



Jul 1st, 12:00 AM

Agent-based simulation of stakeholders' negotiation regarding land development scenarios using a fuzzy Analytic Hierarchy Process

Majeed Pooyandeh

Danielle J. Marceau

Follow this and additional works at: <https://scholarsarchive.byu.edu/iemssconference>

Pooyandeh, Majeed and Marceau, Danielle J., "Agent-based simulation of stakeholders' negotiation regarding land development scenarios using a fuzzy Analytic Hierarchy Process" (2012). *International Congress on Environmental Modelling and Software*. 52.
<https://scholarsarchive.byu.edu/iemssconference/2012/Stream-B/52>

This Event is brought to you for free and open access by the Civil and Environmental Engineering at BYU ScholarsArchive. It has been accepted for inclusion in International Congress on Environmental Modelling and Software by an authorized administrator of BYU ScholarsArchive. For more information, please contact scholarsarchive@byu.edu, ellen_amatangelo@byu.edu.

Agent-based simulation of stakeholders' negotiation regarding land development scenarios using a fuzzy Analytic Hierarchy Process

Majeed Pooyandeh^a and Danielle J. Marceau^b

^{a,b} *Geocomputing Laboratory, Department of Geomatics Engineering, University of Calgary, 2500 University Drive N.W, Calgary, AB, Canada T2N 1N4*

^a *mpooyand@ucalgary.ca, ^b dmarceau@ucalgary.ca*

Abstract: This paper describes an agent-based model (ABM) that was developed to simulate the negotiation process of stakeholders over different land development scenarios in the Elbow River watershed in southern Alberta, an area subject to considerable urbanization pressure due to its proximity to the fast growing City of Calgary. In this initial phase of development, the stakeholders represented as agents include representatives of a Municipal District and two non-profit organizations. The modeling framework contains three main components: a web interface designed to facilitate the interactions of the users with the system, a *PostgreSQL* database in which data regarding the stakeholders' preferences are stored that uses *PostGIS* plugin for spatial functionalities, and an ABM developed in Java that accesses *Repast Symphony* libraries to simulate the negotiation process among stakeholders. The negotiation starts by a development plan being submitted by a user (stakeholder) through the web interface. The ABM module receives this plan and conducts the negotiation process in a step-wise manner. In each time step, the agents move the proposed plan to a new location and evaluate that location based on their stored criteria, using GIS tools provided by *Repast Symphony* and *PostGIS*. The limits of the search space are specified by the plan proposer. As the decision makers are often not willing to assign crisp numerical values to the relative importance of their criteria, in this model the users compare their preferences using linguistic expressions. Due to the uncertainty and fuzzy nature of such comparisons, the agents make use of a fuzzy Analytic Hierarchy Process (AHP) to prioritize their criteria and to bring fuzziness into the pairwise comparison of AHP. In the final step, the ABM investigates the highly ranked locations of all agents to find a common area which is outputted as the result of the negotiation. The proposed simulation model facilitates the interactions of stakeholders who have different perspectives regarding potential land development scenarios in the watershed and allow them to reach an acceptable agreement considering their own preferences along with other stakeholders' preferences.

Keywords: Agent-based modeling, negotiation, Fuzzy analytic hierarchy process, coupled natural/human systems

1 INTRODUCTION

Landscapes are coupled natural/human systems in which both social and biological factors interact in shaping patterns and dynamics (Turner *et al.* 2007), and neglecting any of these components yields an incomplete picture (Walsh and McGinnis 2008). One of the most critical aspects of such systems is the role of "human actors". Due to the technical complexities involved in modeling human-like behaviors, this component has either been neglected or underestimated in computer modeling of natural systems. These difficulties are not only caused by the complicated nature of human decision making, but are also related to the interactions of human actors with themselves and their surrounding environment. Therefore, in many computer models, a community of people are substituted by an average, ignoring different and even conflicting viewpoints involved in that

community. Moreover many conflicts between the stakeholders can be resolved through consideration of others' viewpoints and appreciation of their perspectives (Forester, 1999).

The goal of this study is to incorporate viewpoints of human actors (stakeholders) in the context of land development in the Elbow River watershed in southern Alberta considered as a coupled natural/human system. Moreover this study aims at creating an environment through which the stakeholders can learn and appreciate each other's' perspectives about land development in the watershed and find the alternative plan that satisfies their preferences. To achieve this goal, an agent-based model was developed which employs the fuzzy AHP technique to simulate the negotiation process of the stakeholders. Compared to other methods, such as participatory approaches (Bousquet et al., 2005), optimization techniques (Ito et al. 2012), and knowledge-based approaches (Klein, 2004), the fuzzy AHP technique offers several advantages.

