Journal of Sustainability Science and Management Special Issue No. 3 2017 *ISSN: 1823-8556*
Improving the Health of Setiu Wetlands Ecosystems and Productivity of Crustacean Resources for Livelihood Enhancement: 119-129

A CASE STUDY OF COASTAL COMMUNITY ON APPLICATION OF FUZZY ANALYTIC NETWORK PROCESS FOR DETERMINING WEIGHTS OF QUALITY OF LIFE

SEE XIOU QING AND LAZIM ABDULLAH*

School of Informatics and Applied Mathematics, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia.

**Corresponding author: lazim_m@umt.edu.my*

Abstract: This paper highlights a case study on fuzzy decision making method for determining weights of criteria and sub-criteria that constitute the definition of quality of life (QOL). The weight determination of QOL is a complex problem since many uncertain criteria and sub-criteria that need to considered concurrently. Furthermore, these criteria and sub-criteria are inter-dependent in network of decision making problem. In response to these challenges, the fuzzy analytic network process (fuzzy ANP) is applied to the proposed global weights of ten sub-criteria of QOL for a coastal community of Setiu Wetlands Terengganu. A major advantage of the fuzzy ANP is that it incorporates interdependence relationships between criteria and also sub-criteria. An expert that is familiar with the QOL of coastal community was invited to provide linguistic judgment over the importance of criteria and sub-criteria. The linguistic terms that attached to triangular fuzzy numbers have been used as input to the fuzzy ANP. The result suggests that economics carry the highest weight out of the three criteria. The results also unveiled that the sub-criteria, namely education, health care, and, public transport and communication are the main contributors to the QOL. The main contribution of this paper is the introduction of a fuzzy multi-criteria decision approach for proposing weights of QOL among the coastal community.

Keywords: Analytic network process, coastal community, quality of life (QOL), triangular fuzzy number, weighted criteria

Introduction

A number of decision making tools have been developed over the last four decades to deal with either qualitative or quantitative information of multi-criteria decision making (MCDM) problems. Saaty (1980) pioneered in proposing the decision tool and analytic hierarchy process (AHP) to handle the multiplicity of choices of the decision problems. The AHP is a mathematical device of MCDM in which the decision problem is structured hierarchically. However, in decision analysis, there are many decision problems that cannot be analysed hierarchically due to their interaction and dependencies of higher-level elements in a hierarchy on lower-level elements. In response to these issues, Saaty (1996) proposed the method of analytic network process (ANP) where dependencies and interactions among criteria are taken care of.

Unlike the AHP, the ANP is represented by a network. Furthermore, the ANP is constructed based on feedback in clusters (Saaty, 1996). Many researchers have shown their interest over the applications of this method. The ANP has been widely applied in energy policy planning (Ulutas, 2005), market and logistics (Agarwal *et al*., 2006), economics and finance (Niemura & Saaty, 2004) and civil engineering (Neaupane & Piantanakulchai, 2006). There were also studies on selection of wastewater treatment technology in small communities (Malinos-Senante *et al.,* 2015), and territorial and environmental assessment (Promentilla *et al*., 2006; Bottero *et al*., 2008; Wolfslehner & Vacik, 2008) using this method. There are two types of ANP, which is conventional and fuzzy types.

The conventional ANP gives crisp decision making, but it is unstable and unable to deal with subjective judgement. Therefore, the concept of fuzzy ANP is recommended due to the inheritance of vagueness and tentative decision making with conventional ANP. In light of the uncertainty in decision problems and also in judgment process, fuzzy ANP was introduced. The fuzzy ANP replaces the hierarchies into network structure and it is more applicable (Nobar *et al*., 2011). The fuzzy ANP is a multi-criteria decision making method where interdependencies amongst many diverse criteria can be dealt with a network. The unique features of fuzzy ANP include the development of pair-wise comparison matrices, utilization of interdependencies among decision levels and development of more reliable solutions (Ayag & Ozdemir, 2009).

