Protection Priority in the Coastal Environment Using a Hybrid AHP-TOPSIS Method on the Miaoli Coast, Taiwan

Author(s): Hsien-Kuo Chang , Jin-Cheng Liou , and Wei-Wei Chen
Source: Journal of Coastal Research, 28(2):369-374. 2012.
Published By: Coastal Education and Research Foundation
DOI: http://dx.doi.org/10.2112/JCOASTRES-D-10-00092.1
URL: http://www.bioone.org/doi/full/10.2112/JCOASTRES-D-10-00092.1

Journal of Coastal Research	28	2	369–374	West Palm Beach, Florida	March 2012

Protection Priority in the Coastal Environment Using a Hybrid AHP-TOPSIS Method on the Miaoli Coast, Taiwan

www.cerf-jcr.org

Hsien-Kuo Chang, Jin-Cheng Liou, and Wei-Wei Chen

Department of Civil Engineering
National Chiao Tung University
Hsinchu 300, Taiwan
jcliou.cv87g@nctu.edu.tw

www.JCRonline.org

ABSTRACT

CHANG, H.-K.; LIOU, J.-C., and CHEN, W.-W., 2012. Protection priority in the coastal environment using a hybrid AHP-TOPSIS method on the Miaoli Coast, Taiwan. *Journal of Coastal Research,* 28(2), 369–374. West Palm Beach (Florida), ISSN 0749-0208.

Coastal erosion often happens around the island of Taiwan because of strong waves from typhoons in the summer. The problem of beach erosion cannot be completely solved at this time due to insufficient government budgets. Prioritization of coastal protection should be made yearly to match engineering requirements and annual official budgets. This paper proposes both analytic hierarchy process (AHP) and technique for order preference by similarity to ideal solution (TOPSIS) methods to prioritize the protection of the coastal environment on the Miaoli Coast of Taiwan. The weights of three main criteria (engineering safety, ecology, and coastal landscape) and their subcriteria are determined through the AHP method. Twenty-two segments of the Miaoli Coast are ranked according protection priority by the TOPSIS method. This multipart methodology can help decision makers prioritize coastal engineering and environmental efforts. This procedure also enables researchers to put more expert knowledge together, allowing more precise decisions and moderating personal judgments.

ADDITIONAL INDEX WORDS: *Protection priority, coastal environment, hybrid analytic hierarchy process (AHP) and technique for order preference by similarity to ideal solution (TOPSIS) method.*

INTRODUCTION

The 50-km-long Miaoli Coast is located in NW Taiwan (Figure 1). Over time, suspended sediments from rivers accumulate into wide beaches along the Miaoli Coast. Excluding marine structures of fishing harbor and revetments, approximately 50% of the Miaoli Coast is sandy beach. In recent years, several beaches on the Miaoli Coast have suffered from significant erosion due to the impact of large typhoon waves during the summer. Strong winds from NE monsoons on the Yuanli Coast can transport sand several kilometers inland. Severely eroded beaches and dunes have often been protected in the past by setting snake-caged stone revetments. However, the problems with several slightly eroded places have not been solved because countermeasures are less necessary in those areas and due to budget constraints. This lack of resolution has been troublesome for the engineers, scholars, and administrative unit responsible.

The Water Resource Agency of the Ministry of Economic Affairs is the main department for executing the coastal utilization and development plan. The Second River Management Office of the Water Resource Agency (RMOWRA) in Taiwan is in charge of the Miaoli Coast and tries to protect the eroded beaches and improve environmental functions for marine activities.

It would be prohibitively expensive to protect all eroded beaches and improve all coastal environments in Miaoli County. The Second RMOWRA needs an integrated plan for improving coastal environments of the Miaoli Coast and a policy of protection priority that takes into consideration the annual limitations of the government's budget and the emergency of protecting beaches against erosion.