In participatory approaches, the status and legitimacy of the researchers in the process could be questionable (Bousquet et al., 2005); it also requires the strong involvement of the stakeholders throughout the modeling process, which is not feasible in many cases. Optimization techniques require *a priori* knowledge of the utility functions of the stakeholders (Kersten and Noronha, 1998), which are not always available or meaningful. In comparison, the fuzzy AHP is a multi-criteria decision making approach that takes into account the vagueness of the human thinking in a context of uncertainty. First proposed by Van Laarhoven and Pedrycz (1983), fuzzy AHP has long been used in group decision making (Mikhailov, 2003), though employing it in an ABM framework (López-Ortega and Rosales, 2011; Gao and Hailu, 2012) is a fairly new notion. While in classical AHP, the stakeholder is asked to provide a deterministic comparison of his criteria, in fuzzy AHP he can express them as linguistic judgment intervals (Leung and Cao, 2000).

In this paper, three stakeholders who represent a Municipal District and two non-profit organizations are represented as agents. A web-based application is developed so that the users (stakeholders) can easily access the system. During the negotiation process, agents of the model use the fuzzy AHP method to find the alternative which satisfies the preferences of all agents in a cumulative manner. The ABM serves as a simulation laboratory through which the stakeholders are able to explore various scenarios of land development and examine how their perspectives are perceived by other stakeholders in order to find the best-fit scenario.

2 METHODOLOGY

2.1 Study area

The Elbow River, which is an important tributary of the Bow River in southern Alberta, originates from Elbow Lake in the Elbow-Sheep Wildland Provincial Park in the Canadian Rockies. Passing Bragg Creek, Springbank and the Tsuu T'ina reserve, it enters the City of Calgary where it merges into the Bow River. The watershed occupies an area of 1200 km² and supports several uses including supplying the drinking water, irrigation for crops, and various recreational activities. Sixty-five percent of the watershed is located in the Kananaskis Improvement District and the remaining area is divided among the Municipal District of Rocky View (20%), the Tsuu T'ina Nation (10%), and the City of Calgary (5%) (Elbow River Watershed Partnership 2012). Figure 1 shows a detailed map of the watershed boundaries.

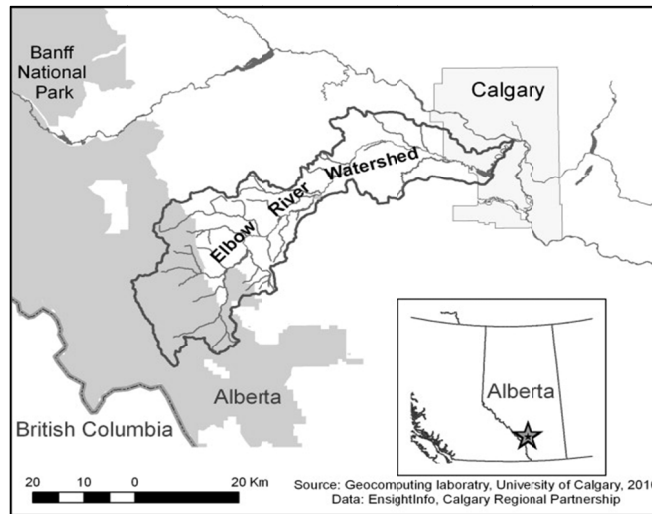


Figure 1. The Elbow River watershed

2.2 Implementation details

Figure 2 provides a schematic representation of the different components of the modeling system.