In the fuzzy ANP, crisp numbers of linguistic evaluation are replaced with triangular fuzzy numbers. With the introduction of triangular fuzzy numbers into the fuzzy ANP, defuzzification process from triangular fuzzy numbers to the final optimal solution in crisp number become more complicated. To alleviate the problem of defuzzification process, Chang (1996) proposed extent analysis method to transform fuzzy numbers to crisp numbers. The extent analysis deals this transformation using the knowledge of intersection between two fuzzy numbers and degree of possibility. Within its complexity to deal with interdependencies among criteria, the fuzzy ANP has been applied in a handful of research. Dagdeviren and Yuksel (2010), and Hermawan *et al*. (2016), for example, introduced the application of fuzzy ANP for Balanced Scorecard (BSC).

The BSC approach was integrated with the fuzzy ANP technique to determine the level of performance of a business on the basis of its vision and strategies. Dagdeviren and Yuksel (2013) have conducted research on the application of fuzzy ANP for measurement of the sectorial competition level. Vinodh *et al*. (2011) and Wicher *et al*. (2016) have proposed a study on applications of the fuzzy ANP for supplier selection in manufacturing organizations and metallurgical supply chain respectively. Very recently, Govindan *et al*. (2016) proposed a model framework of structural modelling and fuzzy ANP and applied to an Indian auto part case industry. So far, however, there has been little past research about the applications of fuzzy ANP to the quality of life (QOL) of a small group of community.

Most studies in the applications of fuzzy ANP have only been carried out in business and manufacturing areas. In contrast to previous works, this paper assessed the QOL among inhabitants of the Setiu Wetlands, Terengganu. Specifically, this paper proposed weights for criteria and sub-criteria of QOL using the simplified eight-step computation of fuzzy ANP. Interdependence among the criteria of QOL would provide an additional effect to the assessment.

In this decision analysis, the importance of QOL criteria could be measured thanks to the interactions and dependencies that characterized the fuzzy ANP.

Preliminaries

Definitions that are attached to the fuzzy ANP are presented in this section. It includes fuzzy sets, triangular fuzzy number, and linguistic variables.

Definition 1 Fuzzy Sets (Zadeh, 1965)

A fuzzy set $\bar{A}$ in the universe of discourse $X = \{x_1, x_2, \ldots, x_n\}$ is defined by

$\overline{A} = \{\langle x, \mu_{\overline{A}}(x)\rangle | x \in X\}$ Which is characterized by membership function $\mu_{\overline{A}} : X \rightarrow [0,1]$, where $\mu_{\overline{A}}(x) \in [0,1]$ indicates the membership degree of the element x to the set $\overline{A}$.

Definition 2 Triangular Fuzzy Number (Kauffman & Gupta, 1985)

A triangular fuzzy number (TFN), A' can be denoted as A' =(l,m,u) and the membership function is given by:

$$\mu_{A'}(x) = \begin{cases} x - l/m - l, & l \le x \le m \\ u - x/u - m, & m \le x \le u \\ 0, & \text{otherwise} \end{cases}$$

The framework of this research is explained in the next section.

Research Framework and Location

This section briefly describes the site or location of Setiu Wetlands. The criteria and sub-criteria of QOL that are employed in this study are also presented. Setiu Wetlands is located in the district of Setiu in the state of Terengganu, east coast of Peninsular Malaysia and directly facing the South China Sea.

Networks of Criteria and Sub-Criteria

Figure 1 shows three stages of networks and interdependencies among criteria and sub-criteria. All these criteria are retrieved from numerous sources of QOL and well-being literature.

