Group Decision Making and Graphical Visualization in E-cognocracy[1]
Toma de Decisiones en Grupo y Visualización Gráfica en E-cognocracia

Alberto Turón Lanuza, José María Moreno Jiménez and Adrián Toncovich
Zaragoza Multicriteria Decision Making Group
Faculty of Economics, University of Zaragoza, Spain
http://gdmz.unizar.es
turon@unizar.es; moreno@unizar.es; toncovic@unizar.es

Abstract

E-cognocracy [Moreno-Jiménez, 2003, 2006; Moreno-Jiménez and Polasek, 2003, 2005] is a new democratic system conceived for the purpose of extracting and diffusing the knowledge derived from the scientific resolution of complex problems that arise in the field of public decision making. For both the modelling and resolution of problems and the diffusion of knowledge, e-cognocracy uses multicriteria decision making techniques. Similarly, with the aim of facilitating knowledge extraction, discussion through collaborative tools, the negotiation processes between the actors involved in the resolution of the problem and both individual and collective learning, e-cognocracy employs a wide range of graphical visualization tools.

This paper presents a set of procedures oriented towards group decision making, for both a reduced and a high number of actors, which use graphical visualization as starting point in the creation of knowledge all the participants involved in the problem resolution. These procedures show the potential of the graphical visualization tools that have been developed within our research group, the Zaragoza Multicriteria Decision Making Group (GDMZ).

Keywords: e-democracy, e-cognocracy, multicriteria decision making, AHP, group decision making, graphical visualization.

Resumen

La e-cognocracia [Moreno-Jiménez, 2003, 2006; Moreno-Jiménez y Polasek, 2003, 2005] es un modelo de representación democrática orientado hacia la extracción y democratización del conocimiento derivado de la resolución científica de los problemas complejos planteados en el ámbito de las decisiones públicas. Tanto en la modelización de los problemas como en la resolución de los mismos y la difusión del conocimiento, la e-cognocracia utiliza técnicas de decisión multicriterio. Asimismo, con el fin de favorecer la extracción de conocimiento, la discusión a través de herramientas colaborativas, los procesos de negociación entre los actores implicados en la resolución del problema y, en general, el aprendizaje tanto individual como colectivo, la e-cognocracia recurre a diversas herramientas de visualización gráfica.

En este trabajo se presentan diferentes procedimientos para la toma de decisión en grupo, tanto para un número reducido como elevado de actores, que utilizan la visualización gráfica como punto de partida en la generación de conocimiento llevada a cabo por todos los participantes implicados en la resolución del problema. Estos procedimientos muestran el potencial de las técnicas de visualización gráfica que se han venido desarrollando en los últimos años en el seno del Grupo Decisión Multicriterio Zaragoza (GDMZ).

Palabras clave: e-democracia, e-cognocracia, decisión multicriterio, AHP, decisión en grupo, visualización gráfica.

1 Introduction

The evolution of the Knowledge Society has brought a variety of changes to the way in which decision making problems are tackled: philosophical (holistic vision of reality), methodological (integration of the intangible) and technological (communication networks). We are in a position to consider problems of a complexity unimaginable a

---

few years ago, by means of approaches made available to individuals that are highly specialized in these contexts. These approaches allow us to make decisions with multiple criteria and actors in a more open, flexible and effective manner than ever before.

As far as public decision making is concerned, one of the aspects that generates most interest is the electronic government of citizens. *E-cognocracy* is a new democratic system conceived for the purpose of extracting and diffusing the knowledge derived from the scientific resolution of problems in the field of public decisions. It allows the citizen to directly take part in the government of society, improving transparency, creativity and social learning. Based on the use of multicriteria decision making techniques as the methodological support, Internet as the communication system and democracy as the catalyzing element of the creation and social diffusion of the knowledge it advocates, this democratic system stimulates the learning procedure intrinsic to the cognitive process that characterizes the human being.