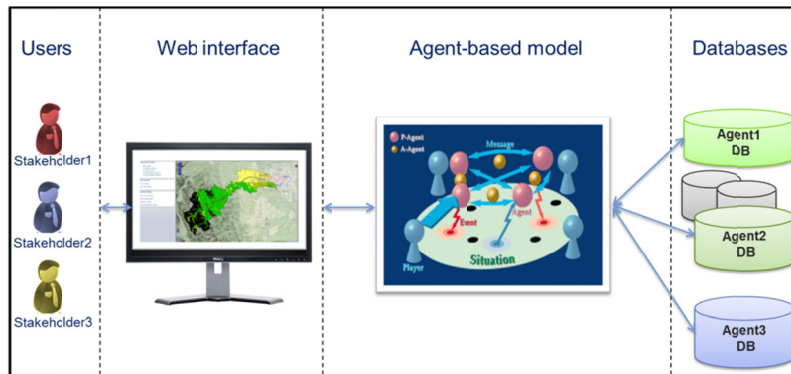


Figure 2. A schematic representation of the developed web-based ABM

2.2.1 Data collection and storage

The first step in the development of the proposed system is to collect data and store them in the databases. A main data source is the information gathered through interviews with stakeholders during which they discussed their mandate, goals, concerns, and preferences regarding the land development in the watershed. This information was used to build the database of each stakeholder. For instance if a stakeholder was concerned about preserving the aquifer, the map of the aquifer was obtained and inputted to the databases to be accessible by the ABM. Since the data were obtained through several sources, the *ArcGIS* software package was used for data preparation. The data preparation includes unifying the maps' coordinate systems and removing the non-developable regions in the study area. Information was also gathered about how each stakeholder evaluates a land development plan. This information was used to build the agents' behavior.

PostgreSQL was used as a free and open source object-relational database management system (ORDBMS) to store and manage these data. Apart from being free, the main reason for this selection is the spatial capabilities that PostGIS provides. PostGIS is an open source software program that adds support for geographic objects to the PostgreSQL database. Another reason for this selection is that PostGIS implementation is based on "light-weight" geometries and indexes that are optimized, which reduces disk and memory footprint. The communication

between the agents and the spatial data were enabled by PostGIS through SQL specifications.

2.2.2 Building the web interface

All the interactions of the users with the model are done through a web interface. These interactions include submitting a new land development plan, comparing the criteria regarding the evaluation of a plan, inputting the negotiation parameters, and receiving the results of the negotiation.

A set of online GIS tools are provided to the user by means of *OpenLayers* and *Geoserver*. Openlayers is an open source JavaScript library for displaying map data in web browsers while Geoserver is an open-source server written in Java which allows users to share and edit geospatial data. The components of the web interface was developed using Oracle ADF faces and functionalities were added to the client side using JavaScript.

2.2.3 Modeling the negotiation process

To perform a web-based ABM negotiation using the fuzzy AHP approach, the first step consists in asking the users to compare their criteria using linguistic expressions. Figure 3 shows the web page that was designed for the criteria comparison. Each row on this page contains three drop down menus. The left and right menus list two similar criteria, while the one in the centre contains the verbal comparisons which can be used to compare the two criteria.

Agricultural lands	Equally important	Green area
Agricultural lands	Weakly more important	Floodway area
Agricultural lands	Strongly more important	Environmental reserves
Wetland	Absolutely more important	Agricultural lands
Floodway area	Very strongly more important	Green area
Environmental reserves		Green area
	Equally important	
	Weakly more important	
	Strongly more important	
	Very strongly more important	
	Absolutely more important	

Submit

Figure 3. Web page designed for the linguistic comparison of stakeholders' criteria

The criteria comparison is stored in the respective database of each agent through the procedure described in section 2.2.1. After comparing the criteria, the user is permitted to submit a new land development plan using the web interface. A land development includes the location and dimensions of a new development. Along with this development plan, three main parameters are transferred to the ABM. The first one is the dimensions of the search space. By depicting this dimension the user conveys how flexible he/she is with the location of the plan. Another parameter that is entered by the user is the search interval, which depicts the resolution of the search. The third parameter which is determined by the user is his/her minimum satisfaction percentage. This is required to make a conditional sum of the results. The reason for applying such a minimum is to avoid a 100% satisfaction for one stakeholder while the other one is 0% satisfied.

After receiving the land development plan and the negotiation parameters, the ABM starts the negotiation in a step-wise manner. This step-wise simulation is performed using the scheduled methods of the Repast Symphony Java libraries. During each time step, the plan is moved to a new location where it is evaluated against the agents' criteria. To perform this evaluation, each agent connects to its database and performs several spatial and non-spatial analyses on the data using PostGIS and Repast Symphony functionalities. For example if the agent's criterion is to respect a setback from the river, the agent calculates the distance of the plan from the river boundary to obtain an evaluation of the plan from this point of view. After calculating the numerical values for these evaluations, the values are normalized to have a uniform scale for judgment.