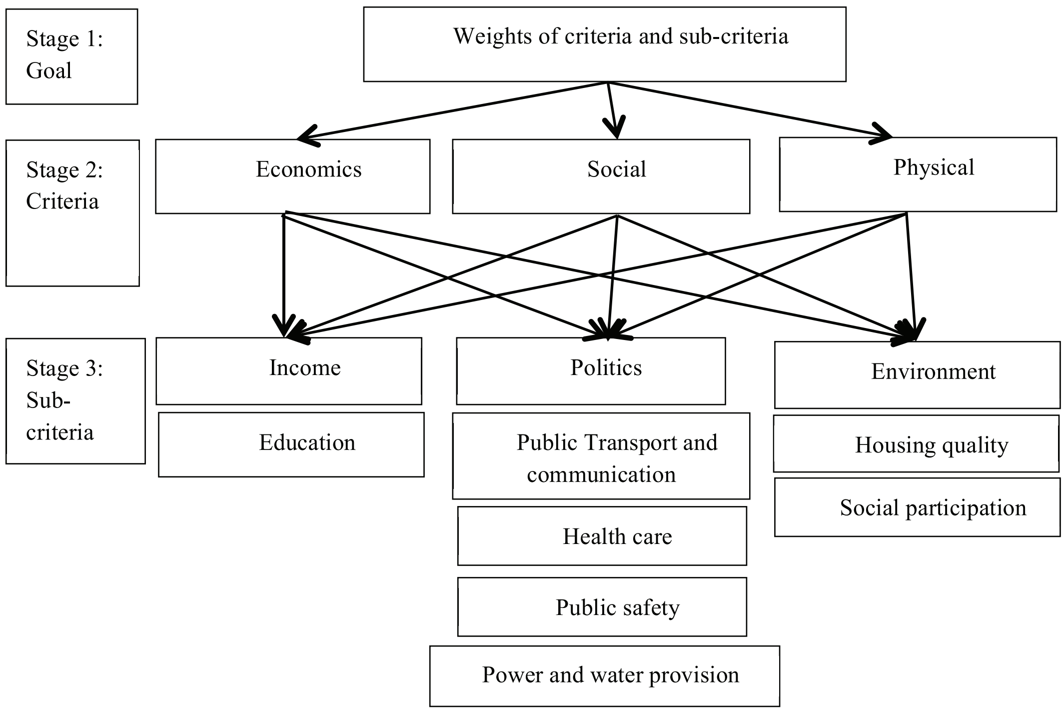

Figure 1: Networks of goal, criteria and sub-criteria of Quality of Life (QOL)

Data Collection

Linguistic data collections were administered to a decision maker who is knowledgeable about QOL among coastal populations. A personal communication was conducted with one of the community leaders in the investigated region. Table 1 shows the scale used in the personal communication which represents the linguistic scale of importance of the criteria and sub-criteria.

Table 1: Linguistic scale of importance and scale value

Linguistic scale of importance	Triangular fuzzy scale	Triangular fuzzy reciprocal scale
Just equal (JE)	(1,1,1)	(1,1,1)
Equally important (EI)	(1/2,1,3/2)	(2/3,1,2)
Weakly more important (WMI)	(1,3/2,2)	(1/2,2/3,1)
Strongly more important (SMI)	(3/2,2,5/2)	(2/5,1/2,2/3)
Very strongly more important (VSMI)	(2,5/2,3)	(1/3,2/5,1/2)
Absolutely more important (AMI)	(5/2,3,7/2)	(2/7,1/3,2/5)

Assessment Model

Chang's Extent Analysis is integrated with the fuzzy ANP to build an assessment model. Details of assessment model are given in the following sub-sections.

Chang's extent analysis

Let $X=\{x_1,x_2,...,x_n\}$ be an object, $U=\{u_1,u_2,...,u_m\}$ be the goal set. Each object is taken and extent analysis for each goal, g_i. Then, for each m Chang's extent analysis for each object can be present by $M_{gi}^1, M_{gi}^2, ..., M_{gi}^m$ where $i=1,2,...,n$, such that for all j {1,2,3,….m}, all the M_{gi}^j are TFNs.
Firstly, the value of fuzzy synthetic extent with respect to the i th object is defined as:

$$s_i = \sum_{j=1}^{m} M_{gi}^j \otimes \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^j\right]^{-1}$$

where

$$\sum_{j=1}^{m} M_{gi}^j = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right)$$

Next we perform the fuzzy addition operation of M_{gi}^j values to get

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^j\right]^{-1}$$

such that

$$\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^j = \left(\sum_{j=1}^{n} l_j, \sum_{j=1}^{n} m_j, \sum_{j=1}^{n} u_j\right)$$

We then compute the inverse of vector,

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^j\right]^{-1} = \left(\frac{1}{\sum_{j=1}^{n} u_j}, \frac{1}{\sum_{j=1}^{n} m_j}, \frac{1}{\sum_{j=1}^{n} l_j}\right)$$

