GDM-VieweR: A new tool in R to visualize the evolution of fuzzy consensus processes.

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Abstract. With the incorporation of web 2.0 frameworks the complexity of decision making situations has exponentially increased, involving in many cases many experts, and a huge number of different alternatives. In the literature we can find a great deal of methodologies to assist multi-person decision making. However these classical approaches are not prepared to deal with such a huge complexity and there is a lack of tools that support the decision processes providing some graphical information. Therefore the main objective of this contribution is to present an open source tool developed in R to provide a quick insight of the evolution of the decision making by means of meaningful graphical representations. Thanks to the modular architecture of this solution this tool can be easily adapted to work with various Group decision making methodologies.

Keywords. Group decision making, fuzzy preference modeling, software development, R

1. Introduction

Nowadays, new paradigms and ways of making decisions, such as web 2.0 frameworks, social networks and e-democracy, have made the complexity of decision making processes to increase, involving in many cases a huge number of decision makers [4]. In the literature we can find a wide range of Group decision making (GDM) approaches. Generally speaking these approaches consist on multiple decision makers, with different knowledge and points of view, interacting to choose the best option among all the available ones [7,15]. Usually those opinions should be considered to arrive at a consensus solution accepted by the whole group [5].

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However these new scenarios require automatic tools not only to combine the information in the best possible way but also to better analyze the whole context, providing a rapid and complete insight about the current state of the process at each stage.

In this sense some initial efforts have been carried out: Alonso et al in [3], presented a web based consensus support system dealing with different types of incomplete preference relations. This system implements the iterative decision making process proposed in [14], among with the consensus reaching process in [12]. Also Perez-Galvez et al. in [20] present a decision approach designed for dynamic mobile systems whose main novelty was its capability to include or remove new alternatives during the decision process. These authors also proposed in [21], a web based consensus approach aimed to deal with a large set of alternatives by defining a fuzzy ontology which selects an smaller sub-set of the most likely ones. On the other hand Palomares et al. in [19] proposed a Matlab graphical monitoring tool based on Self-Organizing Maps (SOMs). These authors also introduced in [18], a consensus system following a multiagent architecture able to deal with GDM processes involving a large number of decision makers overcoming the problem of the human intervention, presenting a semisupervised operation mode in which there is no need to use a human moderator in the different consensus rounds. The main weaknesses identified in the above tools are twofold:

1. The already available tools are developed as closed systems and therefore they are not aimed to be upgraded or extended by other researchers, since in most of the cases they do not provide the source code or they are based in proprietary software. Besides, they are extremely dependent of the user interface and, therefore, they cannot be adapted to work in other environments such as smart phones.
2. The available DSSs do not provide any type of graphical visualizations or output measures providing and a quick and meaningful insight about the evolution of the consensus process.

In this contribution, we present a new open-source software tool developed in R to graphically asses the evolution of the consensus processes.To that aim it offers powerful visualizations tools to quickly verify the state of the decision process. One the one hand, it allows to quickly recognize those experts which are far from the consensus solution and are more reluctant to change their mind. One the other hand, it also identifies those ones who provide more contradictory or inconsistent opinions. The system also allows to check visually the evolution of the global consensus and consistency during the decision process.

The rest of the paper is set out as follows: In Section 2, we introduce the main concepts of a GDM situation. Section 3, presents the proposed system while a practical example to illustrate how the proposed system works, is included in Section 4. Finally Section 5 closures this work pointing out future research lines and summarizing our conclusions.

2. GDM problems

A classical GDM problem may be defined as a decision situation where [9]: (i) there exists a group of two or more decision makers, $E = \{e_1, \ldots, e_m\}$ $(m \geq 2)$, (ii) there is a problem to solve in which a solution must be chosen among a set of possible alternatives, $X = \{x_1, \ldots, x_n\}$ $(n \geq 2)$, and (iii) the decision makers try to achieve a common solution. In a fuzzy context, the objective is to classify the alternatives from best to worst, associating with them some degrees of preference expressed in the $[0, 1]$ interval.

There are various preference representation formats which can be used by decision makers to provide their testimonies. Among them, preference relations are one of the most widely used since it provide the decision makers with more flexibility to enunciate their opinions. Concretely they use of fuzzy preference relations is the most extended in the literature [15,17,24].