In this field, we find the different tools developed by the *Zaragoza Multicriteria Decision Making Group* during the last ten years that are applied with one of the most widespread multicriteria techniques, the *analytic hierarchy process* (AHP). This technique [Saaty, 1980] allows the integration of the wide range of aspects that form reality and the different perceptions that the actors involved in the resolution of a decision making problem have of that reality. The flexibility and adaptability of AHP has enabled its effective use in the resolution of highly complex problems characterized by the existence of multiple scenarios, criteria and actors. In order to facilitate knowledge extraction, discussion through collaborative tools, the negotiation processes between the actors involved in the problem resolution and both individual and collective learning, we make use of graphical visualization tools, as proposed by Turón and Moreno-Jiménez (2006).

These tools enable the analysis of multidimensional data series in order to help the human brain understand the world: the analytic hierarchy process is used to prioritize and choose between a discrete number of alternatives in a multiactor and multicriteria environment with the aim of detecting and identifying behaviour patterns in group decision making. At the same time, graphical visualization tools foster the incorporation of the perceptual abilities of the human brain into the decision making process by assisting in the tasks of data exploration and interaction, information extraction and knowledge generation. They therefore aid the analysis and interpretation of the results. Furthermore, graphical information visualization improves our response time and enables us to extract knowledge form this information more quickly. This is especially true when either the data base size or its complexity make the analytical study of the problem difficult. In addition, graphical visualization increases the degree of reliability in terms of conclusions [Keim, 2002].

The rest of this paper has been structured as follows: Section 2 describes the graphical visualization tools that the GDMZ has developed for AHP; Section 3 presents three cases in which the tools have been applied with the aim of extracting and sharing the knowledge derived from their scientific resolution; Section 4 highlights the most important conclusions of the work.

2 Graphical visualization tools for *e-cognocracy*

To increase the effectiveness of AHP methodology in the resolution of high complexity problems, such as those which arise in *e-cognocracy*, our research group has developed several graphical visualization tools for group decision making with AHP:

2.1 Value paths and radial representation for preference structures and alternatives

One of the more outstanding aspects of AHP (and something that differentiates it from other multicriteria techniques) is that it measures the inconsistency of the actors when eliciting the judgements in a way that is formal, elegant and intrinsic to the mathematical procedure.

Defining *consistency* as the cardinal transitivity in the judgements, that is to say, $a_{ij}a_{jk} = a_{ik}$ for all $i, j, k = 1,...,n$, the measure proposed by Saaty (1980) for evaluating the inconsistency of a pairwise comparison matrix $A_{nxn}=(a_{ij})$, known as *Saaty's consistency ratio,* is given by:

$$CR = \frac{CI}{RI(n)} \tag{1}$$

where $CI = \dfrac{\lambda_{\max}(A) - n}{n - 1} = \dfrac{1}{n(n-1)}\sum_{i \neq j}(e_{ij} - 1)$; $\lambda_{\max}$ is the principal eigenvalue of $A=(a_{ij})$; $RI(n)$ is the random

consistency index for matrices of order n [Aguarón and Moreno-Jiménez, 2003], and $e_{ij} = a_{ij}\dfrac{\omega_j}{\omega_i}$ is the error

obtained when using a_{ij} to estimate ω_i/ω_j.

We define the *preference structures distribution* associated to an interval judgment matrix, as the probability distribution of the $n!$ possible ranking (preference structures) of the n alternatives. The GDMZ has developed several tools for analyzing the evolution of preference structures and favourite alternatives [Moreno-Jiménez *et al.,* 2005a, 2007a].

The *value paths for preference structures* diagram (Fig. 1A) shows the evolution, for different *CRs*, of the probability of each preference structure generated with means of the method. The *value paths for alternatives* diagram (Fig. 1B) shows the evolution for different *CRs* of the probability that each alternative was selected as the best (greater priority). Based on a system of parallel coordinates, each data dimension is represented in a vertical axis and all of them equally spaced. In this way, every element of the multidimensional space is mapped into a polygonal line crossing all the axes.

