A Mobile Decision Support System for Dynamic Group Decision-Making Problems

Ignacio Javier Pérez, Francisco Javier Cabrerizo, and Enrique Herrera-Viedma

***Abstract*—The aim of this paper is to present a decision support system model with two important characteristic: 1) mobile technologies are applied in the decision process and 2) the set of alternatives is not fixed over time to address dynamic decision situations in which the set of solution alternatives could change throughout the decision-making process. We implement a prototype of such mobile decision support system in which experts use mobile phones to provide their preferences anywhere and anytime. To get a general system, experts' preferences are assumed to be represented by different preference representations: 1) fuzzy preference relations; 2) orderings; 3) utility functions; and 4) multiplicative preference relations. Because this prototype incorporates both selection and consensus processes, it allows us to model group decision-making situations. The prototype incorporates a tool for managing the changes on the set of feasible alternatives that could happen throughout the decision process. This way, the prototype provides a new approach to deal with dynamic group decision-making situations to help make decisions anywhere and anytime.**

***Index Terms*—Decision support system (DSS), group decision making (GDM), mobile Internet (M-Internet).**

I. Introduction

A DECISION-MAKING process, which consists of deriving the best option from a feasible set, is present in just about every conceivable human task. As a result, the study of decision making is necessary and important not only in decision theory but also in areas such as management science, operations research, politics, social psychology, artificial intelligence, and soft computing.

It is obvious that the comparison of different actions according to their desirability in decision problems, in many cases, cannot be done by using a single criterion or a unique person. Thus, we interpret the decision process in the framework of group decision making (GDM) [1], [2]. This approach has led to numerous evaluation schemes and has become a major concern of research in decision making. Several authors have provided interesting results on GDM with the help of fuzzy theory, and the reader is referred to the following references [1], [3]–[11].

Manuscript received March 10, 2009; revised September 9, 2009. Date of publication May 18, 2010; date of current version October 15, 2010. This work was supported in part under Research Projects TIN2007-61079 and TIC-05299. This paper was recommended by Associate Editor L. C. Jain.

I. J. Pérez and E. Herrera-Viedma are with the Department of Computer Science and Artificial Intelligence, University of Granada, 18071 Granada, Spain (e-mail: ijperez@decsai.ugr.es; viedma@decsai.ugr.es).

F. J. Cabrerizo is with the Department of Software Engineering and Computer Systems, Distance Learning University of Spain (UNED), 28040 Madrid, Spain (e-mail: cabrerizo@issi.uned.es).

Color versions of one or more of the figures in this paper are available online at http://ieeexplore.ieee.org.

Digital Object Identifier 10.1109/TSMCA.2010.2046732

The central goal of decision support systems (DSSs) [12]–[14] is to process and provide suitable information to support individuals or organizations in their decision-making tasks. Nowadays, information can be supplied, received, and/or used anywhere, and as such, appropriate mobile DSSs can bridge the gap between theory and practice in decision making. It can also provide additional value to users, which can eventually lead to an increase in the number of successful transactions [15].

The application of the latest technologies extends opportunities in decision making and allows us to carry out consensus processes in situations that we cannot correctly address previously. For example, nowadays, it is possible to carry out consensus processes among several experts that are located in different countries around the world. However, it is important to remark that, even with the adoption of mobile technologies [16], [17], new collaboration and information tools are still needed so that the experts can solve decision-making problems when they cannot meet together.

In the cases where direct communication is not possible and experts do not have the possibility of gathering together, a problem arises in many consensus processes for GDM: experts may not have a clear idea about the current consensus status among all the experts involved in the decision process. In these cases, experts will probably need assistance to establish connections among them and to obtain a clear view of the consensus process progress. This help can be provided through mobile technologies, because it can be considered an efficient way for a continuous communication flow: it allows experts to always have dynamic and updated information to determine the current consensus process status, and at the same time, it provides mechanisms for sending expert preferences in real time, i.e., to simulate real discussion processes. With proper DSS tools, it is possible to determine which experts have similar opinions, and thus, experts may join or form different groups to better discuss every alternative and to try to influence other experts.

The incorporation of mobile technologies in GDM processes is based on the assumption that, if the communications are improved, the decisions will improve, because the discussion can be focused on the problem, with less time spent on unimportant issues.

The aim of this paper is to present a prototype of mobile DSSs (MDSS) to deal automatically with GDM problems, assuming different preference representations and based on mobile technologies. MDSS allows us to develop dynamic GDM processes. In fact, at every stage of the decision process, the users can achieve the following benefits: 1) be informed with updated data about the current stage of the decision process; 2) receive recommendations to help them to change their preferences; and 3) send their updated preferences at any moment, thus improving the user participation in the GDM process. In addition, to better simulate real decision-making processes usually carried out in these cases, the proposed model incorporates both consensus and selection processes. Another innovation introduced in the prototype is a tool for managing not only dynamic inputs of new alternatives that, due to some dynamic external factors, can appear during the decision process but also the outputs of some of them considered good alternatives at the beginning of the process but not so later on or are unavailable at the time. This way, a new approach for dealing with dynamic GDM problems is presented. To build a flexible framework and give a high degree of freedom to represent the preferences, experts are allowed to provide their preferences in any of the following four ways: 1) as a preference ordering of the alternatives; 2) as a utility function; 3) as a fuzzy preference relation; or 4) as a multiplicative preference relation.

To achieve this goal, the paper is set out as follows. General considerations about GDM models and mobile technologies are presented in Section II. Section III defines the prototype of a mobile DSS, including a practical experiment. In Section IV, we discuss some of its drawbacks and advantages. Finally, in Section V, conclusions are drawn.

II. PRELIMINARIES

In this section, we present the classical GDM model and the advantages of using mobile technology in GDM problems.

A. GDM Models

In a GDM problem, we have a finite set of feasible alternatives, $X = \{x_1, x_2, \ldots, x_n\}$, $(n \geq 2)$, to be classified from best to worst by using the information given by a set of experts, $E = \{e_1, e_2, \ldots, e_m\}$, $(m \geq 2)$.

Usual resolution methods for GDM problems include two different processes [8], [18] (see Fig. 1).

1) *Consensus process*. Clearly, in any decision process, it is preferred that the experts reach a high degree of consensus on the solution set of alternatives. Thus, this process refers to how we can obtain the maximum degree of consensus or agreement between the set of experts on the solution alternatives.
2) *Selection process*. This process consists of how we can obtain the solution set of alternatives from the opinions on the alternatives given by the experts.

Usually, resolution methods for GDM problems are static, i.e., it is assumed that the number of alternatives and experts that act in the GDM problem remains fixed throughout the decision-making process. However, in real decision-making situations, we find dynamic GDM problems in which the number of alternatives and/or experts varies during the decision-making process. In this paper, we assume dynamic GDM problems with possible changes on the set of alternatives.

On the other hand, because each expert $e_k \in E$ has his own ideas, attitudes, motivations, and personality, it is quite natural to think that different experts can express their preferences in a different way. This fact has led some authors [19]–[24] to assume that experts' preferences over the set of alternatives may be represented in different ways. The most frequently used alternatives in decision-making theory are given as follows.

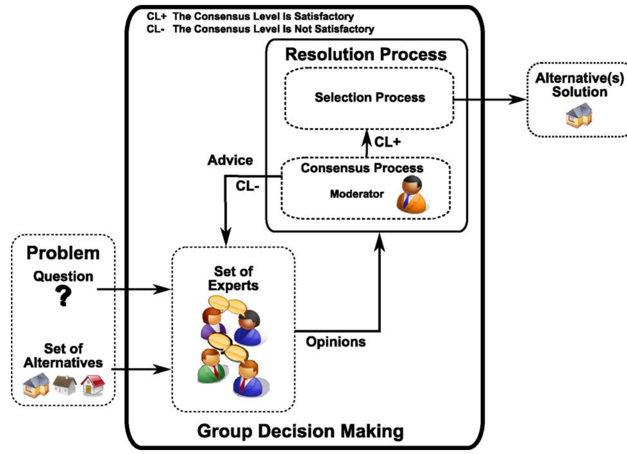


Fig. 1. Resolution process of a GDM.