The Miaoli Coast can be demarcated into several segments depending on geomorphology and marine infrastructures, such as groins or revetments. It is first divided into four main segments by the administration areas of the following towns: Chunan, Houlung, Tunghsiao, and Yuanli. Several subsegments of each main segment are identified according to geomorphology and existing coastal facilities. The divided segments are shown in Figure 1.

Researchers have proposed various methodologies for coastal management. Cendrero and Fischer (1997) proposed a procedure for the determination of environmental quality in coastal areas. This method, based on a series of characteristics, provides suitable indices for natural environmental units and coastal jurisdictions. Phillips and Jones (2006) justified integrated coastal zone management as a tool for managing coastal resources and accommodating increasing pressure from tourists. They also recommended strategies to ameliorate projected impacts. Phillips, Abraham, and Williams (2007) applied functional analysis to the South Wales coastline in the United Kingdom and provided applicable indicators for future

DOI: 10.2112/JCOASTRES-D-10-00092.1 received 18 June 2010; accepted in revision 1 November 2010.

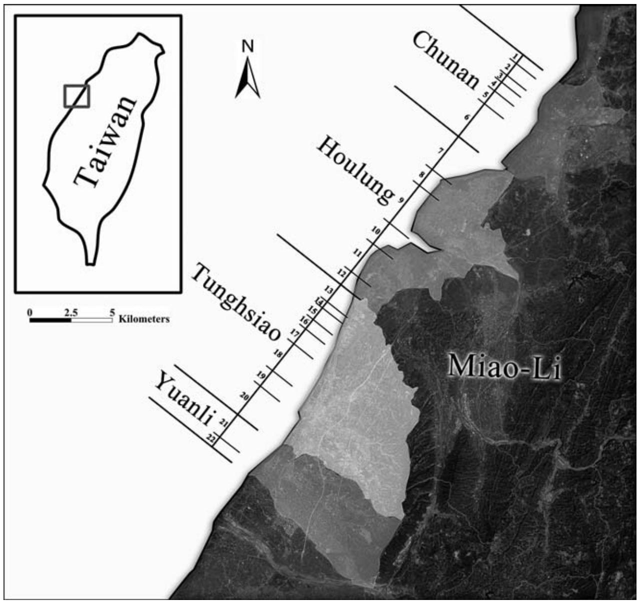

Figure 1. Definition sketch of separated areas of the Miaoli Coast.

sustainability assessment with respect to socioeconomic consideration. Mosadeghi *et al.* (2009) selected an analytic hierarchy process (AHP) and a fuzzy AHP to obtain preference weights of land suitability criteria in a case study area located in SE Queensland, Australia.

An AHP is a key multicriteria decision-making method that is successful in both academic research and engineering applications. The AHP has been widely applied to numerous real-life problems in the past years. Several literature reviews on the AHP and its applications refer to the surveys of Zahedi (1996), Forman and Gass (2001), Golden and Wasil (2003), and Vaidya and Kumar (2006). Van der Kleij, Hulscher, and Louters (2003) presented a methodology for making a decision about a possible airport island location in the North Sea based on uncertain information about the effective factors on the alternatives. The methodology combined AHP and Monte Carlo approaches and allowed comparison of the alternatives on the basis of morphological and ecological effects. Pascoe *et al.* (2009) presented a qualitative framework that aided in the analysis of alternative spatial management options in coastal fisheries. The framework combined expert opinion and an AHP to determine which options performed best, taking into account the multiple objectives inherent to fisheries management. The simplicity and power of the AHP has led to its widespread use of across multiple disciplines in every part of the world (Kristof, 2005).

The technique for order preference by similarity to ideal solution (TOPSIS) is useful in dealing with multiattribute or multicriteria decision-making problems in the real world. It helps the decision maker organize the problems to be solved and then analyze, compare, and rank alternative solutions. In recent years, the TOPSIS has been successfully applied to the areas of human-resource management (Chen and Tzeng, 2004), transportation (Janic, 2003), product design (Kwong and Tam, 2002), manufacturing (Milani, Shanian, and Madoliat, 2005), water management (Srdjevic, Medeiros, and Faria, 2004), quality control (Yang and Chou, 2005), and location analysis (Yoon and Hwang, 1985).