Radial representations map every preference structure or alternative into a planar polygon whose vertices are placed at the end of rays cast from a central point. These rays correspond to the different consistency ratios and their length is proportional to the probability of the associated preference structure or alternative. All the rays are equally spaced and the resulting polygon is obtained by joining every vertex to its neighbours. In both cases (preference structures and alternatives) the polygons obtained are shown in a table which allows us to appreciate the evolution of all them at a glance.
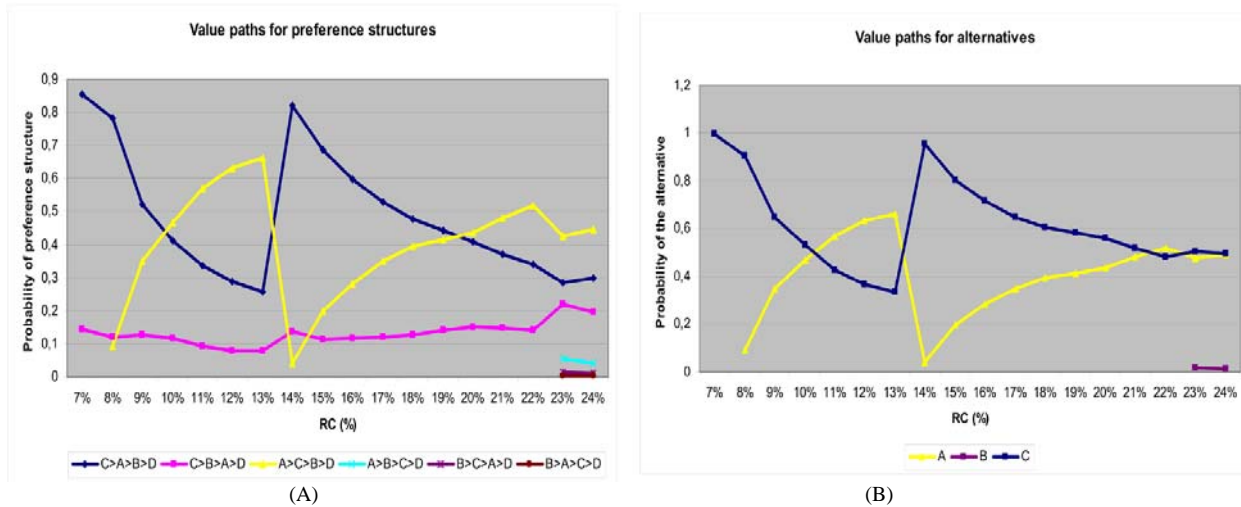

Fig. 1. Value paths for preference structures (A) and for alternatives (B)

2.2 Judgement inconsistency density plot

Once the AHP priorities ω_i have been obtained by means of existing prioritization methods [Saaty, 1980; Aguarón and Moreno-Jiménez, 2003], the judgement inconsistency can be visualized by observing the error made in its estimation: $e_{ij} = a_{ij}(\omega_j/\omega_i)$. The *judgement inconsistency matrix* $\Delta_{n \times n} = (\delta_{ij})$ is created for that purpose, being

$\delta_{ij} = \min\{e_{ij}, e_{ij}^{-1}\}$. This symmetric matrix values range from 0 to 1 and the more inconsistent are the judgements between the pairs considered, the closer to 0 they are; on the contrary, the more consistent the judgements are, the closer they are to 1. This matrix aims to help the decision maker detect critical judgements and alternatives. To that end, especially when the judgement matrices have a high dimension, the *judgement inconsistency density plot* [Turón and Moreno-Jiménez, 2004] is drawn, replacing each element in the matrix by a color selected from a scale varying from white (maximum consistency) to intense red (no consistency at all). The colour scale allows us to locate the more inconsistent judgements, that is to say, those that the decision maker should check (see Fig. 2). The *alternative inconsistency density plot* is defined in the same way.