- *Preference orderings of alternatives.* $O^k = \{o^k(1), \ldots, o^k(n)\}$, where $o^k(\cdot)$ is a permutation function over the index set, $\{1, \ldots, n\}$, for the expert e_k, defining an ordered vector of alternatives, from best to worst.
- *Utility functions.* $U^k = \{u_1^k, \ldots, u_n^k\}$, $u_i^k \in [0, 1]$, where u_i^k represents the utility evaluation given by the expert e_k to x_i.
- *Fuzzy preference relations.* $P^k \subset X\text{x}X$, with a membership function, $\mu_{P^k} : X\text{x}X \to [0, 1]$, where $\mu_{P^k}(x_i, x_j) = p_{ij}^k$ denotes the preference degree of x_i over x_j.
- *Multiplicative preference relations.* $A^k \subset X\text{x}X$, where the intensity of preference a_{ij}^k, is measured using a ratio scale, particularly the 1/9-to-9 scale.

B. Mobile Technologies in GDM Problems

In this section, we present the advantages and limitations of new mobile technologies, and we discuss the use of mobile devices to solve GDM problems.

1) Advantages and Limitations: Mobile communication systems are characterized by a variety of features [16], [17]. They differ from each other in the degree of their complexity, the level of their offered services, and their operational costs.

Mobile web refers to the World Wide Web accessed from mobile devices such as cell phones, personal digital assistants (PDAs), and other portable gadgets connected to a network. Thus, access to web services no longer requires a desktop computer. The following list shows the different advantages that mobile technologies can provide [16], [17].

- The Internet has provided an easy and effective way of delivering information and services to millions of users who are connected to wired network. Evidently, this wired network addresses two major constraints: 1) time and

2) place. These limitations have raised the issue of the mobile Internet (M-Internet), which enables users to access information from any place at any moment by using a mobile wireless device. The possibility of gaining access to this kind of services in wireless environments provides a great mobility to the users. This mobility can increase productivity due to the increasing agility of some tasks, allow users to save displacements and infrastructure costs, improve business processes, ease decision-making processes by obtaining more dynamic and precise solutions, and even improve the offered services.

- The mobile computing paradigm has several interesting and important applications for business, telecommunications, real-time control systems, and remote operations [15], [25], [26].
- Recently, the fast technological innovation has made it possible to provide secure, fast, and quality communications through the wireless network. Moreover, devices that used to deliver limited information can now provide a wide range of information and services such as email, banking, entertainment, and even games.

However, current mobile web access still suffers from interoperability and usability problems. This condition is partly due to the small physical size of the screens of mobile devices and the incompatibility of many mobile devices with both computer operating systems and the format of much of the available information on the Internet.

Some of the limitations that current mobile services have to face are given as follows.

- *Small screen size*. It is difficult or impossible to properly adapt text and graphics prepared for the standard size of a desktop computer screen with current information standards.
- *Lack of windows*. On the mobile web, only one page can be displayed at a time, and pages usually can only be viewed in the sequence that they were originally accessed.
- *Navigation*. Usual mobile devices do not use a mouse-like pointer but simply an up and down function for scrolling, thereby limiting the flexibility of navigation.
- *Format of accessible pages*. Many sites that can be accessed on a desktop cannot be accessed on a mobile device. Many devices cannot show pages with secured connection, Flash or other similar elements, Portable Document Format (PDF) files, or video sites.
- *Speed*. On most mobile devices, the speed of service is very slow, often slower than dial-up Internet access.
- *Size of messages*. Many devices have limits on the number of characters that can be sent in a single message.

To make use of mobile technology in the best way, several conditions need to be fulfilled. The first condition, nowadays achieved, is the widespread use of mobile devices that connect individuals to the mobile network and the contents that provide useful information and services to users. In addition, the technological support in terms of speed, communication quality, and security are also important in the development of the mobile technology [13].

The mobile web mainly uses lightweight pages written in Extensible Hypertext Markup Language (XHTML) or Wireless Markup Language (WML) to deliver content to mobile devices. However, new tools such as Macromedia's Flash Lite or Sun's J2ME enable the production of richer user interfaces customized for mobile devices.

2) Use of Mobile Technology in GDM Problems: During the last decade, organizations have moved from face-to-face group environments to virtual group environments by using communication technology. Many more workers use mobile devices to coordinate and share information with other people. The main objective is that the members of the group can work in an ideal way where they are, having all the necessary information to take the right decisions [16], [17], [27], [28].

To support the new generation of decision makers and to add real-time processes in the GDM problem field, many authors have proposed to develop DSSs based on mobile technologies [29], [30]. Similarly, we propose to incorporate mobile technologies in a DSS obtaining MDSS. Using such a technology should enable a user to maximize the advantages and minimize the drawbacks of DSSs.

The need of a face-to-face meeting disappears with the use of this model, because the own computer system acts as the moderator. Experts can directly communicate with the system by using their mobile device from any place in the world and at any time. Hereby, a continuous information flow among the system and each member of the group is produced, which can help reach a consensus between the experts in a faster way and to obtain better decisions.

In addition, MDSS can help reduce the time constraint in the decision process. Thus, the time saved by using the MDSS can be used for an exhaustive analysis of the problem and to obtain a better problem definition. This time can also be used to identify more feasible alternative solutions to the problem, and thus, the evaluation of a large set of alternatives can increase the possibility of finding a better solution. The MDSS helps in the resolution of GDM problems by providing a propitious environment for the communication, increasing the satisfaction of the user, and, this way, improving the final decisions.

III. MDSS Based on Dynamic Choice of Alternatives

Although DSSs have typically been associated with desktop systems and involve considerable processing, the development of new compact and mobile technologies provides new opportunities to develop this kind of DSSs over M-Internet [12], [16], [17].

In this section, we describe the implemented GDM model that incorporates a tool for managing dynamic decision models in which the alternatives of the set of solution alternatives can change throughout the decision process and uses different formats to represent preferences. It allows us to develop GDM processes at any time and anywhere and to simulate with more accuracy level the real processes of human decision making, which are developed in dynamic environments such as the web, financial investment, and health. Finally, the prototype of the MDSS is presented.

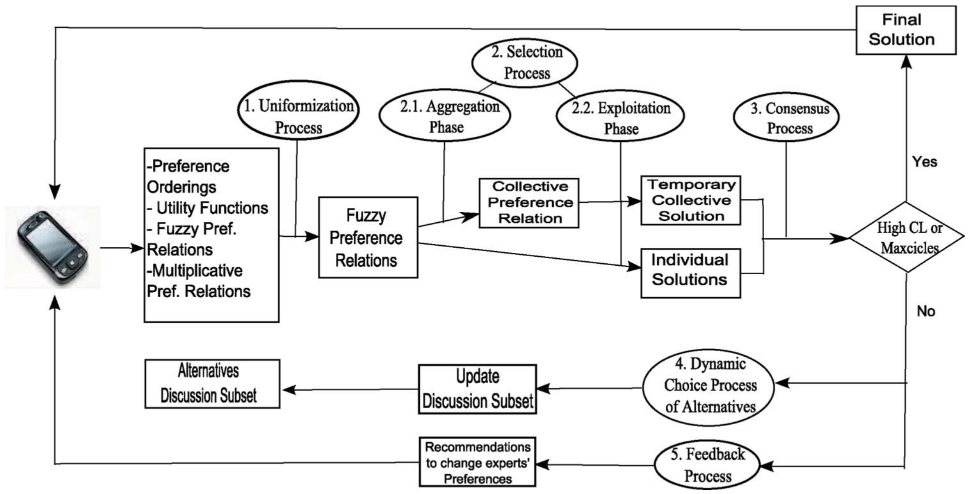


Fig. 2. Operation of the GDM model with multiple preference representation structures.

A. Structure of the Implemented GDM Model

The structure of the proposed MDSS model is composed of the following five processes: 1) uniformization; 2) selection; 3) consensus; 4) dynamic choice process of alternatives; and 5) feedback (see Fig. 2).