Definition 1 *A fuzzy preference relation P^h on a set of alternatives X, given by a decision maker e_h, is a fuzzy set on the Cartesian product $X \times X$, i.e., it is characterized by a membership function $\mu_P\colon X \times X \longrightarrow [0, 1]$.*

A fuzzy preference relation P^h may be represented by the $n \times n$ matrix $P^h = (p^h_{ik})$, being $p^h_{ik} = \mu_{P^h}(x_i, x_k)$ $(\forall i, k \in \{1, \ldots, n\})$ interpreted as the degree or intensity of preference of alternative x_i over x_k: $p^h_{ik} = 1/2$ indicates indifference between x_i and x_k $(x_i \sim x_k)$; $p^h_{ik} = 1$ indicates that x_i is absolutely preferred to x_k; $p^h_{ik} > 1/2$ indicates that x_i is preferred to x_k $(x_i \succ x_k)$. Obviously, we have that $p^h_{ii} = 1/2$ $\forall i \in \{1, \ldots, n\}$ $(x_i \sim x_i)$.

In what follows, we are going to describe two important aspects which need to be addressed in GDM problems involving fuzzy preference relations.

2.1. Consistency

Consistency can be interpreted as a measure of the self-contradiction expressed in the preference relation and is related to the concept of transitivity. A preference relation is considered consistent when the pairwise comparisons among every three alternatives satisfy a particular transitivity property. For fuzzy preference relations, there exist many properties or conditions that have been suggested as rational conditions to be verified by a consistent relation [8]. Among them we can highlight the additive transitivity [14], for fuzzy preference relations. It can be seen as the parallel concept of Saaty's consistency property for multiplicative preference relations [22].

$$(p^h_{ij} - 0.5) + (p^h_{jk} - 0.5) = p^h_{ik} - 0.5, \quad \forall i, j, k \in \{1, \ldots, n\} \tag{1}$$

Additive transitivity implies additive reciprocity. Indeed, because $p^h_{ii} = 0.5$, $\forall i$, if we make $k = i$ in Eq. (1), then we have: $p^h_{ij} + p^h_{ji} = 1$, $\forall i, j \in \{1, \ldots, n\}$. Eq. (1) can be rewritten as follows:

$$p^h_{ik} = p^h_{ij} + p^h_{jk} - 0.5, \quad \forall i, j, k \in \{1, \ldots, n\} \tag{2}$$

A fuzzy preference relation is considered to be "additively consistent" when for every three options encountered in the problem, say x_i, x_j, $x_k \in X$, their associated preference degrees, p^h_{ij}, p^h_{jk}, p^h_{ik}, fulfill Eq. (2).

Given a fuzzy preference relation, Eq. (2) can be used to calculate an estimated value of a preference degree using other preference degrees. Indeed, using an intermediate alternative x_j, the estimated value of p^h_{ik} $(i \neq k)$ can be obtained in three different ways (see [14]).

2.2. GDM steps

The solution for a GDM problem is derived either from the individual preferences provided by the decision makers, without constructing a social opinion, or by computing first a social opinion and then using it to find a solution [15]. Here, we focus on the second one, since we are interested in obtain a solution accepted by the whole group of decision makers (see Fig. 1). In the following, we describe in more details these steps.

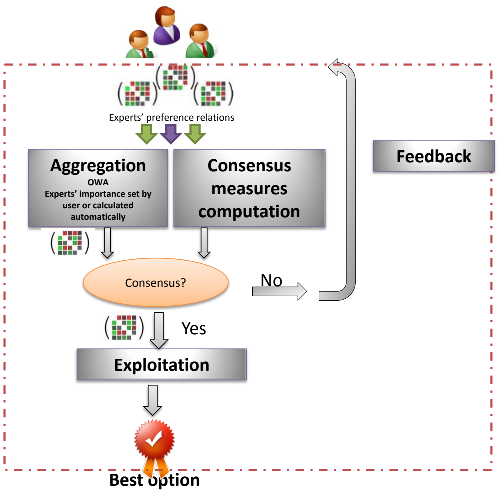

Figure 1. Steps of a GDM process.