Defining the *inconsistency density index* as $\Delta(A) = \frac{1}{n(n-1)} \sum_{i \neq j} (1 - \delta_{ij})$ we obtain a global measure for the inconsistency of a pairwise comparison matrix. This definition follows the schema used by Saaty (1980) to define the consistency index, but a multiplicative definition could also be given, in which the global inconsistency is the geometric mean of the matrix inconsistencies: $\Delta(A) = (\prod_{i<j} \delta_{ij})^{1/n}$.
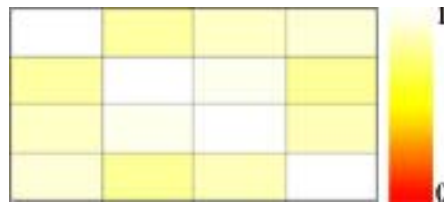

Fig. 2. Judgement inconsistency density plot for an AHP problem

2.3 Ternary diagrams and preference structures/decision makers location plots

Moreno-Jiménez *et al.* (2005b) present a procedure for determining the preference structures associated to each of the different groups of actors that can be identified in a group decision making problem with a large number of individuals. On the basis of the individual priorities and using tools analogous to those of multidimensional scaling, different clusters of decision makers and the associated preference structures are identified. The algorithm is a variation of the *k*-media algorithm, in which the role of the centroids is played by the consensus distribution of the group priorities vector, as defined by Gargallo *et al.* (2006). *Ternary diagrams* (Fig. 3A) represent the individual priorities and the consensus priorities of each group and *preference structures/decision makers location plots* (Fig. 3B) show the relative position of the different preference structures or alternatives and the behaviour of the different decision makers.

The inconsistency level *l* is a parameter that can be selected in each situation, representing how close are the opinions of different decision makers; changes made in this value lead to different clusters of decision makers. The above diagrams have been obtained with inconsistency levels of *l*=0.00, *l*=0.50 and *l*=0.75, respectively.

2.4 Consensus density diagrams

Consensus density diagrams [Moreno-Jiménez *et al.*, 2005b] represent the density of the spatial distribution over the simplex for the different preference structures. They use the consensus distribution mentioned in the previous section and generate, by computer simulation, a set of distribution values and obtain the individual priorities. Such a distribution can be represented either by a three dimensional picture or by a diagram in which every point is drawn in a different colour intensity which is proportional to its density (Fig. 4).
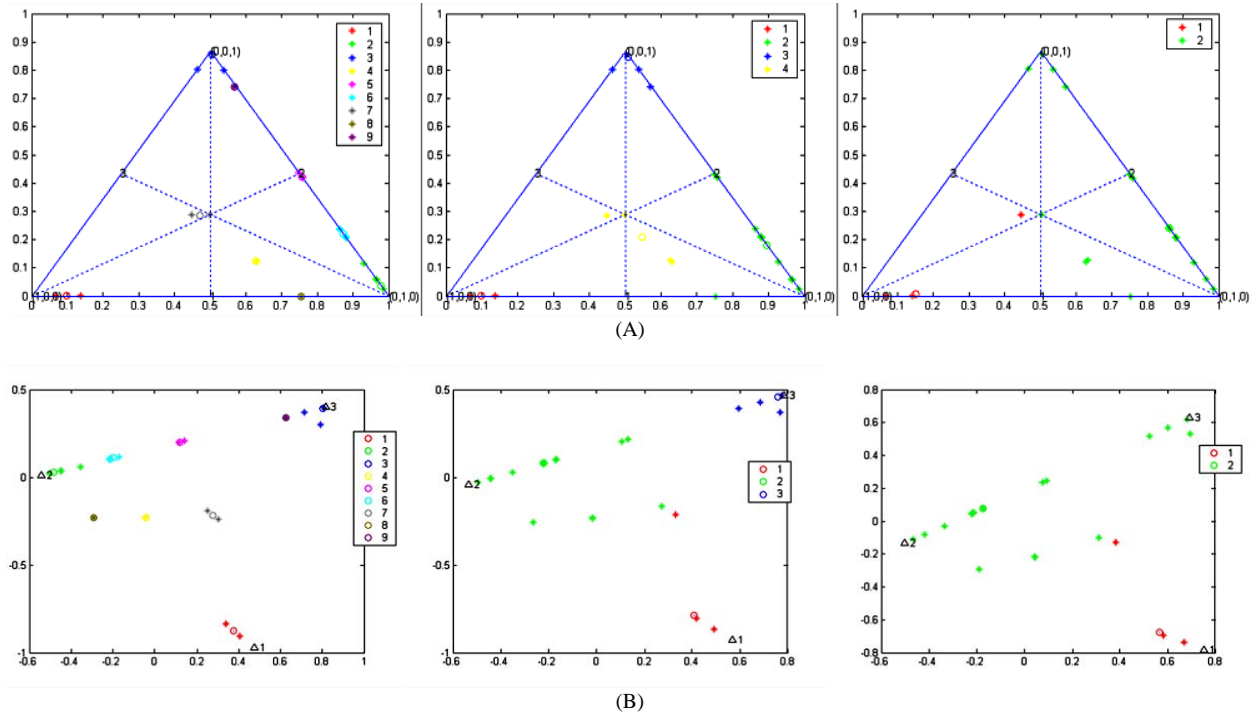
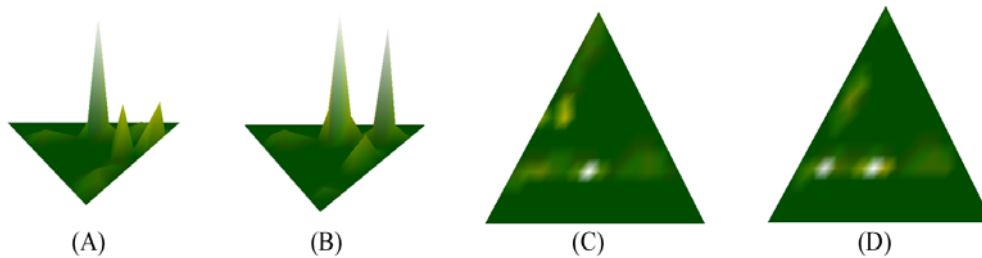**Fig. 3.** Ternary diagrams (A) and preference structures/decision makers location plots (B)