1) Uniformization: To give a higher degree of freedom to the system, we assume that experts can present their preferences by using any of the preference representations presented in Section II-A. Therefore, it is necessary to make the information uniform before applying consensus and selection. Similar to [20], we propose to use fuzzy preference relations as the base element to uniform experts' preferences, and the following transformation functions are used [20]: $f^1(o_i^k, o_j^k) = (1/2)(1 + ((o_j^k - o_i^k)/n - 1)$, $f^2(u_i^k, u_j^k) = (u_i^k)^2/((u_i^k)^2 + (u_j^k)^2)$, and $f^3(a_{ij}^k) = (1/2)(1 + \log_9 a_{ij}^k)$.

2) Selection: Once the information is made uniform, we have a set of m individual fuzzy preference relations, and then, we apply a selection process with two phases [2], [31]: 1) *aggregation* and 2) *exploitation*.

- *Aggregation*. This phase defines a collective preference relation, $P^c = (p_{ij}^c)$, obtained with the aggregation of all individual fuzzy preference relations $\{P^1, P^2, \ldots, P^m\}$. It indicates the global preference between every pair of alternatives according to the opinions of the majority of experts. For example, aggregation can be carried out through an ordered weighted averaging (OWA) operator [32], [33].
- *Exploitation*. This phase transforms the global information about the alternatives into a global ranking of them, from which the set of solution alternatives is obtained. The global ranking is obtained by applying two choice degrees of alternatives to the collective fuzzy preference relation [7]: 1) the *quantifier-guided dominance degree* (QGDD) and 2) the *quantifier-guided nondominance degree* (QGNDD). Finally, the solution X_{sol} is obtained by applying these two choice degrees and, thus, selecting the alternatives with maximum choice degrees.

3) Consensus Process: In our MDSS, we use a consensus model for GDM problems with different preference representations similar to [34]. This model presents the following main characteristics.

- It is based on two soft consensus criteria: 1) global consensus measure on the set of alternatives X, symbolized as C_X, and 2) the proximity measures of each expert e_i on X, called P_X^i.
- Both consensus criteria are defined by comparing the individual solutions with the collective solution using as comparison criterion the positions of the alternatives in each solution.

Initially, in this consensus model, we consider that, in any nontrivial GDM problem, the experts disagree in their opinions so that consensus has to be viewed as an iterated process. This approach means that agreement is obtained only after rounds of consultation. In each round, the DSS calculates both the consensus and the proximity measures. The consensus measures evaluate the agreement that exists among experts, and the proximity measures are used in the feedback mechanism to support the group discussion phase of the consensus process.

4) Dynamic Choice Process of Alternatives: In real world, we find many dynamic decision frameworks: 1) health; 2) financial investment; 3) military operations; and 4) Web. In such cases, due to different factors, the set of solution alternatives can vary throughout the decision process. One typical example of this situation is the medical diagnosis. This environment is dynamic in the sense that a patient can present new symptoms, or he can set better due to the medication, and thus, any change in state of the patient should be taken into account by the doctors.

Classical GDM models are defined within static frameworks. To make the decision-making process more realistic, we provide a new tool to deal with dynamic alternatives in decision making. This way, we can solve dynamic decision problems in which, at every stage of the process, the discussion can be centered at different alternatives.

To do so, we define a method that allows us to remove and insert new alternatives into the discussion process. First, the

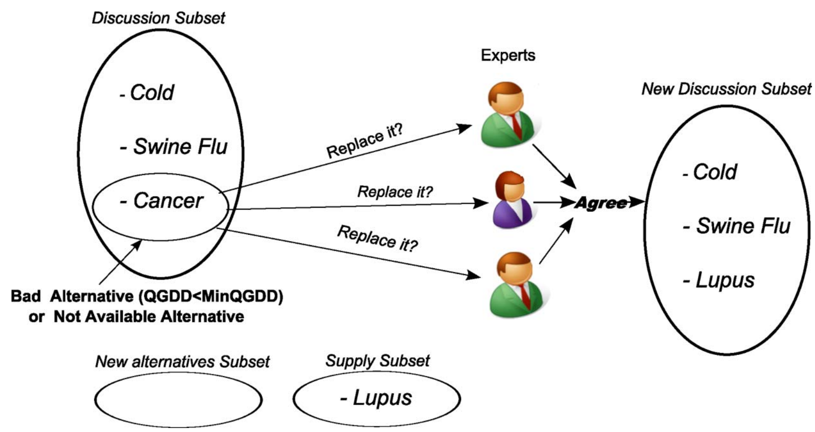


Fig. 3. Dynamic choice process of alternatives: Case 1.

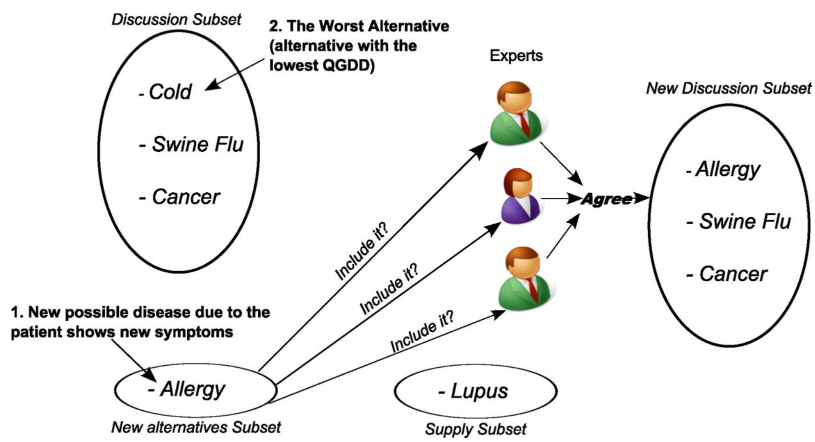


Fig. 4. Dynamic choice process of alternatives: Case 2.

system identifies the worst alternatives that might be removed and the new alternatives to include in the set. These new alternatives can be obtained from a set of new alternatives that appeared at a time or from the supply set of alternatives that includes all the alternatives that we had at the beginning of the process but were not included in the discussion subset because of limitations due to specific parameters of the problem.

Thus, the method has two different phases.

1) *Remove old bad alternatives*. The first phase manages situations in which alternatives of the discussion subset are not available at the moment due to dynamic external factors or because the experts have evaluated them poorly and they have a low dominance degree $(QGDD)$. Therefore, the system checks the availability and the $QGDD$ of each alternative in the current discussion subset. If an alternative is not available or has a $QGDD$ lower than a threshold $(minQGDD)$, the system looks for a new good alternative in the new alternatives subset. If this subset is empty, the system uses the supply subset of alternatives provided by the expert at the beginning of the decision process and that were not taken into account then because of the impossibility of comparing all the alternatives at the same time. Then, the system asks for the experts' opinions about the replacement and acts according to them (see Fig. 3).
2) *Insert new good alternatives*. The second case manages the opposite situation, i.e., when new alternatives have emerged. The system checks if new good alternatives have appeared in the new alternatives subset due to dynamic external factors. If this is the case, the system has to identify the worst alternatives of the current discussion subset. To do this, the system again uses the dominance degree $QGDD$ of all alternatives to choose the worst alternatives. Then, the system asks for the experts' opinions about the replacement and acts according to them (see Fig. 4).

To avoid stagnation at this point, a *maxTime* threshold is established. If the majority of experts that answered the question in *maxTime* think that the changes are appropriate, the system updates the discussion subset according to the aforementioned cases. The possibility of these changes makes experts more involved in the process and improves their satisfaction with the final results.

5) Feedback Process: To guide the change of the experts' opinions, the DSS simulates a group discussion session in which a feedback mechanism is applied to quickly obtain a high level of consensus. This mechanism can substitute the moderator's actions in the consensus process. The main problem is how the experts can find a way of making individual positions converge and, therefore, how it can support the experts in obtaining and agreeing with a particular solution.

When the consensus measure C_X has not reached the required consensus level (CL) and the number of rounds has not reached a maximum number of iterations (MAXCYCLE), defined before the decision process begins, the experts' opinions must be modified. As aforementioned, we use the proximity measures to build a feedback mechanism so that experts can change their opinions and narrow their positions.

This feedback mechanism uses the proximity measures to give simple rules on how experts' preferences can be changed.