In this paper, the AHP method is used to weigh assessment criteria. The weights and performance scores are then combined to obtain aggregated scores using the TOPSIS method. The purpose of this study is to provide an objective tool for setting coastal protection priorities.

METHODOLOGY

The AHP Method

The AHP method, first proposed by Saaty (1980), uses a typical pairwise comparison method to extract relative weights of criteria based on a hierarchical structure. In a hierarchical problem, each element at a given level is associated with some or all elements at the level immediately below. Elements at a single level are compared in terms of relative importance with respect to an element in the immediately higher level. Such pairwise comparisons are then analyzed using an eigenvector method. The AHP method described earlier is a structured, systematic, and effective approach for determining the relative importance of weights. The procedure of AHP can be expressed in a series of steps:

(1) Construct a paired comparison matrix.

A pairwise comparison matrix of criteria is constructed using a scale of relative importance. The judgments are entered using the fundamental scale of the AHP, which is shown in Table 1. In total, $n(n-1)/2$ pairwise comparisons are evaluated for n criteria. Let A represent an $n \times n$ pairwise comparison matrix:

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} & \cdots & 1 \end{bmatrix} \tag{1}$$

The diagonal elements in matrix A are self-compared; thus, $a_{ij} = 1$. The values on the left and right sides of the matrix diagonal represent the strength of the relative importance degree of the ith element compared to the jth element. Let $a_{ji} = 1/a_{ij}$, where $a_{ij} > 0$, $i \neq j$.

(2) Calculate the importance degrees.

The average of normalized columns in a reciprocal matrix provides a good estimate of the principal right eigenvector in the deterministic case (Vargas, 1982). Let W_i denote the importance degree for the ith criteria. Then,

$$W_i = \frac{1}{n}\sum_{j=1}^{n}(a_{ij}/\sum_{i=1}^{n}a_{ij}), \quad i,j = 1, 2, \ldots, n \tag{2}$$

(3) Test the consistency of the importance degrees.

Due to the limitation of Saaty's discrete nine-value scale and the inconsistency of human judgments when assessing weights during the pairwise comparison process, the aggregation weight vector might be invalid. Examination of consistency of the importance degrees should be made to avoid inconsistencies occurring when using different measurement scales in the evaluation process (Karapetrovic and Rosenbloom, 1999;

Table 1. *The relational scale proposed by Saaty (1980) for pairwise comparisons.*

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgment slightly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Very strong or demonstrated importance	One activity is favored very strongly over another; its dominance is demonstrated in practice
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between adjacent scale value	Used when compromise is needed
Reciprocals		If activity i has one of the preceding numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i
Rationals	Ratios arising from the scale	Used if consistency were forced by obtaining n numerical values to span the matrix

Kwiesielewicz and van Udem, 2004). Saaty (1980) suggested the maximal eigenvalue $\lambda_{\max}$ be used to evaluate the effectiveness of measurements. To check the consistency between pairwise comparison judgments, the consistency index (CI) and consistency ratio (CR) are calculated using the equations

$$\mathrm{CI} = (\lambda_{\max} - n)/(n-1) \text{ and } \mathrm{CR} = \mathrm{CI}/\mathrm{RI} \quad (3)$$

where RI is a random index with a value obtained from Table 2 by different orders of pairwise comparison matrices. If the value of the CR is below 0.1, the evaluation of the importance degrees is considered to be reasonable. In general, the AHP is developed to select the best of a number of alternatives with respect to several criteria.

The TOPSIS Method

The TOPSIS method was developed by Hwang and Yoon (1981) and modified by Yoon (1987) and Hwang, Lai, and Liu (1993). The TOPSIS is a multicriteria method for identifying solutions from a finite set of alternatives. The basic principle of the TOPSIS is that the chosen alternative should have the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution. The procedure of the TOPSIS can be expressed in a series of steps:

(1) Construct a normalized decision matrix.