Therefore

$$s_i = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right) \otimes \left(\frac{1}{\sum_{j=1}^{n} u_j}, \frac{1}{\sum_{j=1}^{n} m_j}, \frac{1}{\sum_{j=1}^{n} l_j}\right) \quad (1)$$

Secondly, the degree of possibility of $S_2=(l_2,m_2,u_2)\geq S_1=(l_1,m_1,u_1)$ is defined as

$$V(S_2 \geq S_1) = \sup\left[\min\left(\mu_{S_1}(x), \mu_{S_2}(y)\right)\right]$$

and can be stated as follows:

$$V(s_2 \geq s_1) = \begin{cases} 1, & \text{if } m_2 \geq m_1 \\ 0, & \text{if } l_1 \geq u_2 \\ \dfrac{l_1 - u_2}{(m_2 - u_2)(m_1 - l_1)}, & \text{otherwise,} \end{cases}$$

Figure 2 shows the intersection between m_1 and m_2

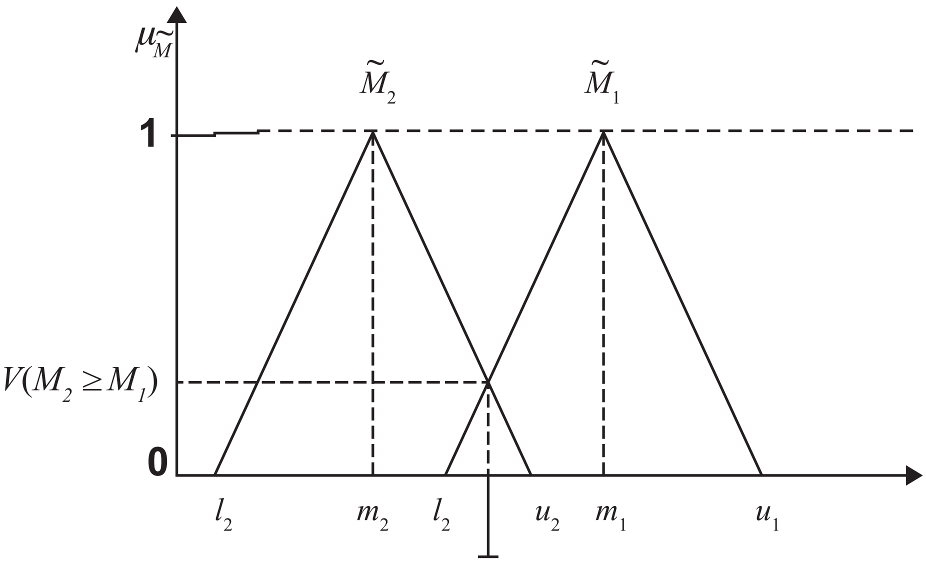

Figure 2: Intersection between m_1 and m_2

To compare s_1 and s_2, both the values of $V(s_1 \geq s_2)$ and $V(s_2 \geq s_1)$ are needed.
Thirdly, the degree possibility for a convex fuzzy number to be greater than k convex fuzzy numbers S_i (1,2,⋯,k)can be defined by

$V(S \geq s_1, s_2, \cdots, s_k) = V(S \geq s_1),\ V(S \geq s_2)$ $\cdots$ and $V(S \geq s_k) = \min V(S \geq s_i)$,
$i = 1,2,\cdots.k$

Assume that $d'(A_i) = \min V(s_i \geq s_k)$
$k = 1,2,\cdots,n \;\&\; k \neq i$. (3)

Then the weight vector is given by
$W' = (d'(A_1), d'(A_2), \cdots, d'(A_n))^T$ (4)

where $A_i (i = 1,2,\cdots,n)$ are n element. Via normalization, the normalized vectors are $W' = (d(A_1), d(A_2), \cdots, d(A_n))^T$, where W is non-fuzzy number.

Fuzzy ANP

Fuzzy ANP replaces the hierarchies into network structure, where criteria and sub-criteria are interdependent. Interdependence weights of the criteria are calculated, in which the dependencies among the criteria are assumed. Interdependence weights of criteria are calculated by multiplying degree of relative impact and local weight of criteria. Local weights are determined from the Chang extent analysis.