2.2.1. Aggregation step

In order to obtain a collective fuzzy preference relation, the aggregation step of a GDM problem consists in combining all the preferences given by the decision makers into only one preference structure that summarizes or reflects the properties contained in all the individual preferences. This aggregation can be carried out by means of various aggregation operators [28]. Among them, the Ordered Weighted Averaging (OWA) operator proposed by Yager [26] and the Induced Ordered Weighted Averaging (IOWA) operator [27] are the most widely used.

2.2.2. Exploitation step

In order to identify the solution set of alternatives, the exploitation step uses the information produced in the aggregation step. Here, some mechanism must be applied to obtain a partial order of the alternatives and thus select the best one(s). There are several ways to do this. A usual one is to associate a certain utility value to each alternative, based on the aggregated information, producing a natural order of the alternatives. To do so, two quantifier-guided choice degrees of alternatives can be used: a dominance and a non-dominance degree [14].

2.2.3. Consensus

In order to avoid that some decision makers disagree with the final solution arguing that their opinions have not been taken into consideration [5,**?**], it is preferable to include mechanism to check the agreement among the decision makers before obtaining a solution ensuring that enough agreement have been achieved. Those mechanisms are widely known as consensus processes [13] and they consist on iterative negotiations where the decision makers agree to change their testimonies following the advice given by a moderator, which calculates the agreement or consensus degree at each iteration [6]. If enough agreement have been reached the consensus process stops and the aggregation and the exploitation is carried out. Otherwise, some feedback is given to the decision makers to help them to reach the desired agreement.

3. The proposed system

The proposed solution is a graphical monitoring tool to support decision makers by providing them with easily understandable visual information about the current status and the evolution of the decision process. This tool eases the analysis of diverse crucial aspects that are common in these problems, among them, we can highlight the following:

- Monitoring the evolution of the global consensus across the whole GDM process.
- Monitoring the decision makers' consistency along the whole GDM process. This is especially important to make sure that they are keeping an acceptable consistency level in their preferences after the recommendation rounds.
- Detection of the alternatives that are posing more controversy in the GDM process.
- Detection of those decision makers or group of them, whose preferences are further from the consensus solution, or those that are more reluctant to change their point of view.
- Detection of those decision makers that are being influenced or manipulated to provide preferences far from the consensus solution.
- Providing information to the decision makers about the GDM process, and showing them how their preferences are located with respect to the consensus one.

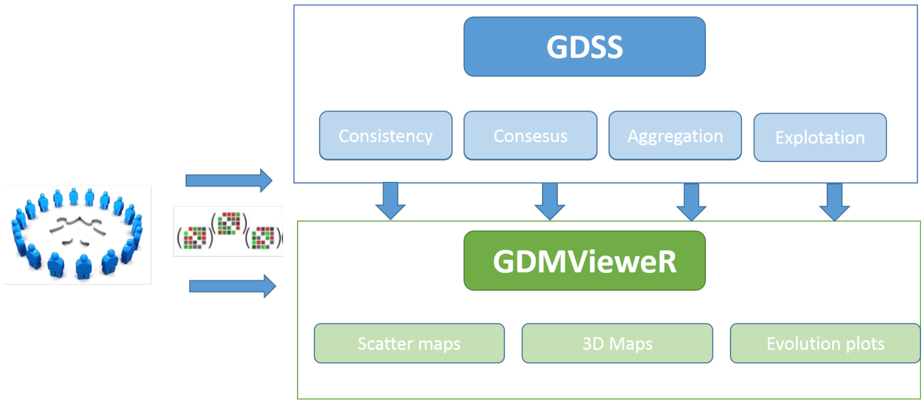

Figure 2. Working flow

The proposed system is fully developed in R [1]which provides very powerful tools to carry out graphical representations. Among them we can highlight Lattice [23], Scatterplot3D [16] and Rgl3 [2] to be the ones that have been mainly used in the proposed solution.

Due to the fact that our tool is built to work in collaboration with a Group Decision support system, GDSS, in order to ease its integration it has been designed following a Model-View-Controller architectural pattern [10] where the logic is completely separated from the data storage requirements and from the user interface. This design also enables its adaptation to different platforms, such us web or mobile environments. Fig. 2 depicts an overview of the proposed tool and its integration with the GDSS. As we can observe the GDMViewR platform receives as input the the experts preferences an also the metrics computed in the decision support system, that is, the consistency, and consensus measures, the collective decision matrix and the ranking of the alternatives.