Fig. 4. Consensus density diagrams: (A) 3D view for $e_{max} = 200$; (B) 3D view for $e_{max} = 500$;
(C) density diagram for $e_{max} = 200$; (D) density diagram for $e_{max} = 500$

The three-dimensional view gives wider information on the position of every decision maker with respect to the consensus group; ternary diagrams do not show this information. The three-dimensional graphics of Fig. 4 have been obtained from a geometric model of the simulated data; this allows us to interactively modify the viewpoint by means of a 3D visualization tool. This is an important advance in the data interpretation and knowledge extraction phase as these kinds of tools enable easy identification of patterns associated with the different attitudes, individual or collective, in the set of decision makers. As in the previous case, a parameter, e_{max}, represents the threshold wihtin which different decision makers belong to the same group.

2.5 Ternary diagrams for voting problems in several rounds

In an electronic voting problem, with several rounds and an intermediate discussion, visual inspection of the ternary diagrams generated in each round demonstrates how the decision makers and the decision making groups vary their preferences with respect to each alternative, as can be seen in Figure 5 [Turón and Moreno-Jiménez, 2007]. Three

groups of decision makers are obtained, depending on their most preferred option. Each group is represented by a colour; triangles are decision makers and for every group the corresponding square indicates the centroid. The asterisk indicates the centroid of the whole set of decision makers.
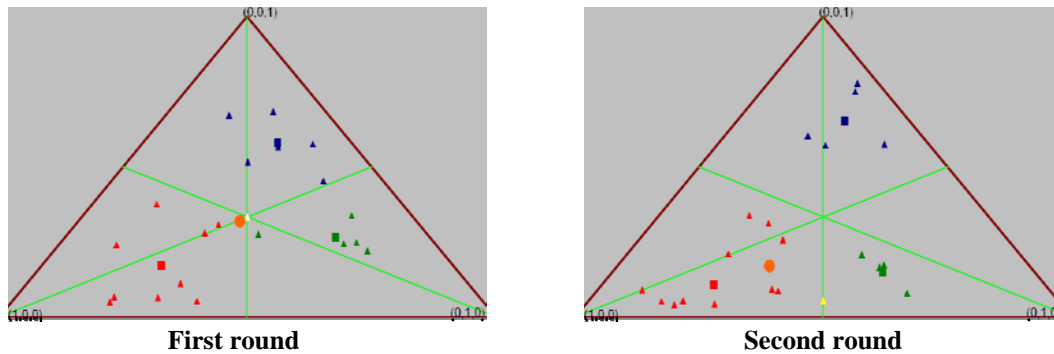