- *Rules for changing the preferences*. The rules provided by the feedback mechanism are easy to understand and apply, because they are provided in a natural language.
  1) Each expert e_i is classified by associating experts to their respective total proximity measure P_X^i. Each expert is given his position and his proximity in each alternative.
  2) If the expert's position in the ranking is high (first, second, etc.), then that expert should not change his opinion much, but if it is low, then that expert has to substantially change his opinion. In other words, experts who will change their opinions are those whose individual solutions are farthest from the collective temporary solution. At this point, we have to calculate, using a threshold defined at the beginning of the decision process, how many experts have to change their opinions.

  The rules for changing opinions are given as follows.
  - If the proximity of alternative $p_i(x_j)$ is positive, then we have the rule "decrease values associated to alternative x_j."
  - If the proximity of alternative $p_i(x_j)$ is negative, then we have the rule "increase values associated to alternative x_j."

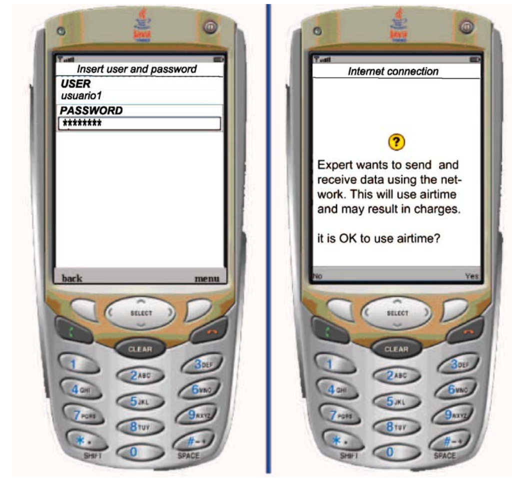
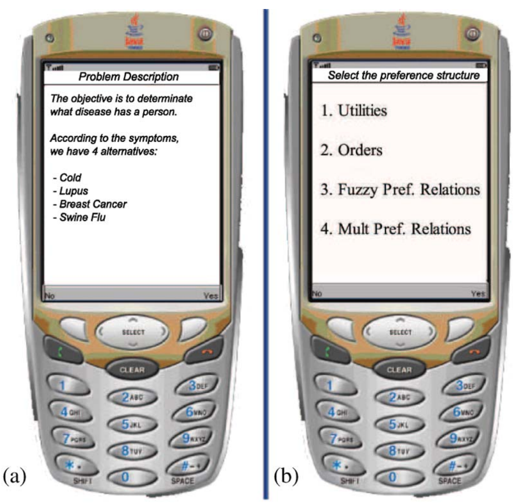


Fig. 5. Authentication and M-Internet connection.



(a) (b)

Fig. 6. Problem description and selection of preference representations.

B. Prototype of MDSS

Here, we present the prototype of MDSS, explaining the architecture of the system and the communication and workflow that summarizes the functions of the DSS.

A DSS can be built in several ways, and the technology that was used determines how a DSS has to be developed [14], [15]. The chosen architecture for our prototype of MDSS is a "client/server" architecture, where the client is a mobile device. The client/server paradigm is founded on the concept that clients (such as personal computers or mobile devices) and servers (computer) are both connected by a network that enables servers to provide different services for the clients. Furthermore, the technologies that we have used to implement the prototype of the MDSS comprise Java and Java Midlets for the client software, PHP for the server functions, and MySQL for the database management.

According to the GDM model proposed in the previous section, the prototype lets the user send his/her preferences to the DSS through a mobile device, and the system returns to the expert the final solution or recommendations to increase the CL, depending on the stage of the decision process. One important aspect is that the user–system interaction can be done anytime and anywhere, which facilitates expert's participation and the resolution of the decision process.

In what follows, we describe in detail the client and server of the MDSS prototype.

1) Client: For the implementation of the DSS, we have chosen a thin client model. This model primarily depends on the central server for the processing activities. This prototype is designed to operate on mobile devices with Internet connection.

The client software has to show to the experts the following eight interfaces.

- *Connection*. The device must be connected to the network to send/receive information to the server.
- *Authentication*. The device will ask for a user and password data to access the system (see Fig. 5).
- *Problem description*. When a decision process is started, the device shows to the experts a brief description of the problem and the discussion subset of alternatives [see Fig. 6(a)].
- *Selection of preference representations* [see Fig. 6(b)].
- *Insertion of preferences*. The device will have four different interfaces, one for each different format of preference representation (see Fig. 7).

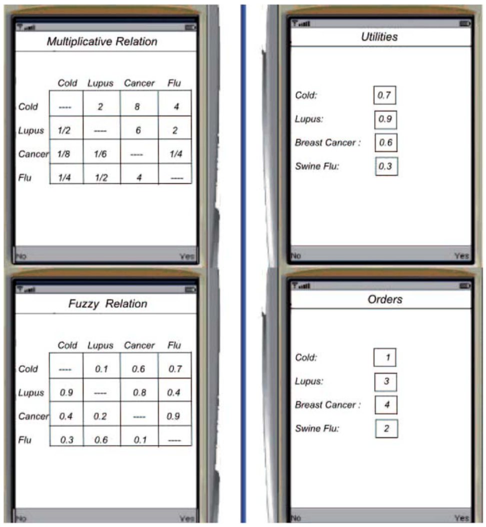


Fig. 7. Insertion of preferences.

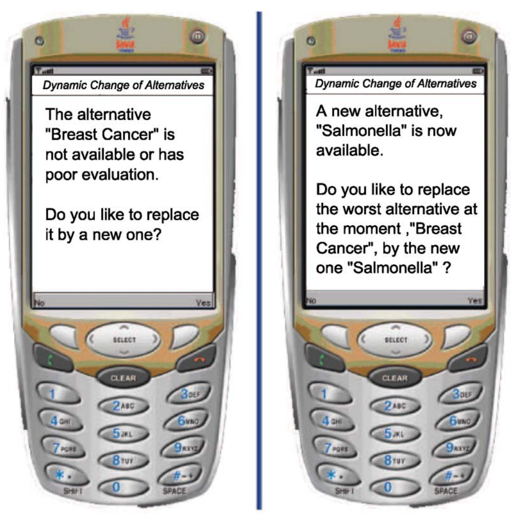


Fig. 8. Change of alternatives question.

- *Change of alternatives*. When a bad or unavailable alternative deserves to be removed from the discussion subset or a new alternative deserves be inserted in the discussion subset, using the new management process of alternatives, the experts can assess if they want to update the discussion subset by changing these alternatives (see Fig. 8).
- *Feedback*. When opinions should be modified, the device shows to the experts the recommendations and lets them send their new preferences [see Fig. 9(a)].
- *Output*. At the end of the decision process, the device will show to the experts the set of solution alternatives as an ordered set of alternatives, marking the most relevant ones [see Fig. 9(b)].

On the technical side of the development of the client part of the DSS, it is worth noting that the client application complies with the MIDP 2.0 specifications [35] and that the J2ME Wireless Toolkit 2.2 [36] provided by Sun was used in the development phase. This wireless toolkit is a set of tools that provide J2ME developers with emulation environments,

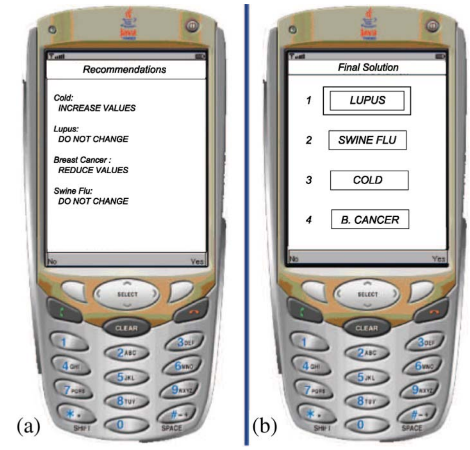


Fig. 9. Recommendations and final solution.