Use elements defined by the following:

$$r_{ij} = x_{ij} \Big/ \sqrt{\sum_{i=1}^{m} x_{ij}^2}, \quad j = 1, 2, \ldots, n \quad (4)$$

Consequently, each attribute has the same unit length of vector.

(2) Construct a weighted normalized decision matrix.

Use elements given by

$$v_{ij} = w_j \cdot r_{ij}, \quad i = 1, 2, \ldots, m, \quad j = 1, 2, \ldots, n \quad (5)$$

where w_j is the weight of the jth attribute or criterion.

(3) Determine the positive ideal and negative ideal solutions as follows:

$$A^+ = \{(\max v_{ij} | j \in J) \text{ or } (\min v_{ij} | j \in J') \text{ for } i = 1, 2, \ldots, m\} = \{v_1^+, v_2^+, \ldots, v_n^+\} \quad (6)$$

$$A^- = \{(\min v_{ij} | j \in J) \text{ or } (\max v_{ij} | j \in J') \text{ for } i = 1, 2, \ldots, m\} = \{v_1^-, v_2^-, \ldots, v_n^-\} \quad (7)$$

Here, $J = \{j = 1, \ldots, n | j$ associated with benefit or positive criteria$\}$ and $J9 = \{j = 1, \ldots, n | j$ associated with cost or negative criteria$\}$.

(4) Calculate the separation measures.

Use the n-dimensional Euclidean distance. The separation of each alternative from the ideal solution is given as follows:

$$S_i^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^+)^2}, \quad i = 1, 2, \ldots, m \quad (8)$$

Similarly, the separation from the negative ideal solution is given as follows:

$$S_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2}, \quad i = 1, 2, \ldots, m \quad (9)$$

(5) Calculate the relative closeness to the ideal solution.

$$C_i^+ = S_i^- / (S_i^+ + S_i^-), \quad 0 < C_i^+ < 1, \quad i = 1, 2, \ldots, m \quad (10)$$

(6) Rank the preference order.

Now, a set of alternatives can be preference ranked according to the descending order of C_i^+.

Table 2. *Random index (RI) values.*

Matrix order	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

DETERMINATION OF WEIGHTS OF ASSESSMENT CRITERIA

To identify the main factors in the coastal environment, a meeting of experts was held to discuss possible factors in coastal environment management. Fourteen experts were in attendance, including three coastal engineers, two ecologists, two landscape specialists, and seven coastal planning and administration experts. Four groups of experts in multiple domains were considered to applicably and efficiently choose possible factors for evaluating coastal environments and to avoid individual bias. At the meeting, the current situation of the Miaoli Coast was introduced to the participants, and an interactive discussion of assessment criteria proceeded. Finally, a hierarchy consisting of three main criteria and nine subcriteria (shown in Table 3) was determined in the meeting by these specialists.

Engineering safety, marine ecology, and coastal landscape are important factors in current coastal engineering and management and thus form the three main criteria in the AHP. Marine infrastructures, such as detached breakwaters and groins, are generally built to protect eroded beaches and dunes. The scales of such marine infrastructures are related to the degree and range of beach erosion. Some places along the Miaoli Coast are suffering from strong wind-blown sands. Arranged fences on the shores have been commonly used for these areas. However, the problem is not completely solved by setting arranged fences, so alternative solutions must also be proposed to reduce the negative effects of wind-blown sands. Large typhoon waves in the summer and strong tidal currents also cause beach erosion. If the current coast is left natural, without any countermeasure, the beach will erode under wave or current impacts. Thus, engineering requirements for preventing beach erosion, potential of wind-blown sands, and wave or current forces are significant factors in determining the scale of marine infrastructures for solving these problems of beach protection.