First round   **Second round**

Fig. 5. Ternary diagram for a voting problem in two rounds

2.6 Area diagram

A new ternary diagram, the *area diagram* [Turón and Moreno-Jiménez, 2007], represents the convex hull of each group of decision makers. The variation of the area between both rounds can be interpreted as a measure of the change in the preferences expressed by each decision maker for each alternative. We therefore have both a numerical measure and a visual representation of such variation at our disposal (Fig. 6).
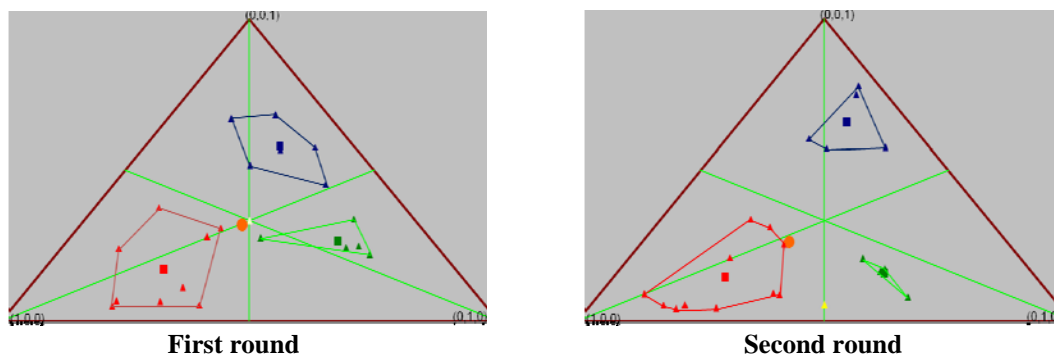

First round   **Second round**

Fig. 6. Area diagrams for the voting problem of the previous section

2.7 Intertemporary evolution diagrams

For in-depth knowledge of the influence that the intermediate discussion has on each decision maker we need to track the changes in their respective location in the ternary diagram from one round to the other. Two *intertemporary evolution diagrams* have been developed [Turón and Moreno-Jiménez, 2007] for this purpose; the individual preferences for two different instants can be easily visualized, as well as the temporary evolution (Fig. 7). In diagram (A) every arrow is represented by an intensity proportional to its lenght; diagram (B) uses a colour code that stresses the changes in the decision maker priority. Red, green and blue arrows represent decision makers whose preference is alternative 1, 2 or 3 in both rounds, respectively. Arrows with an interweaving combining different colours indicate the various changes in the preference from one round to the other.
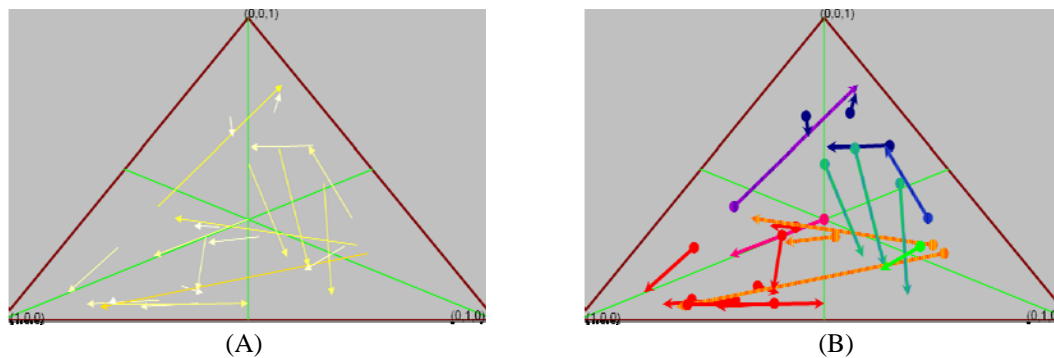
(A)   (B)