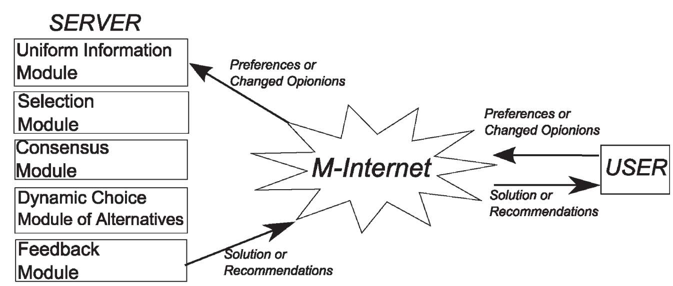


Fig. 10. Operation structure of the MDSS prototype.

documentation, and examples to develop MIDP-compliant applications. The application was later tested using a Java-enabled mobile phone on a Global System for Mobile Communications (GSM) network using a general packet radio service (GPRS)-enabled subscriber identity module (SIM) card. The MIDP application is packaged inside a Java archive (JAR) file, which contains the applications classes and resource files. This JAR file is downloaded to the physical device (mobile phone), along with the Java application descriptor file, when an expert wants to use the MDSS.

2) Server: The server is the other fundamental part of the DSS. It is based on five main modules, which receive/send information from/to the experts through M-Internet technologies (see Fig. 10).

- *Uniform information module*. This module makes expert preferences uniform by using the transformation functions in Section III-A1 to convert all different types of preferences into fuzzy preference relations.
- *Selection module*. After the information is made uniform, the server applies the selection process to obtain a temporary solution of the problem. This process has two phases: 1) aggregation and 2) exploitation. In the aggregation phase, the collective fuzzy preference relation is obtained. In the exploitation phase, the server obtains the QGDDs of alternatives acting over the collective fuzzy preference relation. This degree allows us to establish an order in the alternatives to obtain the ranking of the temporary alternative solutions, from best to worse.

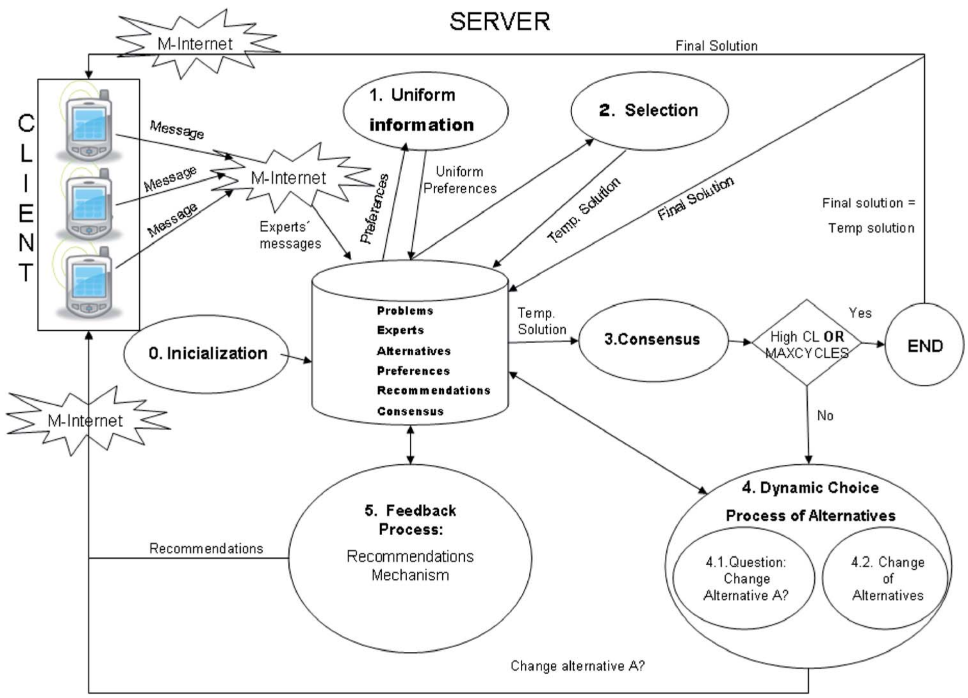


Fig. 11. Functions scheme of the system.

- *Consensus module*. In this module, the consensus and proximity measures are calculated by the server. If the consensus measure has reached the minimum CL defined as a parameter of the problem, the consensus process stops. This temporary collective solution becomes the final consensual solution and is sent to the experts. In other cases, the consensus process should continue.
- *Dynamic choice module of alternatives*. If an old alternative has to be removed from the discussion subset or a new alternative deserves to be inserted in the discussion subset and the minimum CL has not been reached, the server applies the management process of alternatives to determine if the replacement should be done. To do that, the server asks the experts if they agree with the proposed change. If the majority of the experts accept it, the *discussion subset* of alternatives is updated by changing the worst alternative of the set by the new one or by the first one in the supply list.
- *Feedback module*. When a consensus stage is finished without reaching the minimum CL, the server starts a feedback mechanism that generates recommendations rules. These recommendations demand the experts to change their preferences and explain how they will do it (increasing or decreasing preferences).

  This way, the consensus process will converge, and eventually, the solution will reach a high consensus degree.

The server also implements a database that stores all the data of the problem, as well as the experts' data, alternatives data, preferences, consensus measures, recommendations, consensus parameters, and selection parameters.

3) Communication and Work Flow: The DSS has to carry out the following functions, also represented in Fig. 11. In the diagram, we can see all the functions of the system, the form in which they are connected together with the database, and the order in which each of them is executed.

---

0) **Initialization**. The first step to the start of the execution of the system consists of the insertion in the database of all the initial parameters of the problem, the experts, and the set of alternatives. Before starting the decision process, it is necessary to set suitable values for all of the parameters according to the problem, particularly those that limit the time that will be spent in its resolution. It is not the same as an urgent medical situation where experts have to quickly decide the best medical treatment to choose a country to visit during holidays. In the first case, the MAXCYCLE of the consensus process and the maximum time of waiting for the expert opinions should be shorter than the second one, because the final solution is required as soon as possible. Therefore, these values are very dependent on the problem at hand, and they have to be established according to the special needs of each situation.

1) **Verify the user messages and store the main information**. When an expert wants to access the system, he/she has to send a message through M-Internet by using his mobile device. The user can send the following two kinds of messages.

i) *Preferences message*. It is composed of authentication information (login and password) and the user's preferences about the problem, using any of these four available formats: 1) *preference orderings*; 2) *utility functions*; 3) *fuzzy preference relations*; or 4) *multiplicative preference relations.*

ii) *Change of alternatives message*. It is composed of authentication information (login and password) and the answer to the change of alternatives question.The message is verified by the server, which checks the login and password in the database. If the authentication process is correct, the rest of the information of the message is stored in the database, and the server decides when the consensus stage can start (if all experts have provided their preferences) or when the change of alternatives mechanism can be finished (if enough experts answer the change of alternatives question).

2) **Make the experts' preferences uniform**. The server makes the information uniform by using fuzzy preference relations as the base element of preferences representation. The server saves this information in the database.

3) **Computation of the set of solution alternatives**. The selection module returns the solution set of alternatives in each stage of the decision process. All the information about the temporary solution is saved in the database.

4) **Computation of the consensus measures**. In this step, the consensus and proximity measures are computed by the server and saved in the database.

5) **Control the consensus state**. In this step, the server determines if the required agreement degree has been reached (and thus, the decision process must finish by applying the selection process) or if a new round of consensus using the feedback mechanism that generates recommendations to change the experts' preferences should begin.

6) **Control the change of alternatives**. When the minimum CL has not been reached and alternatives deserve to be removed or inserted in the discussion subset, the system offers the possibility to update the discussion subset on time.

7) **Generate the recommendations**. In this step, the server generates the recommendations and sends a message to the experts advising that they can use the software again for reading the recommendations and start a new consensus stage. To avoid that the collective solution does not converge after several discussion rounds, the prototype stops if the number of rounds reaches MAXCYCLES.

The results are saved in the database and are sent to the experts through M-Internet to help them change their preferences.

8) **Go to Step 1**. A new round of the decision-making process starts.

The system operation will be illustrated in more detail in the next section, with a practical example.

C. Practical Example of MDSS

In this section, we will illustrate a simple real example of use of the DSS. Take note of the behavior of the system under complex problems, because the prototype allows dynamic sets of alternatives, it manages their inputs and outputs in real time, and it can also address problems with large sets of alternatives them. When all the alternatives cannot be displayed on a mobile screen at the same time, the remaining ones can be ordered in a supply list and be evaluated later in the process. Therefore, the system can support a big number of experts and alternatives to solve complex problems. To illustrate how the prototype works, we will follow the communication flow presented in the previous section.