Subcriteria in the marine ecology domain include construction of ecological habitat, water quality, and interruption of the growth corridor to neighboring lands. Construction of ecological habitat leads to increases in the adaptability of life in environments of marine beings from the nearshore to the coastline zones. Water quality is important for the existence of marine beings and is a key factor indicating the health of a marine ecology. Finally, high seawalls and revetments with surface whitewash commonly interrupt the movement of some marine reptilians in the coastal zone, separating their growth corridors.

Natural coastal landscape is an important resource of coastal tourism. Good coastal landscape with a good transportation network makes it easier to attract tourists. Artificial leisure facilities, such as pavilions, trails or steps on promenade revetments, and amusement parks, provide recreational activities in coastal areas. The definitions of the subcriteria show that all criteria are mutually independent.

The author summarized the responses from experts and designed a structured questionnaire in the form of a pairwise comparison based on the identified factors. This questionnaire was sent to the 14 participants so that their responses could be statistically analyzed. Through this survey, the experts assessed the relative importance of the criteria in each pair using a weight scale with nine grades. Eleven questionnaires were returned. Although the number of participants was low, the procedure was similar to a part of the Delphi method, which constitutes experts who are more likely than nonexperts to be correct about questions in their field and identify the full range of important issues (Gordon, 2003). The Delphi method is for obtaining independent forecasts from an expert panel over two or more rounds, with summaries of the anonymous forecasts provided after each round (Armstrong, 2001).

The authors applied the AHP approach (Golden, Wasil, and Harker, 1989; Saaty, 1977, 1990) to these questionnaires to establish weights for the main criteria and subcriteria. The resulting weights, with their different levels of importance, are shown in Table 3. The experts' responses ranked engineering safety as the most important main criterion, with a weight more than twice that of the least important criterion, coastal landscape. In Taiwan, early seawalls and revetments with armored blocks were built on eroded beaches, with engineering safety as the primary concern, almost neglecting ecological and landscape factors.

Recently, coastal ecological issues have been widely discussed among scholars and the general population in Taiwan due to the growing focus on ecological conservation and engineering. More people are beginning to focus more on ecological problems than before, and they are making efforts to protect marine ecology from pollution and erosion. The use of ecological engineering to protect coastlines is becoming more popular, as opposed to the old method of building infrastructures without consideration of ecology and landscapes. However, a less in-depth assessment of the Miaoli Coast's landscape may still occur due to the low population

Table 3. *Criteria and weights used in the comparison.*

Main Criterion	Weight	Subcriterion	Weight
Engineering safety	0.440	Coastal erosion defense	0.413
		Deflation potential	0.296
		Wave or current force	0.291
Ecology	0.356	Construction of ecological habitat	0.482
		Water purification	0.281
		Construction of ecological corridor	0.237
Coastal landscape	0.205	Construction of leisure environment	0.373
		Construction of landscape	0.358
		Traffic convenience	0.269

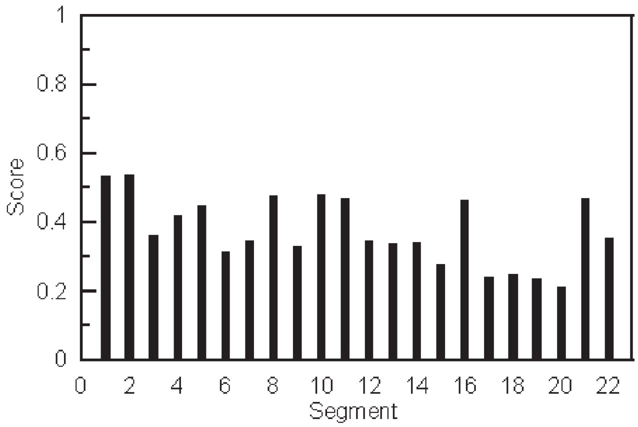

Figure 2. Ranking scores of protection priority on the Miaoli Coast.

in the Miaoli coastal zone and its predominant use for farming and fishing.

