierarchical Structures. Journal of Mathematical Psychology 15. 234-281.

Saaty, T. L., 1990. Multi-criteria decision Making: The Analytic Hierarchy Process AHP Series Vol. 1. RWS Publications. Pittsburgh.

SECTRA, 1997. Manual para la Evaluacion Social de Proyectos. Planning Ministry. Government of Chile. Santiago. (in Spanish).

Tinch, R., 1995. Valuation of Environmental Externalities. Full Report. The Department of Transport. Transport Report. HMSO. London.

Tudela, A., 1998. Un enfoque multi criterio para evaluar el nivel de sustentabilidad de inversiones en transporte. Proceeding 10th Panamerican Conference on Traffic and Transport Engineering. September. Santander. (in Spanish).

Weber, M., 1997. Remarks on the measurement of preferences in the Analytic Hierarchy Process. Journal of Multicriteria Decision Analysis. 6. 320-321.