The information that our solution provides can be divided in two wide groups, depending on if they show the evolution among the various consensus rounds, or if they show information related to a single round:

- Evolution across the consensus rounds:
  - ∗ *Consistency vs consensus evolution in the GDM process.* This representation shows the evolution of both global consistency and global consensus in each consensus round. The desirable situation is that most of the points or at least the final ones lie over the diagonal line showing a positive tendency. That means that the final solution has reached a high level of agreement and it is consistent. This representation also enables to detect whether the consensus process is not only helping to bring the decision makers' opinions closer but also to keep or increase their consistency.
  - ∗ *Decision maker's consistency vs decision maker's consensus in the GDM process.* This representation allows to check how decision makers' consensus and consistency evolves during the GDM process. It also enables to visually check the different decision makers profiles depend-

ing on the shape of the curve for each decision maker. On the one hand, curves with a positive tendency and located over the diagonal represent the desired situation of those decision makers that are more willing to change their opinions in the interest of increasing the global consensus while keeping a highly consistency level. On the other hand, curves parallel to the y-axis represents those decision makers which are reluctant to change their mind during the process, and therefore they may require special attention.

- Consensus and consistency state in each single round:
  - ∗ *Barplot of each decision maker's proximity to the aggregated solution.* This representation enables to check who are the decision makers whose opinions are closer to achieve a high degree of consensus, and who are those with highly disagree with the proposed solution.
  - ∗ *Barplot of the average consensus achieved for each alternative.* Thanks to this representation, one can identify the alternatives that are posing more controversy in the decision process.
  - ∗ *Barplot of the average consistency achieved for each decision maker.* Thanks to this representation, one can identify those decision makers providing more consistent fuzzy preference relations in the decision making process.
  - ∗ *2D representation map of the decision makers' fuzzy preference relations and the consensus solution.* This representation provides a quick insight of the current state of the decision process and enables the rapid identification of sub groups of decision makers who share similar opinions. It also eases the detection of conflicts among decision makers. Moreover, it provides the decision makers with a good idea about the status of the consensus process and how far their opinions are from the consensus solution. This 2D representation is obtained after carrying out a classical 2D multidimensional scaling reduction of the decision makers' fuzzy preference relation matrix [11]. In addition, R also offers the possibility of non metric multidimensional scaling.
  - ∗ *3D representation of the position of each decision maker with respect to the consensus solution among with their consistency.* This plot easily allows to identify those groups of decision makers that are far from the consensus solution but keep a high degree of consistency, and, therefore, need special attention. To easily visualize this plot, we have also included a interactive representation.

4. Illustrative example

To analyze the performance of the proposed system we consider a GDM situation involving 20 decision makers and 4 different alternatives, where the minimum consensus threshold that needs to be achieved is 0.8, and the maximum number of consensus rounds is four. Recall that the system can also work indicating only the maximum number of possible rounds or only the desired level of consensus. In