TABLE I
ALTERNATIVES OF THE PROBLEM

$Code$	$Name$	$Capacity$	$Prize$	$City$
r_1	Las Tinajas	75	20-50 Euros	Granada
r_2	La Pataleta	45	20-40 Euros	Granada
r_3	La Ermita	55	22-35 Euros	Granada
r_4	Kudam	60	25-55 Euros	Granada
r_5	Casa Ramon	60	30-52 Euros	Granada
r_6	Il Gondoliere	45	31-41 Euros	Granada

TABLE II
EXPERTS OF THE PROBLEM AND MOBILE DEVICES USED

$Code$	$Name$	$City$	$MobileDevice$
e_1	Enrique	Granada (Spain)	Nokia N70
e_2	Paco	Leicester (UK)	Nokia 6234
e_3	Javier	Madrid (Spain)	HTC Touch
e_4	Sergio	Granada (Spain)	LG Viewty

TABLE III
INITIAL PARAMETERS OF THE PROBLEM

$Name$	$Value$	$Description$
b	1	Control the proximity measures
β	0.5	Control the S-OWA operator
$minConsDegree$	0.8	Minimum consensus level
$minProxDegree$	0.7	Minimum proximity level
$MAXCYCLES$	4	Maximum number of iterations
$maxTime$	12 (hours)	Maximum waiting time
$minQGDD$	0.2	Minimum dominance level
$DSsize$	4	Discussion subset size

The experiment dealt with the choice of the best restaurant for a Christmas dinner by four members (experts) of a work group. They used their last generation mobile devices, because they live in different countries and cannot gather together to plan the meeting.

In the beginning, the secretary of the work group had to look for a set of available restaurants. Later, a list of six of these available restaurants was created as the feasible candidates to celebrate the dinner. These candidates, arranged according to prize, made up the initial set of alternatives for the problem.

The first step to solve a problem using our prototype is to insert all the parameters of the problem (experts, alternatives, thresholds, timing, and so on) in the database. (See Tables I–III.)

When the initial parameters were defined according to the problem requirements, the decision-making process starts.

Note that the set of alternatives has six restaurants $X = \{R_1, \ldots, R_6\}$, but we suppose that the experts cannot compare all of them altogether. Thus, they will evaluate only four of them ($\mathrm{DSsize} = 4$), i.e., the initial discussion subset will consist of the first four, $X' = \{R_1, \ldots, R_4\}$. The remaining restaurants are included in the supply set to support changes in the discussion subset at the following iterations of the decision process. These changes can be made when some of the current restaurants obtain a low evaluation or are no longer available for booking.

The first four restaurants are presented to the group of four experts, $E = \{e_1, \ldots, e_4\}$. They are asked to give their opinions about them using our MDSS.

The experiment was carried out using a real set of the latest technology mobile devices (see Table II). Therefore, we have

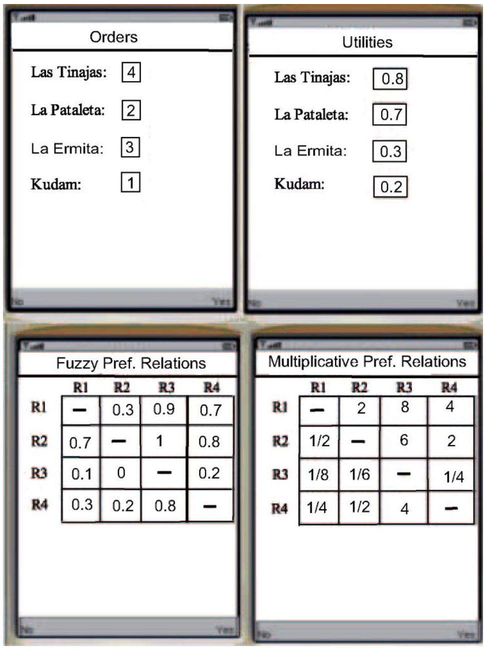


Fig. 12. Expert preferences.

to illustrate the input and output interfaces by using a mobile emulator provided by Sun Microsystem. The input and output data sets are the same as in the real experiment. The interfaces depend on the device screen but are very similar.

Expert e_1 gave his opinions by using preference orderings, e_2 by using utility values, e_3 by using fuzzy preference relations, and, finally, e_4 by using multiplicative preference relations. Experts' initial opinions are shown in Fig. 12.

These preferences and the authentication information are sent to the server by each expert, and if the authentication process is correct, the preferences are stored in the table *preferences* of the database. When the last expert has sent his message, the decision process is started by the server.

1) First Stage in the Decision Process:

a) Uniform information module: Using the transformation functions presented in Section III-A, the system obtains the following individual fuzzy preference relations:

$$P^1 = \begin{pmatrix} 0.5 & 0.16 & 0.33 & 0 \\ 0.83 & 0.5 & 0.66 & 0.33 \\ 0.66 & 0.33 & 0.5 & 0.16 \\ 1 & 0.66 & 0.83 & 0.5 \end{pmatrix}$$

$$P^2 = \begin{pmatrix} 0.5 & 0.57 & 0.88 & 0.94 \\ 0.43 & 0.5 & 0.84 & 0.92 \\ 0.22 & 0.16 & 0.5 & 0.69 \\ 0.06 & 0.08 & 0.21 & 0.5 \end{pmatrix}$$

$$P^3 = \begin{pmatrix} 0.5 & 0.3 & 0.9 & 0.7 \\ 0.7 & 0.5 & 1 & 0.8 \\ 0.1 & 0 & 0.5 & 0.2 \\ 0.3 & 0.2 & 0.8 & 0.5 \end{pmatrix}$$

$$P^4 = \begin{pmatrix} 0.5 & 0.66 & 0.97 & 0.82 \\ 0.34 & 0.5 & 0.91 & 0.66 \\ 0.03 & 0.09 & 0.5 & 0.18 \\ 0.18 & 0.34 & 0.82 & 0.5 \end{pmatrix}.$$

These four relations are also stored in the table *preferences* of the database.

b) Selection module: Using the fuzzy majority criterion with the corresponding OWA operator with the weighting vector $W = [0.5, 0.2, 0.17, 0.13]$ ("most of"), the collective fuzzy preference relation is computed as

$$P^c = \begin{pmatrix} 0.5 & 0.52 & 0.86 & 0.75 \\ 0.48 & 0.5 & 0.91 & 0.77 \\ 0.14 & 0.09 & 0.5 & 0.44 \\ 0.25 & 0.23 & 0.56 & 0.5 \end{pmatrix}.$$

We apply the exploitation process with the corresponding OWA operator with the weighting vector $W = [0.07, 0.67, 0.26]$ ("most of") and compute the dominance choice degree $(QGDD_i)$ over the collective fuzzy preference relation: $QGDD_1 = 0.696$, $QGDD_2 = 0.702$, $QGDD_3 = 0.146$, $QGDD_4 = 0.265$.

These values represent the *dominance that one alternative has over "most of" the alternatives according to "most of" the experts.*

We can see that the best current candidate is R_2, and the collective order of restaurants is $\{R_2, R_1, R_4, R_3\}$. This order is shown as our temporary solution in this first consensus stage.

c) Consensus module: The system computes the individual orders for each expert in a way similar to the global solution, i.e.,

$$e_1 : \{R_4, R_2, R_3, R_1\}$$
$$e_2 : \{R_1, R_2, R_3, R_4\}$$
$$e_3 : \{R_1, R_2, R_4, R_3\}$$
$$e_4 : \{R_2, R_1, R_4, R_3\}.$$

Consensus degrees of the set of experts over the individual alternatives are given as follows: $C(R_1) = 0.55$, $C(R_2) = 0.66$, $C(R_3) = 0.77$, $C(R_4) = 0.66$.

The global consensus measure is computed using an OWA operator, and we obtain the following value: $C_X = 0.67$.

The proximity measures are also computed using an OWA operator: $P_X^1 = 0.55$, $P_X^2 = 0.67$, $P_X^3 = 0.78$, $P_X^4 = 1$.