Then each agent performs a fuzzy AHP operation on the results to prioritize the criteria and sort the locations based on the weighted criteria. The analytic hierarchy process (AHP) is an extensively used technique for multi criteria decision making (Saaty 2008). The basic idea behind the AHP is structuring the problem into a hierarchy of different levels. Each level of this hierarchy consists of a number of elements which can be compared to one another, two at a time. The AHP uses these comparisons to prioritize the elements of the hierarchy. Although the AHP approach has been a popular approach for several years, in many cases the decision maker's preference model is uncertain and fuzzy (Mikhailov 2003); therefore this approach is being criticized for neglecting the vagueness of the human thinking (Deng 1999). To avoid assigning crisp values to the human preference model, such uncertain judgments can be expressed as fuzzy sets or fuzzy numbers. Fuzzy set theory is a mathematical theory proposed by Zadeh [1965] to model the vagueness or imprecision of human cognitive processes.

A normal fuzzy set \tilde{N} is a triangular fuzzy number which can be expressed as (l, m, u) where where m is the most possible value and l and u are the lower and the upper bounds. This number has a linear piecewise continuous membership function $\mu_{\tilde{N}}(x)$ with the following characteristics (Dubois and Prade 1980):

1. A continuous mapping from \mathfrak{R} to the closed interval $[0,1]$;
2. $\mu_{\tilde{N}}(x) = 0$ for all $x \in [-\infty, l]$ and for all $x \in [u, +\infty]$;
3. Strictly linearly increasing on $[l, m]$ and strictly linearly decreasing on $[m, u]$;
4. $\mu_{\tilde{N}}(x) = 1$ for $x = m$.

The fuzzy AHP process workflow contains four main steps:

1- Fuzzifying the crisp pairwise comparison matrix

After the user submits the pairwise comparison of his criteria by verbal judgments, the pairwise comparison matrix of criteria is built using Table 1. In the first step, the

crisp PCM, $A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{m1} & \cdots & a_{mn} \end{bmatrix}$ is fuzzified using the membership function to obtain the fuzzy PCM, $\tilde{A} = \begin{bmatrix} a_{11l}a_{11m}a_{11u} & \cdots & a_{1nl}a_{1nm}a_{1nu} \\ \vdots & \ddots & \vdots \\ a_{m1l}a_{m1m}a_{m1u} & \cdots & a_{mnl}a_{mnm}a_{mnu} \end{bmatrix}$.

Table 1. Scales in pairwise comparisons (Adapted from Saaty 2008)

<i>Intensity of importance</i>	<i>Verbal judgment of preference</i>
1	Equally Important
3	Weakly more important
5	Strongly more important
7	Very strongly more important
9	Absolutely more important

2. Fuzzy extent analysis

Fuzzy extent analysis is applied to get the fuzzy decision or performance matrix (\tilde{X}_i) and fuzzy weights \tilde{W} . This will yield the fuzzy weighted performance matrix \tilde{P} .

$$\tilde{X}_i \text{ or } \tilde{W}_j = \frac{\sum_{j=1}^k \tilde{a}_j}{\sum_{i=1}^k \sum_{j=1}^k \tilde{a}_{ij}}$$

$$\tilde{X}_i = \begin{bmatrix} (x_{11l}x_{11m}x_{11u}) \\ (x_{21l}x_{21m}x_{21u}) \\ \vdots \\ (x_{ijl}x_{ijm}x_{iju}) \end{bmatrix} \quad \tilde{P} = \tilde{X}_i * \tilde{W} = \begin{bmatrix} (w_lx_{11l}w_mx_{11m}w_mx_{11u}) \\ (w_mx_{21l}w_mx_{21m}w_mx_{21u}) \\ \vdots \\ (w_mx_{ijl}w_mx_{ijm}w_mx_{iju}) \end{bmatrix} = \begin{bmatrix} P_{1l}P_{1m}P_{1u} \\ P_{2l}P_{2m}P_{2u} \\ \vdots \\ P_{il}P_{im}P_{iu} \end{bmatrix}$$

When this stage is finished, the total weighted performance matrix for each alternative is calculated.

3. Alpha cut analysis

To make a crisp choice among the alternatives, the alpha-cuts-based method is needed for checking and comparing fuzzy numbers (Wang 1997). The alpha cut is determined to account for the uncertainty in the fuzzy range chosen.

$$\tilde{P}_\alpha = \begin{bmatrix} [p_{1l\alpha}, p_{1r\alpha}] \\ [p_{2l\alpha}, p_{2r\alpha}] \\ \vdots \\ [p_{il\alpha}, p_{ir\alpha}] \end{bmatrix}$$

$$\alpha_{Left} = [\alpha * (Middle_fuzzy - Left_fuzzy)] + Left_fuzzy$$

$$\alpha_{Right} = Right_fuzzy - [\alpha * (Right_fuzzy - Middle_fuzzy)]$$

4. Lambda function and normalization of crisp values

Through the alpha cut analysis, two values are obtained, namely Alpha_Right (maximum range) and Alpha_Left (minimum range), which need to be converted into a crisp value. This is done by applying the Lambda function which represents the attitude of the stakeholder.