According to Table 3, the weight for construction of ecological habitat approaches 0.482, the highest value among the criteria and subcriteria. This priority indicates that the most important criterion in ecological factors is to construct a harmonious ecological habitat. Preventing beach erosion is a key aspect of engineering safety. Natural landscaping and constructing leisure environment are both important to increase the aesthetics of the coastal landscape.

PROTECTION PRIORITY IN COASTAL ENVIRONMENT

When the weight of each criterion was determined through the AHP method, performance scores were determined for each criterion and for all 22 segments of the coast using field surveys and literature reports. A coast with a rich marine ecology and a comfortable landscape has more socioeconomic values for tourism than one with a poor marine ecology and an unattractive landscape. Thus, rich marine ecology and comfortable landscapes have higher ranking in the TOPSIS. A beach with severe erosion or strong wind-blown sands generally requires higher engineering costs than that with sight erosion or weak wind-blown sands. Therefore, the beaches with erosion and strong wind-blown sands have negative benefit in the TOPSIS. There is also a cost related to not protecting the shoreline, depending on socioeconomic importance. However, such a cost is generally lower and less urgent than the engineering cost for already-eroded beaches.

Figure 3. Scouring of the foredune at Segment 2 of the Miaoli Coast.

Figure 4. The beach and seawalls at Segment 20 of the Miaoli Coast.

Applying the TOPSIS method, we ranked protection priority of the 22 segments of the Miaoli Coast by the ranking scores shown in Figure 2. Segment 2 has the highest value, showing that improving the environment in the second segment of the Miaoli Coast is the highest priority. Segment 2 has high coastal dunes with a diverse and valuable ecosystem and provides a tourist recreational area. It is suffering from scouring of the foredune, as shown in Figure 3, and needs low-cost engineering to remedy the toe scour. In contrast, the lowest ranking zone is Segment 20, shown in Figure 4, where both marine ecology and landscape are in poor condition and the engineering requirement is not urgent because an industrial area is planned and another organization will manage this area.

CONCLUSIONS

This paper presents a method, using the techniques of an AHP and the TOPSIS, for making decisions for the prioritization of coastal protection on Taiwan's Miaoli Coast. The criteria of engineering safety, marine ecology, and coastal landscape are the main factors for the coastal environment obtained through the AHP method and can be ranked according to experts' opinions of importance. Through the TOPSIS method, Segment 2 is identified as the highest protection priority among all segments of the Miaoli Coast due to its rich ecology and low-cost engineering requirements. The proposed method for prioritizing coastal protection provides a good tool for coastal management and planning.

ACKNOWLEDGMENTS

This study was supported in part by the Second RMOWRA, Ministry of Economic Affairs, through MOEA/WRA-0950276 grants.

LITERATURE CITED

Armstrong, J.S., 2001. *Principles of Forecasting: A Handbook for Researchers and Practitioners*. Boston: Kluwer Academics Publishers.

Cendrero, A. and Fischer, D.W., 1997. A procedure for assessing the environmental quality of coastal areas for planning and management. *Journal of Coastal Research,* 13(3), 732–744.

Chen, M.F. and Tzeng, G.H., 2004. Combining gray relation and TOPSIS concepts for selecting an expatriate host country. *Mathematical and Computer Modelling,* 40, 1473–1490.

Forman, E. and Gass, S.I., 2001. The analytic hierarchy process: an exposition. *Operations Research,* 49, 469–486.

Golden, B.L. and Wasil, E.A., 2003. Celebrating 25 years of AHP-based decision making. *Computers and Operations Research,* 30, 1419–1420.

Golden, B.L.; Wasil, E.A., and Harker, P.T., 1989. *The Analytic Hierarchy Process, Applications and Studies*. Heidelberg, Berlin: Springer-Verlag.

Gordon, T.J., 2003. The Delphi method. *In:* Glenn, J.C. and Gordon, T.J. (eds.), *Futures Research Methodology,* Version 2.0. Washington: American Council for the United Nations University.

Hwang, C.L. and Yoon, K., 1981. *Multiple Attribute Decision Making: Methods and Applications*. New York: Springer-Verlag.