$w_{criteria} = \frac{1}{2}$ [Degree of relative impact for criteria x local weights of criteria].

$$W_{criteria} = \frac{1}{2}\left[\begin{pmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \cdots & \vdots \\ a_{m1} & \cdots & a_{mn} \end{pmatrix} \times d(A_1), d(A_2), \ldots d(A_n))^T\right] \quad (5)$$

Global weights of the sub-criteria are calculated by using interdependence weights of the criteria and local weights of sub-criteria.

Global sub-criteria weight =
local weight of sub-criteria × relative-interdependence weight of the criteria to which it belongs

$$= W_{criteria} \times d(A_1), d(A_2), \ldots d(A_n))^T \quad (6)$$

The eight-step computation is proposed as to ease the computational procedures. Linguistic data collected from the investigated region become the input data to the eight-step computational procedures. Details of the computations are presented in the following section

Computations and Results

Chang's extent analysis is utilised to calculate the fuzzy pairwise comparison weight matrix. The output of this extent analysis is local weights of criteria or sub-criteria (Goztepe *et al.,* 2013). The local weights are transformed into crisp numbers as to simplify the computation of the fuzzy ANP. The final global weights are obtained as a result of sequenced computation steps. This section presents a simplified eight-step computational procedures where the linguistic data are computationally processed to obtain global weights of the sub-criteria.

Step 1: Construct pairwise comparison matrix
A judgment made by an expert is translated into a pairwise comparison matrix of criteria.
Pairwise comparison matrix of criteria =

$$\begin{pmatrix} (1,1,1) & \left(\frac{3}{2},2,\frac{5}{2}\right) & \left(\frac{3}{2},2,\frac{5}{2}\right) \\ \left(\frac{2}{5},\frac{1}{2},\frac{2}{3}\right) & (1,1,1) & \left(\frac{3}{2},2,\frac{5}{2}\right) \\ \left(\frac{2}{5},\frac{1}{2},\frac{2}{3}\right) & \left(\frac{2}{5},\frac{1}{2},\frac{2}{3}\right) & (1,1,1) \end{pmatrix}$$

Step 2: Find the value of fuzzy synthetic extent using equation (1)
where

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = \left[\frac{2}{25},\frac{2}{21},\frac{10}{87}\right]$$

S_1 = Economics S_2 = Social
S_3 = Physical

$$S_1 = [l_1, m_1, u_1] = [0.32, 0.47619, 0.6897]$$

$$S_2 = [l_2, m_2, u_2] = [0.232, 0.3333, 0.4789]$$

$$S_3 = [l_3, m_3, u_3] = [0.216, 0.1905, 0.2682]$$

Step 3: Determine the degree of possibility of S_1, S_2, S_3 using equation (2)

$V(S_1 \geq S_2) = 1.0\,(m_1 \geq m_2) \qquad V(S_1 \geq S_3) = 1.0\,(m_1 \geq m_3)$

$V(S_2 \geq S_1) = 0.5265$

$V(S_2 \geq S_3) = 1.0\,(m_2 \geq m_3) \qquad V(S_3 \geq S_1) = 0\,(l_1 \geq u_3)$

$V(S_3 \geq S_2) = 0.20223$

Step 4: Find minimum of degree of possibility using equation (3)

$d'(A_1) = \min V(1.0, 1.0) = 0.5364$

$d'(A_2) = \min V(0.5265, 1.0) = 0.4094$

$d'(A_3) = \min V(0, 0.20223) = 0.0542$

Step 5: Find therelative local weights of criteriausing equation (4)

$$W' = \begin{pmatrix} 0.5364 \\ 0.4094 \\ 0.0542 \end{pmatrix}$$

Table 2 shows the local weights for respective criteria.

Table 2: Local weights of criteria

Criteria	Local Weights
Economics	0.5364
Social	0.4094
Physical	0.0542

The result suggests that the criteria of economics are relatively more important that other two criteria. It comprises more than 50% of relative local weights where interdependencies are not assumed.

Step 1 to Step 5 are iterated to obtain local weights for all sub-criteria. Table 3, Table 4, and Table 5 show the local weights for sub-criteria of economics, social and physical respectively.