As we can see, the consensus has not reached the minimum required by the problem $(C_X < 0.8)$, and consequently, the decision process should continue applying both the dynamic choice process of alternatives and the feedback process.

d) Dynamic Choice Process of Alternatives: As soon as the system has verified that the minimum CL among the experts has not been reached and before beginning a new round of consensus, it is necessary to update all the information of the problem that could be changed during the process.

To do so, the system tries to remove and replace the restaurants that cannot be booked at the moment due to theirs being already fully booked or whose dominance degree is below the required minimum value, i.e., $QGDD_i < MinQGDD = 0.2$. New restaurants or restaurants in waiting in the supply list are given as replacement alternatives. In this case, all the restaurants are available for booking; however, La Ermita restaurant has a choice degree $QGDD_3$ lower than $MinQGDD$. Due to external factors, e.g., bookings cancelled, a new good restaurant

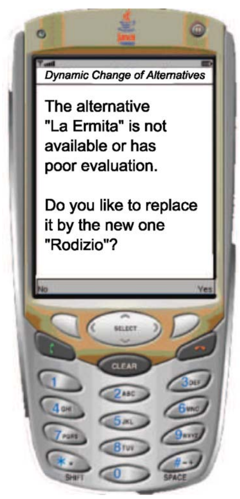


Fig. 13. Change of alternative question.

called “Rodizio” is now available to celebrate dinner. Therefore, the list of new alternatives has a new element, and the system suggests that the bad restaurant is removed and the new one is inserted in the discussion subset.

Because there are no more new alternatives, the question (Fig. 13) is sent to all the experts, and the system waits for the experts’ answers to update the discussion subset. Experts e_1, e_3, and e_4 answer that they agree with the change. e_2 does not answer the question within the threshold waiting time $maxTime$. Thus, the restaurant R_3 is replaced with the new restaurant R_7 into the discussion subset of alternatives.

e) Feedback Process: Next, the feedback process is applied, and recommendation to the experts are given on their preference values to change to improve the CL. This approach is done in the following two steps.

- *Classification of experts*. The system ranks the experts according to their proximity measures: e_4, e_3, e_2, and e_1.
- *Changing the opinions*. At this point, two of the experts, e_1 and e_2, whose proximity measures are lower than the parameter $minProxDegree$, are asked to change their opinions. They are not requested to change preferences on the restaurant R_3, because it is replaced by R_7. Obviously, all the experts were asked to introduce their preferences about the new alternative R_7.

We can see the recommendations received by the experts in their mobile devices in Fig. 14.

2) Second Stage in the Decision Process: In this stage, all the experts have to send their preferences again, because the alternative set has been modified (the candidate R_7 replaced the candidate R_3). Experts e_1 and e_2 also received recommendations to change their preferences, because their proximity levels were low in the previous round.

The experts’ opinions given in the second round are shown in Fig. 15.

The *uniform information module* transforms these preferences to fuzzy preference relations, and the *selection module*, with the same operations that in the previous stage, obtains a new temporary solution. The new collective ranking of restaurants is given as follows: $\{R_2, R_1, R_7, R_4\}$.

Fig. 14. Recommendations.

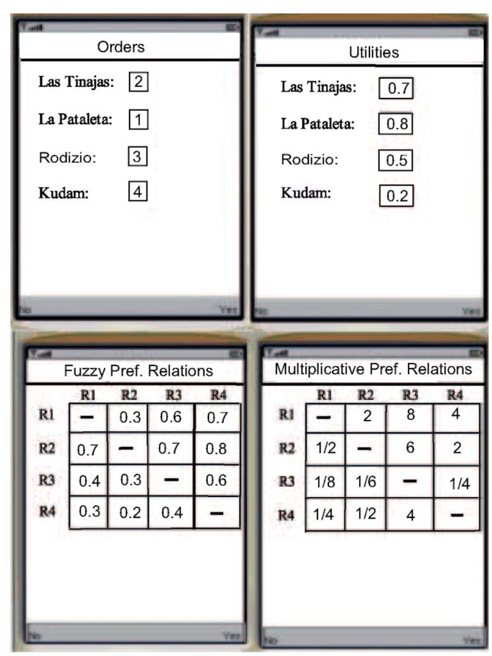


Fig. 15. New experts’ preferences.

The next module, i.e, the *“Consensus module,”* obtains the CL: $C_X = 0.88$.

This CL has reached the minimum level required by the problem $(C_X > 0.8)$, and in this case, the decision-making process has finished, with R_2 being the best alternative. The restaurants R_1, R_7, and R_4 make up the supply list, and the solution is stored in the table *consensus* of the database. All this information is sent to experts by their mobile phones (see Fig. 16).

Fig. 16. Final solution.

IV. Discussion: Drawbacks and Advantages

In this section, we point out some drawbacks and advantages of the implemented MDSS.

- *Drawbacks*. We find the following drawbacks of our system.
  1) To take part in the GDM process the users need a last-generation mobile device to install the MDSS, and this condition can be very expensive for them.
  2) The user interfaces have to be easy and very simple, because the mobile device screen is very small.
  3) The MDSS prototype can only be applied in numerical decision contexts, and it would be desirable to use other more flexible frameworks such as linguistic contexts.
  4) Studies on the incorporation of consistency measures and dealing with missing values would be desirable.
- *Advantages*. On the other hand, we find the following advantages.
  1) MDSS allows us to develop a distributed GDM process, because the experts do not have to gather together to discuss the problem to solve.
  2) MDSS improves the speed of the classical DSSs, because the experts receive and send the information using their mobile devices, which are carried at all times.
  3) MDSS provides a higher flexibility degree in the representation of preferences, because the experts can use different preference representations formats to express their opinions. This way, we allow experts to provide their preferences anywhere, anytime, and in multiple formats.
  4) MDSS incorporates a feedback mechanism that provides linguistic recommendations to the experts to quickly obtain a high consensus degree.
  5) MDSS allows us to address large sets of alternatives in decision problems, because it incorporates the management of dynamic sets of alternatives.

V. Concluding Remarks

We have presented a prototype of MDSS for GDM problems based on dynamic decision environments, which incorporates a new tool for managing dynamic inputs and outputs of alternatives in the set of solution alternatives throughout the decision process. The prototype uses the advantages of M-Internet technologies to improve user satisfaction with the decision process and develop decision processes anytime and anywhere. We have used mobile phones as the device used by the experts to send their preferences, but the structure of the prototype is designed to use any other mobile device, such as PDAs. The prototype can be used with four different formats to represent the preferences in the best way according to the kind of problem and the experts' knowledge level.

References

[1] J. Kacprzyk and M. Fedrizzi, *Multiperson Decision Making Models Using Fuzzy Sets and Possibility Theory*. Dordrecht, The Netherlands: Kluwer, 1990.

[2] M. Roubens, "Fuzzy sets and decision analysis," *Fuzzy Sets Syst.*, vol. 90, no. 2, pp. 199–206, Sep. 1997.

[3] D. Ben-Arieh and Z. Chen, "Linguistic-labels aggregation and consensus measure for autocratic decision making using group recommendations," *IEEE Trans. Syst., Man, Cybern. A: Syst., Humans*, vol. 36, no. 3, pp. 558–568, May 2006.

[4] D. Ben-Arieh, T. Easton, and B. Evans, "Minimum cost consensus with quadratic cost functions," *IEEE Trans. Syst., Man, Cybern. A: Syst., Humans*, vol. 39, no. 1, pp. 210–217, Jan. 2009.

[5] C. Dae-Young, "Aggregation of preferences based on FSAM in GDSS," *IEEE Trans. Syst., Man, Cybern. A: Syst., Humans*, vol. 38, no. 1, pp. 2–8, Jan. 2008.

[6] J. Fodors and M. Roubens, *Fuzzy Preference Modelling and Multicriteria Decision Support*. Dordrecht, The Netherlands: Kluwer, 1994.

[7] F. Herrera, E. Herrera-Viedma, and J. Verdegay, "A sequential selection process in group decision making with a linguistic assessment approach," *Inf. Sci.*, vol. 85, no. 4, pp. 223–239, Jul. 1995.