$$Crisp_Value = \lambda * \alpha_{Right} + [(1 - \lambda) * \alpha_{Left}]$$

$$C_{i\lambda} = \frac{C_{i\lambda}}{\sum C_{i\lambda}}$$

$$C_\lambda = \lambda * p_{r\alpha} + (1 - \lambda) * p_{l\alpha}, \text{ where } \lambda = [0,1]$$

$$C_\lambda = \begin{bmatrix} C_{1\lambda} \\ C_{2\lambda} \\ \vdots \\ C_{i\lambda} \end{bmatrix}$$

After prioritizing the alternative locations for each agent, a conditional sum is conducted to find the location that is most satisfying to all agents. The results are summed based on the minimum satisfaction percentage inputted by the user. By enforcing the conditional summation of results, we ensure that all agents are satisfied at a certain level. This will avoid a result which is biased towards a single agent or a group of agents.

2.2.4 Running simulations

In a run of the system, four main steps are followed:

1. A land development plan, along with a number of parameters is proposed by the user through the web interface and is transferred to the ABM.
2. At each time step, each agent in the model moves the development plan around a search space and evaluates each new location.
3. Each agent employs the fuzzy AHP approach to prioritize the locations based on its stored preferences.
4. The agents report the results and the best location for the development plan is determined through a conditional sum of the results.

To test the capabilities of the system, a hypothetical land development plan along with the negotiation parameters were proposed through the web interface (refer to section 2.2.3 for the details regarding these parameters). The model was tested using three agents.

3 RESULTS

Figure 4 illustrates the web page designed for the output of the negotiation process. The location proposed as the most satisfactory location for all agents is shown in this figure. A transparent mesh is overlaid on top of the map that represents the candidate locations which have been evaluated by the agents. On

the left side of the page, the satisfaction factors for each agent at each location are displayed both in a table and as a graph. The conditional overlay performed in this study guarantees that all agents are satisfied to a certain degree, which is 60% for this study. If the minimum satisfaction for all agents is not satisfied, the procedure is repeated with a new search area.

To evaluate the results of our system, an offline procedure was conducted to compare the results. The analyses that were performed by the agents using PostGIS and Repast Symphony, were manually performed using the ArcGIS software package, i.e. at each time step, the spatial analyses were manually performed. Then the results of these analyses were inputted to a MATLAB software package to conduct the fuzzy AHP procedure and prioritize the locations for each agent. The results of the two different procedures yielded the same location as the outcome.

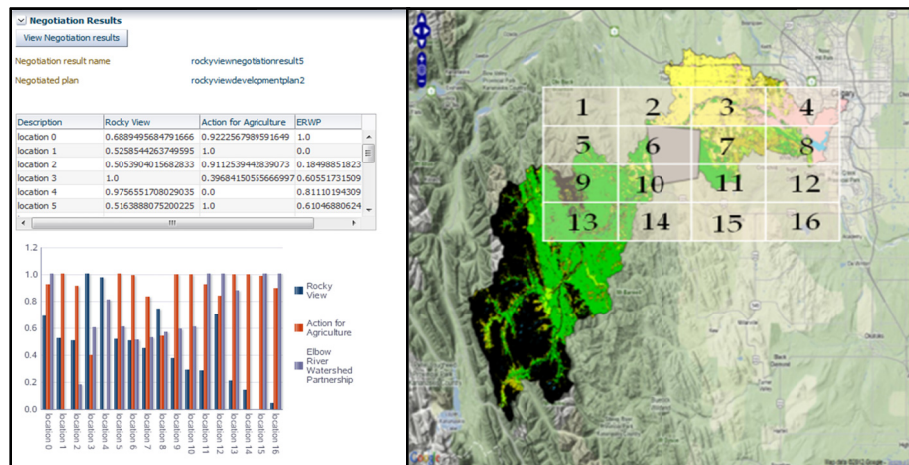


Figure 4. Results of the negotiation process: left) the score of each evaluated location for each agent, right) the evaluated locations and the position of the selected location

4 CONCLUSIONS

The goal of this study was to consider the perspectives of different stakeholders regarding land development scenarios in the Elbow River watershed. Through this incorporation the stakeholders can learn about each other's preferences and ideals and appreciate a perspective which might conflict with their own goals. While in many real world cases the preferences of less influential stakeholders are underestimated, in this study the agents don't have any priority over each other.