Hwang, C.L.; Lai, Y.L., and Liu, T.Y., 1993. A new approach for multiple objective decision making. *Computers and Operation Research,* 20, 889–899.

Janic, M., 2003. Multicriteria evaluation of high-speed rail, Transrapid Maglev, and air passenger transport in Europe. *Transportation Planning and Technology,* 26, 491–512.

Karapetrovic, S. and Rosenbloom, E.S., 1999. Quality control approach to consistency paradoxes in AHP. *European Journal of Operational Research,* 119, 704–718.

Kristof, G.M., 2005. Planning Business Improvement Using Analytical Hierarchy Process and Design Structure Matrix. Bozeman, Montana: Montana State University, Master's thesis, 111p.

Kwiesielewicz, M. and van Uden, E., 2004. Inconsistent and contradictory judgements in pairwise comparison method in the AHP. *Computers and Operations Research,* 31, 713–719.

Kwong, C.K. and Tam, S.M., 2002. Case-based reasoning approach to concurrent design of low power transformers. *Journal of Materials Processing Technology,* 128, 136–141.

Milani, A.S.; Shanian, A., and Madoliat, R., 2005. The effect of normalization norms in multiple attribute decision making models: a case study in gear material selection. *Structural Multidisciplinary Optimization,* 29, 312–318.

Mosadeghi, R.; Tomlinson, R.; Mirfenderesk, H., and Warnken, J., 2009. Coastal management issues in Queensland and application of the multi-criteria decision making techniques. *Journal of Coastal Research,* Special Issue No. 56, pp. 1252–1256.

Pascoe, S.; Bustamante, R.; Wilcox, C., and Gibbs, M., 2009. Spatial fisheries management: a framework for multi-objective qualitative assessment. *Ocean & Coastal Management,* 52, 130–138.

Phillips, M.R. and Jones, A.L., 2006. Erosion and tourism infrastructure in the coastal zone: problems, consequences and management. *Tourism Management,* 27, 517–524.

Phillips, M.R.; Abraham, E.J., and Williams, A.T., 2007. Functional analysis as a coastal management tool: the South Wales coastline, UK. *Journal of Coastal Conservation,* 11, 159–170.

Saaty, T.L., 1977. A scaling method for priorities in the hierarchical structures. *Journal of Mathematical Psychology,* 15, 234–281.

Saaty, T.L., 1980. *The Analytic Hierarchy Process*. New York: McGraw-Hill.

Saaty, T.L., 1990. How to make a decision: the analytic hierarchy process. *European Journal of Operation Research,* 48, 9–26.

Srdjevic, B.; Medeiros, Y.D.P., and Faria, A.S., 2004. An objective multi-criteria evaluation of water management scenarios. *Water Resources Management,* 18, 35–54.

Vaidya, O.S. and Kumar, S., 2006. Analytic hierarchy process: an overview of applications. *European Journal of Operational Research,* 169, 1–29.

van der Kleij, C.S.; Hulscher, S.J.M.H., and Louters, T., 2003. Comparing uncertain alternatives for a possible airport island location in the North Sea. *Ocean & Coastal Management,* 46, 1031–1047.

Vargas, L.G., 1982. Reciprocal matrices with random coefficients. *Mathematical Modeling,* 3, 69–81.

Yang, T. and Chou, P., 2005. Solving a multiresponse simulation–optimization problem with discrete variables using a multi-attribute decision-making method. *Mathematics and Computers in Simulation,* 68, 9–21.

Yoon, K., 1987. A reconciliation among discrete compromise situation. *Journal of Operational Research Society,* 38, 277–286.

Yoon, K. and Hwang, C.L., 1985. Manufacturing plant location analysis by multiple attribute decision making: part I—single-plant strategy. *International Journal of Production Research,* 23, 345–359.

Zahedi, F., 1996. The analytical hierarchy process: a survey of the method and its applications. *Interfaces*, 16, 96–108.