Fig. 7. Intertemporary evolution diagrams for the problem of previous sections

3 Implementation

The tools we propose here have been implemented in the module AHP-GDM, developed in Visual Basic for Microsoft Excel. The interactivity of the spreadsheet makes these graphs a powerful tool for the analysis of information, for understanding preference structures behaviour and the exploration of their inter-relationships. The data used to illustrate these applications come from several projects undertaken by our group:

(i) A survey of second year students at the Faculty of Economics in Zaragoza, asking them to express the intensity of their preferences for three options related to the Treaty establishing a Constitution for Europe, approved by Spanish citizens on the 20th of February, 2005. The three options proposed were: (A) to accept the Treaty; (B) to reject the Treaty; (C) to call to a new, binding referendum. From the results, the preference structures of each student were obtained using AHP.

(ii) A Participative Budget for the Zaragoza City Council (Spain) [2] . Using AHP as the multicriteria methodological support and the Internet as the communication tool to obtain the preferences of each individual, the amount of the budget that the district of *El Rabal* (Zaragoza) assigns to each one of four alternatives proposed by the Neighbourhood Associations and the members of the District Council was obtained. The four alternatives were prioritized, taking into account three criteria and six subcriteria. The graphics exclusively consider the prioritization problem presented at the first level of the hierarchy, where three criteria (Economic, Social and Environmental) hang from the goal of the problem. From the individual priorities, we set up decision maker opinion groups and from these groups we obtained the preference structure associated with them. The graphical visualization tools were then applied to the preference structures.

(iii) A workshop held on March the 1st 2007 within the framework of the *II Congress on E-Commerce* arranged by the University of Zaragoza GDMZ and Communications Technology (GTC) groups and the Zaragoza City Council[3]. The objective was to show the user the features of an ideal electronic voting system. A case study based on the location or rejection of a NATO intelligence base in the vicinity of Zaragoza was used. A detailed account of the problem can be found in Moreno-Jiménez *et al.* (2007b). To model the problem, a hierarchy common to all decision makers was designed; four criteria were considered (C1: benefits, C2: costs, C3: opportunities and C4: risks) and three alternatives (A1: locate; A2: locate at more than 50 km from the city; and A3: do not locate). The experiment involved 21 participants at the JCEL Seminar; each participant was issued with a smart card for use as identification in the poll.

---

[2] http://www.zaragoza.es/presupuestosparticipativos/ElRabal/
[3]http://jcel.unizar.es

4 Conclusions

Several graphical visualization tools have been constructed that are oriented towards the detection and identification of patterns of behaviour in group decision making when the analytic hierarchy process (AHP) is used to prioritize and select between a discrete number of alternatives in a multiactor and multicriteria environment. These tools have been implemented as part of the spreadsheet module AHP-GDM, developed with Microsoft Excel and Visual Basic. They favour the perception of consensus paths between the actors involved in the resolution of the problem, the interpretation of the results and the extraction of the underlying knowledge associated with the decisional process that is useful in the subsequent negotiation processes.

   The knowledge derived from the perception of these figures wolud be employed as an initial step in the iterative resolution process followed in the consensus building.