Table 3: Local weights of sub-criteria (economics)

Economics	Local weights
Income	0.1283
Education	0.8717

Table 4: Local weights of sub-criteria (social)

Social	Local weights
Politics	0.1654
Public transport and communication	0.2194
Health care	0.2431
Public safety	0.1810
Power and water provision	0.1911

Table 5: Local weights of sub-criteria (physical)

Physical	Local weights
Environment	0.0000
Housing quality	0.4324
Social participation	0.5676

Step 6: Find the degree of relative impact for criteria

The three criteria are now assumed to be interdependent where one criterion depends on other criteria. The better judgment to deal with these interdependencies is through finding relative weight with respect to a criterion.

Again, Step 1 until Step 5 are iterated to obtain the relative impact of criteria and sub-criteria. However, at this stage, degree of impact is measured relatively one criterion with respect to another criterion. These degrees of relative impacts reflect the interdependencies among the criteria. Table's 6, 7 and 8 summarize the relative impact of criteria with respect to economics, social and physical respectively.

Table 6: Degree of relative impact of social and physical with respect to economics

Economics	**Degree of relative impact**
Social	0.6842
Physical	0.3158

Table 7: Degree of relative impact of economics and physical with respect to social

Social	**Degree of relative impact**
Economic	1.0
Physical	0

Table 8: Degree of relative impact of social and economic with respect to physical

Physical	**Degree of relative impact**
Social	0
Economic 1	.0

Step 7: Find the relative interdependence weight of criteria using equation (5).

The degree relative impact is multiplied by the local weights to obtain relative interdependence weights. Table 9 shows the relative interdependence weights of criteria.

Table 9: Relative interdependence weights of criteria

Criteria	**Relative Inter-dependence-weights**
Economic	0.5000
Social	0.3882
Physical	0.1118

The result suggests that the criteria of economics are relatively more important that other two criteria. It comprises exactly 50% of relative weights where interdependencies are assumed.
Step 8: Find global weights

Finally global weights for sub-criteria are calculated using the multiplication formula (see equation (6)).

Global weights represent the magnitude of each sub- criteria to the QOL. Table 10 shows the global weights of all sub-criteria. The assessment model indicates education as the highest global weight compared to other sub-criteria. It is good to note that the results identify three main sub-criteria contributed to the total QOL. The three sub-criteria are education, health care, and, public transport and communication.

Table 10: Global weights of sub-criteria

Sub-criteria	Global weights
Income	0.06415
Education	0.50000
Politic	0.06421
Public Transport and communication	0.08517
Health care	0.09437
Public safety	0.07026
Power and water provision	0.07419
Environment	0.00000
Housing quality	0.04834
Social participation	0.06346

The assessment model indicates education as the highest global weight compared to other sub-criteria. It is good to note that the results identify three main sub-criteria contributed to the total QOL. The three sub-criteria are education, health care, and, public transport and communication.

Conclusion

Assessment of QOL is not a straightforward process as too many criteria and sub-criteria need to be considered concurrently. There is no direct way to assess the QOL as different people have different opinion on the QOL (Cobb, 2000).

In this paper, fuzzy ANP has been applied as an assessment model in proposing weights of criteria and sub-criteria of QOL of a coastal community in Setiu Wetlands, Terengganu, Malaysia. Linguistic assessments provided by an expert were used as input data to the fuzzy ANP. The results suggest that economics is the most important criteria out of three criteria. Sub-criteria of education, health care, and, public transport and communication are identified as the main contributors to the QOL of Setiu Wetlands. The fuzzy ANP is found to be practically feasible and compatible not only in the industrial scenario, but also can be extended to social economics studies. This study has shown the ability of fuzzy ANP in finding a way to close the gaps between applications in industries and social research. However, the present study is far from comprehensive. Reliability of the results and sensitivity analysis are among the potential research areas that could be reserved for future research direction.

Acknowledgements

The authors would like to extend a deep appreciation to the Universiti Malaysia Terengganu for providing financial support under the Niche Research Grant Scheme (NRGS). This paper is an output of the NRGS project with vote number NRGS/2015/53131/7.

References

Agarwal, A. Shankar, R., & Tiwari, M. K. (2006). Modelling the metrics of lean, agile andleagile supply chain: an ANP-based approach. *European Journal of Operational Research,* 173: 211-225.