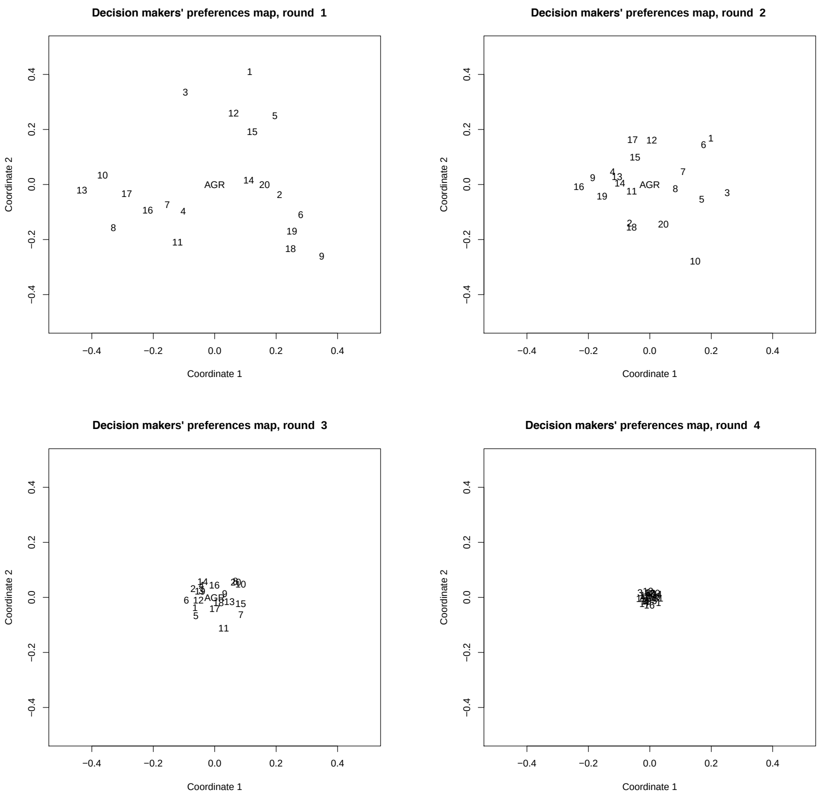

Table 1. Evolution of the decision makers' preferences among the consensus rounds.

addition, the initial average level of consistency of the fuzzy preference relations is 0.8 and the initial average level of consensus is 0.6.

First of all, in Table 1, we can visualize a 2D map with the position of each decision maker with respect to the aggregated solution in the different consensus rounds. The global solution is presented always in the center of the plot in order to ease the rapid detection of those decision makers whose opinions are far from the global solution as it is the case, in this example, of decision maker 1. Hence, in real case situations, some especial actions can be taken with these decision makers depending on the characteristics of the process, such as discarding their opinions since they can be considered as outliers. Moreover, we can observe how in the first round, the preferences are in general pretty spread up. However, after each round of recommendations, we observe that the opinions of the decision makers get closer and closer, which able to verify that the decision making process is going in the right direction. Therefore, this type of maps allow to easily recognize those decision makers who are reluctant to change their opinions in order to achieve a solution accepted by the whole group. These maps also are useful to recognize small sub-communities of decision makers that share similar opinions, but whose preferences are far from the global solution, and those who exert a greater influence on their sub-communities.

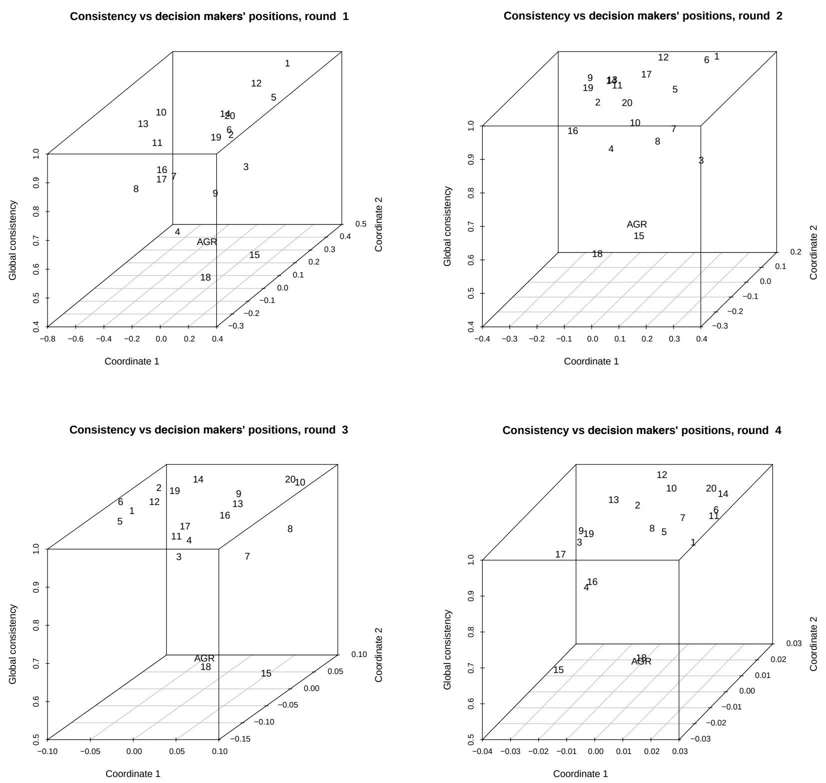

Table 2. Evolution of the decision makers preferences among the consensus rounds.