References

1. **Aguarón, J.,** and **J. M. Moreno-Jiménez,** "The Geometric Consistency Index: Approximated Thresholds". *European Journal of Operational Research,* 147(1), 137-145 (2003).
2. **Gargallo, P., J. M. Moreno-Jiménez,** and **M. Salvador,** "AHP-Group Decision Making: A Bayesian Approach based on Mixtures". *Group Decision and Negotiation* (DOI 10.1007/s10726-006-9068-0) (2006).
3. **Keim, D. A.,** "Information Visualization and Visual Data Mining". *IEEE Transactions on Visualization and Computer Graphics,* 8(1), 1-8 (2002).
4. **Moreno-Jiménez, J. M.,** "E-cognocracia: Nueva Sociedad, Nueva Democracia". *Estudios de Economía Aplicada,* 24(1-2), 559-581 (2006).
5. **Moreno-Jiménez, J. M., J. Aguarón,** and **M. T. Escobar,** "The Core of Consistency in AHP-Group Decision Making". *Group Decision and Negotiation* (DOI 10.1007/s10726-007-9072-z) (2007a).
6. **Moreno-Jiménez, J. M., J. Aguarón, A. Raluy,** and **A. Turón,** "A Spreadsheet Module for Consistent Consensus Building in AHP-Group Decision Making". *Group Decision and Negotiation* 14(2), 89-108 (2005a).
7. **Moreno-Jiménez, J. M., J. Piles, J. Ruiz, J. L. Salazar,** and **A. Sanz,** "E-cognocracia y voto electrónico. Aplicación a un problema de localización". *XXI Anales de Economía Aplicada,* Valladolid, España (2007b).
8. **Moreno-Jiménez, J. M.,** and **W. Polasek,** "E-democracy and Knowledge. A Multicriteria Framework for the New Democratic Era". *Journal of Multicriteria Decision Analysis,* 12, 163-176 (2003).
9. **Moreno-Jiménez, J. M.,** and **W. Polasek,** "E-cognocracy and the participation of immigrants in e-governance". In Böhlen *et al.* (eds.): *TED Conference on e-government 2005. Electronic democracy: The challenge ahead,* University Rudolf Trauner-Verlag, Schriftenreihe Informatik, 13, 18-26 (2005).
10. **Moreno-Jiménez, J. M., M. Salvador,** and **A. Turón,** "Preference Structures in AHP Group Decision Making". *2nd Compositional Data Analysis Workshop (CODAWork05),* Gerona, Spain (2005b).
11. **Saaty, T. L.,** *Multicriteria Decision Making: The Analytic Hierarchy Process.* McGraw-Hill, 1980.
12. **Turón, A.,** and **J. M. Moreno-Jiménez,** "Visualización de Información en el Proceso Analítico Jerárquico (AHP)". *XVIII Anales de Economía Aplicada,* León, España, 2004.
13. **Turón, A.,** and **J. M. Moreno-Jiménez,** "Graphical Visualisation Tools for AHP-group decision making". *Proceedings GDN06*, Karlsruhe, Alemania, 2006.
14. **Turón, A.,** and **J. M. Moreno-Jiménez,** "Herramientas de visualización gráfica para el análisis de la evolución dinámica en la e-cognocracia". *XXI Anales de Economía Aplicada,* Valladolid, España, 2007.

Alberto Turón Lanuza *is a Lecturer at University of Zaragoza, Spain. He received his Ph.D. from the Computer Systems Engineering program and is currently working in the field of Information Visualization and its applications to the Decision Making Science. His research has been published in international journals as European Journal of Operational Research, Computers & Graphics or Group Decision and Negotiation. His research interests are Information Visualization, Multicriteria Decision Making and Decisional Systems.*

José María Moreno-Jiménez *received his Ph.D. in Mathematics and holds a degree in Economics and Business Administration. He is Professor of Operational Research and Multicriteria Decision Making at the Faculty of Economics and Business Administration of Zaragoza University, Spain. He has published more than 150 research papers in several books and journals as European Journal of Operational Research, Group Decision & Negotiation; Omega; Journal of Multi-Criteria Decision Analysis; Mathematical and Computer Modelling, TOP, EPIO, Pesquisa Operacional.*

Adrián Toncovich *received his B.S. degree in industrial engineering and his M.S. degree in engineering from the Universidad Nacional del Sur, Argentina, in 2001, and 2006, respectively. He is currently working towards a Ph. D. degree in design and manufacturing engineering from the Universidad de Zaragoza, Spain. He is currently a Professor in the Department of Engineering at the UNS, Argentina. His research interests include social data mining, multicriteria decision-making methods, and production planning and scheduling.*