[8] F. Herrera, E. Herrera-Viedma, and J. Verdegay, "A model of consensus in group decision making under linguistic assessments," *Fuzzy Sets Syst.*, vol. 78, no. 1, pp. 73–87, Feb. 1996.

[9] F. Herrera, E. Herrera-Viedma, and L. Martinez, "A fuzzy linguistic methodology to deal with unbalanced linguistic term sets," *IEEE Trans. Fuzzy Syst.*, vol. 16, no. 2, pp. 354–370, Apr. 2008.

[10] L. Kitainick, *Fuzzy Decision Procedures with Binary Relations: Towards a Unified Theory*. Dordrecht, The Netherlands: Kluwer, 1993.

[11] C. Kobashikawa, Y. Hatakeyama, F. Dong, and K. Hirota, "Fuzzy algorithm for group decision making with participants having finite discriminating abilities," *IEEE Trans. Syst., Man, Cybern. A: Syst., Humans*, vol. 39, no. 1, pp. 86–95, Jan. 2009.

[12] J. Aronson, T. Liang, and E. Turban, *Decision Support Systems and Intelligent Systems*. Upper Saddle River, NJ: Pearson, 2005.

[13] F. Burstein and C. Holsapple, *Handbook on Decision Support Systems*. New York: Springer-Verlag, 2008.

[14] S. French and M. Turoff, "Decision support systems," *Commun. ACM*, vol. 50, no. 3, pp. 39–40, Mar. 2007.

[15] J. Muntermann, "Mobile Notification and Decision Support for Private Investors," in *Event-Driven mobile Financial Information Services*. Wiesbaden, Germany: Deutscher Universitäts-Verlag, 2008.

[16] J. Schiller, *Mobile Communications,* 2nd ed. Reading, MA: Addison-Wesley, 2003.

[17] J. Katz, *Handbook of Mobile Communication Studies*. Cambridge, MA: MIT Press, 2008.

[18] F. Cabrerizo, S. Alonso, and E. Herrera-Viedma, "A consensus model for group decision-making problems with unbalanced fuzzy linguistic information," *Int. J. Inf. Technol. Decision Making*, vol. 8, no. 1, pp. 109–131, 2009.

[19] G. Buyukozkan, O. Feyzioglu, and D. Ruan, "Fuzzy group decision making to multiple preference formats in quality function deployment," *Comput. Ind.*, vol. 58, no. 5, pp. 392–402, Jun. 2007.

[20] F. Chiclana, F. Herrera, and E. Herrera-Viedma, "Integrating three representation models in fuzzy multipurpose decision making based on fuzzy preference relations," *Fuzzy Sets Syst.*, vol. 97, no. 1, pp. 33–48, Jul. 1998.
[21] F. Chiclana, F. Herrera, and E. Herrera-Viedma, "Integrating multiplicative preference relations in a multipurpose decision making model based on fuzzy preference relations," *Fuzzy Sets Syst.*, vol. 122, no. 2, pp. 277–291, Sep. 2001.
[22] J. Ma, Z. Fan, and Y. Jiang, "An optimization approach to multiperson decision making based on different formats of preference information," *IEEE Trans. Syst., Man, Cybern. A: Syst., Humans*, vol. 36, no. 5, pp. 876–889, Sep. 2006.
[23] Z. H. Xu, "Multiple-attribute group decision making with different formats of preference information on attributes," *IEEE Trans. Syst., Man, Cybern. B: Cybern.*, vol. 37, no. 6, pp. 1500–1511, Dec. 2007.
[24] Z. S. Xu and J. Chen, "MAGDM linear-programming models with distinct uncertain preference structures," *IEEE Trans. Syst., Man, Cybern. B: Cybern.*, vol. 38, no. 5, pp. 1356–1370, Oct. 2008.
[25] J. Cowie and F. Burstein, "Quality of data model for supporting mobile decision making," *Decision Support Syst.*, vol. 43, no. 4, pp. 1675–1683, Aug. 2007.
[26] U. Varsney and R. Vetter, "Emerging mobile and wireless networks," *Commun. ACM*, vol. 43, no. 6, pp. 73–81, Jun. 2000.
[27] T. Imielinski and B. Badrinath, "Mobile wireless computing: Challenges in data management," *Commun. ACM*, vol. 37, no. 10, pp. 18–28, Oct. 1994.
[28] W. Wen, Y. Chen, and H. Pao, "A mobile knowledge management decision support system for automatically conducting an electronic business," *Knowl.-Based Syst.*, vol. 21, no. 7, pp. 540–550, Oct. 2008.
[29] A. Eren, A. Subasi, and O. Coskun, "A decision support system for telemedicine through the mobile telecommunications platform," *J. Med. Syst.*, vol. 32, no. 1, pp. 31–35, Feb. 2008.
[30] F. Ricci and Q. Nguyen, "Acquiring and revising preferences in a critique-based mobile recommender system," *IEEE Intell. Syst.*, vol. 22, no. 3, pp. 22–29, May/Jun. 2007.
[31] E. Triantaphyllou, *Multi-Criteria Decision Making Methods: A Comparative Study*. Dordrecht, The Netherlands: Kluwer, 2000.
[32] R. Yager, "On ordered weighted averaging aggregation operators in multicriteria decision making," *IEEE Trans. Syst., Man, Cybern.*, vol. 18, no. 1, pp. 183–190, Jan./Feb. 1988.
[33] R. Yager, "Weighted maximum entropy OWA aggregation with applications to decision making under risk," *IEEE Trans. Syst., Man, Cybern. A: Syst., Humans*, vol. 39, no. 3, pp. 555–564, May 2009.
[34] E. Herrera-Viedma, F. Herrera, and F. Chiclana, "A consensus model for multiperson decision making with different preference structures," *IEEE Trans. Syst., Man, Cybern. A: Syst., Humans*, vol. 32, no. 3, pp. 394–402, May 2002.
[35] MIDP 2.0 Specifications, [Online]. Available: http://java.sun.com/products/midp/
[36] Java Wireless Toolkit, [Online]. Available: http://java.sun.com/products/sjwtoolkit/

Ignacio Javier Pérez was born in Granada, Spain, on June 8, 1984. He received the M.Sc. degree in computer sciences from the University of Granada, Granada, in 2007 and is currently working toward the Ph.D. degree in the Department of Computer Science and Artificial Intelligence, University of Granada.

He is currently also a Research Fellow with the Department of Computer Science and Artificial Intelligence, University of Granada. His research interests include group decision making, decision support systems, consensus models, linguistic modeling, modeling situations with missing/incomplete information, aggregation of information, digital libraries, and web quality evaluation.

Francisco Javier Cabrerizo was born in Jódar, Spain, on February 8, 1983. He received the M.Sc. and Ph.D. degrees in computer sciences from the University of Granada, Granada, Spain, in 2006 and 2008, respectively.

He is currently an Associate Professor with the Department of Software Engineering and Computer Systems, Distance Learning University of Spain (UNED), Madrid, Spain. He is a member of the editorial board of the *Journal of Universal Computer Science*. His research interests include group decision making, decision support systems, consensus models, linguistic modeling, modeling situations with missing/incomplete information, aggregation of information, digital libraries, web quality evaluation, and bibliometric measures.

Enrique Herrera-Viedma was born in 1969. He received the M.Sc. and Ph.D. degrees in computer science from the University of Granada, Granada, Spain, in 1993 and 1996, respectively.

He is currently a Professor with the Department of Computer Science and Artificial Intelligence, University of Granada. He is a member of the editorial board of the journals *Fuzzy Sets and Systems, Soft Computing,* and the *International Journal of Information Technology and Decision Making*. He is the author or coauthor of more than 80 papers published in international journals. Six of his papers are classed as highly cited as well as being in the top 1% of the most cited papers in its field. His current research interests include group decision making, consensus models, linguistic modeling, aggregation of information, information retrieval, bibliometric measures, digital libraries, web quality evaluation, and recommender systems.

Dr. Herrera-Viedma's h-index is 26, and he is classed as one of the Most Cited Scientists in Engineering in the ISI Web of Science—Essential Science Indicators, i.e., he is in the top 1% of the most cited scientists in the field of engineering.