In Table 2, a 3D map of the decision makers preferences among with the degree of consistency for each decision maker is shown. These maps allow to recognize the decision makers whose preferences are more consistent and how close their opinions are to the global solution. For example, in the very first iteration, for the decision maker number 1, we can observe that even though his/her preferences are far from the consensus solution, his/her consistency level is very high. Therefore, this decision maker's opinions are worth to be taken into consideration. It also allows to quickly recognize communities of decision makers who share the same points of views, and also identify those decision makers who have more influence or more persuasion power over the group. They can be recognized easily since they do not change their opinions with the time, but they attract others forming small clusters in the map that become bigger with the time. Usually, the most influential decision makers also present a high level of consistency.

In Table 3, the system presents a barplot with the decision makers average consensus and consistency degree per round, along with both lines showing the

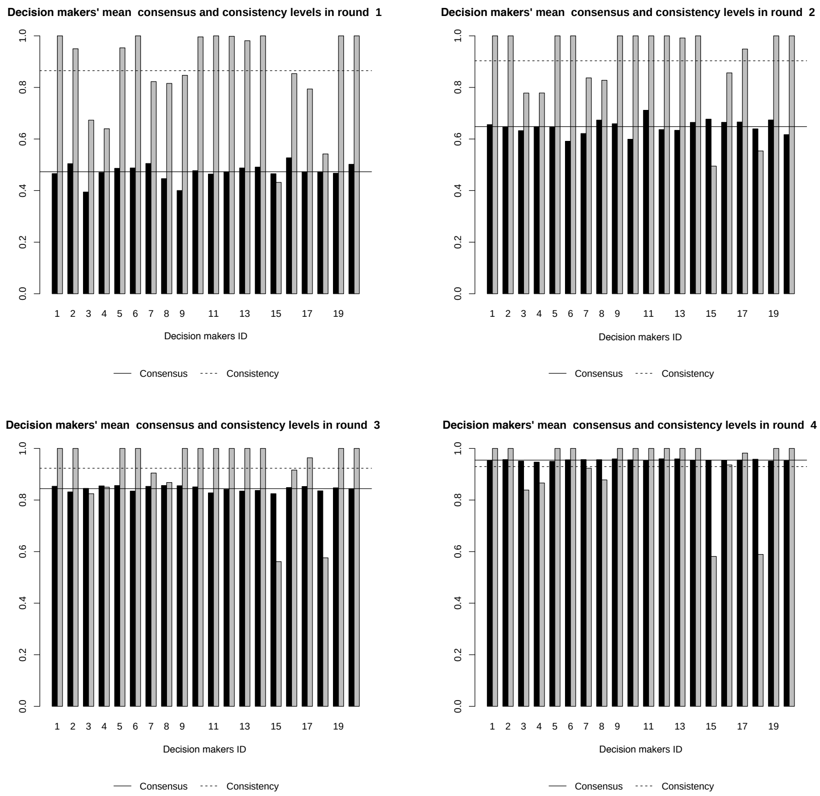

Table 3. Evolution of the decision makers' consistency and consensus in each round.

global average consensus and consistency degrees. These plots easily allow to asses the evolution of both consensus and consistency and recognize those decision makers that may present more controvert opinions, or less consistent ones, and take especial actions with those ones.

4.1. Results of the GDM process

The decision making process finishes when the maximum number of rounds has been overpassed or when the desired consensus degree has been achieved. In Fig. 3, we can observe the evolution of the consensus vs the evolution of the consistency in each round of consensus. Depending on the slope of the line in this plot, we can easily recognize how the decision process has gone. For example, if the line is almost parallel to the x-axis it will mean that the the different rounds of the decision process have only contributed to increase the global consistency. That is, in average the decision makers' opinions have become more consistent with the time, but the decision makers had not change their mind to increase the consensus. This type of line allows to recognize that the decision makers are very committed to provide non contradictory solutions to the problem, but they present a non cooperative behavior towards achieving a solution accepted for the whole group.