Ayag, Z., & Ozdemir, R. G. (2009) A hybrid approach to concept selection through fuzzy analytic network process. *Computers and Industrial Engineering,* 56(1): 368-379.

Bottero, M., & Mondini, G. (2008). An appraisal of analytic network process and its role in sustainability assessment in Northern Italy. *Management of Environmental Quality: An International Journal,* 19: 642-660.

Chang, D. Y. (1996). Application of the extent analysis method on fuzzy AHP ,*European Journal of Operational Research,* 95(3): 649-655.

Cobb, C. W. (2000). Measurement tools and the quality of life. Redefining Progress. San Francisco:www.rprogress.org/pubs/pdf/measure_qol.pdf.

Dagdeviren, M., & Yuksel, I. (2010). Using the fuzzy analytic network process (ANP) for Balanced Scorecard(BSC):A Case study for a manufacturing firm. *Expert Systems with Applications,* 37: 1270-1278.

Dagdeviren. M., & Yuksel, I. (2013). A fuzzy analytic network process (ANP) model for measurement of the sectoral competition level (SCL). *Expert Systems with Applications,*37: 1005-1014.

Govindan, K., Madan S. K., & Kannan, D. (2016). Application of fuzzy analytic network process for barrier evaluation in automotive parts remanufacturing towards cleaner production : A study in an Indian scenario. *Journal of Cleaner Production,* 114: 199-213.

Goztepe, K., Boran, S., & Yazgan, H. R. (2013). Estimating Fuzzy Analytic Network Process (FANP) Comparison Matrix Weights using Artificial Neural Network. *International Journal of Advanced Information Science and Technology,* 6(5): 1-14.

Hermawan, Fauzi, A., & Anshari, M. (2016). Performance measurement of project management by using FANP Balanced ScoreCard. *Journal of Theoretical and Applied Information Technology,* 83 (2): 262-269.

Kauffman, A., & Gupta, M. M. (1985). Introduction of fuzzy arithmetic*:* Theory and applications.Van Nostrand, New York.

Molinos-Senante, M., Gómez, T., Caballero, R., Hernández-Sancho, F. & Sala-Garrido, R. (2015). Assessment of wastewater treatment alternatives for small communities: An analytic network process approach. *Science of the Total Environment,* 532: 676-687.

Neaupane, K. M., & Piantanakulchai, M. (2006). Analytic network process model for landslide hazard zonation. *Engineering Geology,* 85: 281-294.

Niemura, M. P., & Saaty, T. L. (2004). An analytic network process model for financial-crisis forecasting. *International Journal of Forecasting,* 20: 573-587.

Nobar, M. N., Steak, M., & Tafti, A. F.(2011). Selecting Suppliers of 2nd Layer Suppliers by Utilizing FANP Procedure. *International Journal of Business and Management,* 6(2): 265-275.

Promentilla, M., Furuichi, T., Ishii, K., & Tanikawa, N. (2006). Evaluation of Remedial Counter measures using the Analytic Network Process. *Waste Management,* 26: 1410-1421

Saaty T. L. (1980). *The analytic hierarchy process*. McGraw-Hill Book Co, New York.

Saaty, T. L. (1996). *Decision making with dependence and feedback: The analytic network process*, RWS Publications, Pittsburgh.

Ulutas, B. H. (2005). Determination of the appropriate energy policy for Turkey. *Energy.* 30: 1146-1161.

Vinodh, S., Ramiya, R. A., & Gautham, S. G. (2011). Applications of fuzzy analytic network process for supplier selection in a manufacturing organization. *Expert Systems with Applications,* 38: 272-280.

Wicher, P., Zapletal, F., Lenort, R., & Staš, D. (2016). Measuring the metallurgical supply chain resilience using fuzzy analytic network process, *Metalurgija*. 55 (4): 783-786.

Wolfslehner, B., & Vacik, H. (2008). Evaluating sustainable forest management strategies with the analytic network process in a pressure-state-response framework. *Journal of Environmental Management,* 88: 1-10.

Zadeh, L. A. (1965). Fuzzy Sets. *Information and Control,* 8: 338-353.