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Practice Summaries: Distribution Companies Use the Analytical Hierarchy Process for Environmental Assessment of Transportation Routes Crossing the Pyrenees in Navarre, Spain

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In this paper we discuss our use of the analytic hierarchy process (AHP) to perform an environmental assessment analysis of the main transportation roads that cross the Pyrenees between Spain and France. We use AHP to select the most sustainable distribution routes to mitigate the pollution impact of transportation activities. Two companies in Navarre, Hydro Inasa and GamesaEólica, have implemented our recommendations into their distribution activities. Openbravo has also incorporated them into its software development to select the most environmentally suitable routes in the delivery processes for its customers.

Key words: environmental management; transportation research; GIS; multicriteria analysis; AHP; decision making.

Since the European parliament enacted the Eurovignette legislation (European Commission 2006), many national and local governments have shown an interest in having green corridors (i.e., environmentally friendly roads characterized by low pollution levels) cross their territories. To this end, the government of Navarre funded the interdisciplinary group of logistics and transportation (GILT), a research group of the Public University of Navarre, to assess the five main roads available for crossing the Pyrenees from the city of Pamplona in Navarre, Spain into France. The main goal of our study was to obtain a set of routes that minimizes the environmental impact of transportation activity in the region by analyzing how the passage of vehicles would affect the surrounding areas (Weintraub et al. 2007, Filar and Haurie 2010).

To solve this problem, we built a multicriteria decision model based on the analytic hierarchy process (AHP). We based our analysis on the method defined in Saaty (1994) and evaluated each road based on criteria that we measured using a geographic information system (GIS). We selected some buffer areas (i.e., areas of influence) close to the roads to test the transportation-related pollution, and then

Criteria description	Criteria priority	Subcriteria description	Subcriteria priority	Final priority per subcriteria
Economic	0.2	Conifer/leafy	0.46	0.092
		Nonwooded forest	0.22	0.044
		Irrigated crops	0.16	0.032
		Unirrigated crops	0.11	0.022
		Unproductive land	0.05	0.010
Social	0.4	Urban centers	0.07	0.280
		Heritage sites	0.19	0.076
		Recreational zones	0.11	0.044
Natural areas	0.4	Natural parks	0.40	0.160
		Protected landscapes	0.23	0.092
		Natural reserves	0.18	0.072
		Special areas of conservation	0.13	0.052
		Sites of community interest	0.06	0.024

Table 1: The table lists the hierarchy and priorities of the criteria and subcriteria that we considered in selecting the most sustainable alternative.

classified the buffer areas according to their width, shape, and structure relative to geographical criteria (e.g., areas that cross a hunting reserve or national park). We defined three main criteria to associate with the buffer areas: social, economic, and natural areas (Malczewski 1999). Each criterion includes several subcriteria to better describe their characteristics and peculiarities (see Table 1). In Table 1, we calculated the values in the column entitled *Final priority per subcriteria* by multiplying the columns associated with *Subcriteria priority* and *Criteria priority*.

Whenever a criterion or subcriterion was associated with a buffer area, we quantified its importance as a percentage or weight, which we labeled priority. We estimated these priorities using the pairwise comparison method, which we based on interviews with experts (mainly staff of the transportation department of the government of Navarre, environmental issues researchers, and staff of transportation companies). We compared the experts' scores first to the subcriteria and second to the criteria to determine the priorities as weighted averages of those scores. The two upper subtables and the lower-left subtable of Table 2 show the final scores for the criteria evaluation. All the consistency indices that the AHP procedure generated showed that the ranking intensities in Table 2 are consistent (Steuer 1986, Sinha and Labi 2007). Considering the alternative road i ($i =$ A, B, C, D, E), we defined the overall priority function (in environmental sciences, this is referred to as impact), I_{F_i}, as a weighted average of the percentage of soil affected in road i for a subcriterion j and the priority of that subcriterion j, considering all subcriteria and all roads.

Table 2 presents the comparison matrices among the alternative roads based on the method defined in Saaty (1994). We calculated the vectors of preferences in Table 2 using the overall priority function, considering the comparison matrices and the subcriteria priorities (see Table 1). After multiplying the criteria priorities vector (i.e., 0.2, 0.4, 0.4) in Table 1 by the decisional matrix (see Table 2), the ranking

Economic	Road A	Road B	Road C	Road D	Road E	Preference
Road A	1	2	1	2	1/2	0.20
Road B	1/2	1	1/2	1	1/4	0.10
Road C	1	2	1	2	1/2	0.20
Road D	1/2	1	1/2	1	1/4	0.10
Road E	2	4	2	4	1	0.40

Natural areas	Road A	Road B	Road C	Road D	Road E	Preference
Road A	1	9	9	1	1	0.31
Road B	1/9	1	1	1/9	1/8	0.04
Road C	1/9	1	1	1/9	1/8	0.04
Road D	1	9	9	1	1	0.31
Road E	1	8	8	1	1	0.30

Social	Road A	Road B	Road C	Road D	Road E	Preference
Road A	1	1	3	3	1	0.3
Road B	1	1	2	2	1	0.24
Road C	1/3	1/2	1	1	1/2	0.11
Road D	1/3	1/2	1	1	1/2	0.11
Road E	1	1	2	2	1	0.24

Decisional matrix	Road A	Road B	Road C	Road D	Road E
Economic	0.2	0.1	0.2	0.1	0.4
Social	0.3	0.24	0.11	0.11	0.24
Natural areas	0.31	0.04	0.04	0.31	0.30

Table 2: We used the AHP method to select the most sustainable route. The subtables show three pairwise comparison matrices and the decisional matrix.

results for the overall priority function associated with the five road alternatives were I_{F_i} (Road A) = 0.281; I_{F_i} (Road B) = 0.132; I_{F_i} (Road C) = 0.099; I_{F_i} (Road D) = 0.191; and I_{F_i} (Road E) = 0.297. Based on this method, Road E is the best alternative; however, Road A's ranking is close, suggesting that a different evaluation of the subcriteria priorities could make Road A a better alternative than Road E. Therefore, we performed a sensitivity analysis by using simulation in an Excel spreadsheet in which we randomly perturbed the priorities of the criteria and subcriteria. This allowed us to perform a sensitivity (what-if) analysis of the main model. The simulation results indicated that Road E was the best option in 91 percent of the cases. Similarly, experts at three companies—Hydro Inasa (http://www.hydro.com), GamesaEólica (http://www.gamesacorp.com), and Openbravo (www.openbravo.com)—evaluated these two alternatives and confirmed our analysis and final results.

Our study resulted in a set of recommendations for the most environmentally suitable roads for delivery companies and logistic carriers to support their logistics-planning activities. Hydro Inasa and GamesaEólica implemented our recommendations. Openbravo, a company that develops free software for client institutions, included our model inside the logistic module of its decision support system (DSS) to enable this DSS to consider environmental costs in planning logistics operations. The main benefits that Hydro Inasa and GamesaEólica obtained are (1) reduction of environmental impact of their transportation fleets, (2) improved ability to demonstrate their environmental concerns in marketing campaigns, and (3) increased awareness among drivers of petrol consumption reduction by their vehicles. Additionally, this work has become a starting point for discussion with other companies in Navarre.

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