This model facilitates interaction and learning among the stakeholders through a number of ways. First, working with this model enables them to observe how their desired land development scenario is perceived by others and to understand each other's perspectives. This could lead to a collective learning of the issues regarding the land development in the watershed.

To hide the complexities of the computer model, an easy-to-use web interface was designed to address the needs of users with any level of expertise. Moreover, a fuzzy approach was implemented to avoid assigning crisp values to the stakeholders' preferences. Work currently in progress consists in running the model with additional agents and data corresponding to real land development scenarios to assess the utility of the proposed system in guiding decision making. Moreover new algorithms are being tested to make the whole negotiation process automated, i.e. if the satisfaction is not obtained in the first step, the agents change their weights automatically to facilitate the negotiation.

ACKNOWLEDGMENTS

This research is funded by a research grant awarded to D. J. Marceau by GEOIDE (Canadian Network of Centres of Excellence in Geomatics) and Tecterra, and by University of Calgary's scholarships awarded to M. Pooyandeh. We thank all the stakeholders for their invaluable contribution to this project.

REFERENCES

- Bousquet, F., Trebil, G., Hardy, B. (Eds.), Companion modeling and multi-agent systems for integrated natural resource management in Asia. IRRI Press, Los Banos, the Philippines, 2005.
- Deng H., Multi-criteria analysis with fuzzy pairwise comparisons, *International Journal of Approximate Reasoning*, 21: 215–231, 1999.
- Dubois D. and Prade H., *Fuzzy Sets and Systems*, Academic Press, New York, 1980.
- Elbow River Watershed Partnership., 2012. <http://www.erwp.org/index.html>.
- Forester, J., *The deliberative practitioner: encouraging participatory planning processes*, Cambridge, MA, MIT Press, 1999.
- Gao, L., and Hailu, A., Ranking management strategies with complex outcomes: an AHP fuzzy evaluation of recreational fishing using an integrated agent-based model of a coral reef ecosystem, *Environmental Modelling and Software*, 31: 3-18, 2012.
- Ito T., M. Zhang, V. Robu, S. Fatima, T. Matsuo, New trends in agent-based complex automated negotiations, *Studies in Computational Intelligence*, 383, 2012.
- Kersten, G.E., Noronha, S.J., Rational agents, contract curves, and inefficient compromises. *IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans*, 28: 326-338, 1998.
- Klein, M., A knowledge-based methodology for designing reliable multi-agent systems. In: *Fourth International Workshop on Agent-Oriented Software Engineering*. P. Giorgini, J. Müller and J. Odell (Eds). LNCS 2935: 85–95, Springer-Verlag, 2004.
- Leung, L.C. and Cao, D., On consistency and ranking of alternatives in fuzzy AHP, *European Journal of Operational Research*, Vol. 124: 102-113, 2000.
- López-Ortega O, Rosales M-A., An agent-oriented decision support system combining fuzzy clustering and the AHP, in *Expert Systems with Applications*, 38 (7): 8275-8284, 2011.
- Mikhailov L., Deriving priorities from fuzzy pairwise comparison judgments, *Fuzzy Sets and Systems* 134: 365–385, 2003.
- Saaty T.L., Relative measurement and its generalization in decision making: Why pairwise comparisons are central in mathematics for the measurement of intangible factors - The Analytic Hierarchy/Network Process, *RACSAM (Review of the Royal Spanish Academy of Sciences, Series A, Mathematics)*, 102(2): 251–318, 2008.
- Turner B.L.I., Lambin E.F., Reenberg A., The emergence of land change science for global environmental change and sustainability. *Proceedings of the National Academy of Sciences of the United States of America*, 104(52): 20666–20671, 2007.
- Van Laarhoven, P.J.M., Pedrycz, W., A fuzzy extension of Saaty's priority theory. *Fuzzy Sets and Systems* 11: 229-241, 1983.
- Walsh, S.J., and McGinnis D., Biocomplexity in coupled human-natural systems: The study of population and environment interactions. *Geoforum* 39:773-775, 2008.
- Wang, L. X., *A Course in Fuzzy Systems and Control*. United States of America: Prentice-Hall, 1977.
- Zadeh L. A., *Fuzzy sets Information and Control*, 8(3): 338-353, 1965.