A similar situation would happen if the line is parallel to the y-axis, but in this case it would mean that the consensus has improved whereas the decision makers consistency has barely changed. This situation means that decision makers are easily manipulated to change their minds, without caring about the quality of the provided solution.

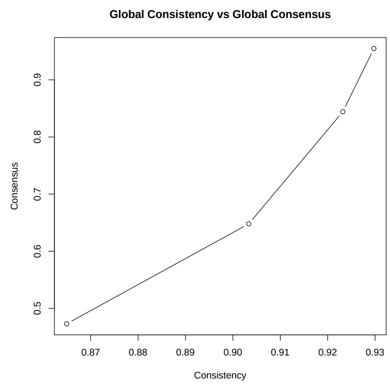

Figure 3. Global consensus and consistency evolution along the consensus rounds.

The most desired solution is having a line with positive slope, like the one in Fig. 3, that means that the different rounds have contributed to positive increase both the consensus and the consistency of the decision makers. Also the average slope of this line also provide us with a general measure of how fast the consensus increase vs the consistency, this measurement can be leverage to test the performance of different decision making approaches.

Finally, the system provides a graphical representation with the ranking of the alternatives using both the dominance and the non-dominance degrees as we have explained in previous sections. In Table 4, we can observe the evolution of these degrees during the consensus rounds. More concretely, for this example, we can observe that from the beginning it was clear that the most desired alternative was the number two.

5. Conclusion and future work

In this paper, we have presented GDM VieweR, a new open source solution fully implemented in R, aimed to overcome the weaknesses of the previous software systems proposed for supporting GDM processes. To that aim it displays various graphical representations which provide a rapid insight of the state of the GDM process and enable, among them, to identify decision makers whose opinions are far from the group solution and those who are reluctant to change their mind in order to reach an agreement.

As future work, we point out several directions as the extension of this solution to work with different interfaces such as mobile and web based frameworks. Extending the system to carry out GDM processes in environments in which the

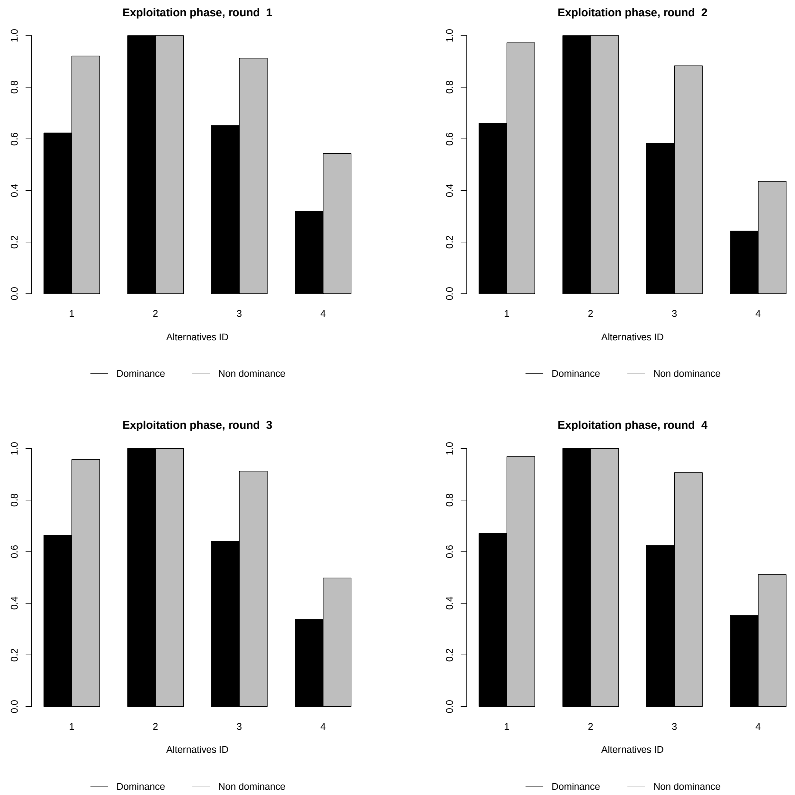

Table 4. Dominance and non-dominace degrees in the exploitation phase.

decision makers can access to the decision process from different platforms and locations. In addition, more complex approaches based on ontologies [21] and trust networks [25] will be included.

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