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A web-based group decision support system for multicriteria problems

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Summary

One of the most important factors to determine the success of an organization is the quality of decisions made. Supporting a decision-making process is a complex task, mainly when decision-makers are dispersed. Group decision support systems (GDSSs) have been studied over the last decades with the goal of providing support to decision-makers; however, their acceptance by organizations has been difficult. This happens mostly due to usability problems, loss of interaction between decision-makers, and consequently, loss of information. In this work, we present a web-based GDSS developed to support groups of decision-makers, regardless of their geographic location. The system allows the creation of multicriteria problems and the configuration of the preferences, intentions, and interests of each decision-maker. The presented system uses a multiagent system to combine and process this information, using virtual agents that represent each decision-maker. We believe that, with this approach, we will proceed in the refinements of a successful GDSS to correctly support decision-makers while preserving the valuable intelligence and knowledge that can be generated in face-to-face meetings. Furthermore, the high level of usability that the system provides will contribute to an easier acceptance and adoption of this kind of systems.

KEYWORDS

automatic negotiation, group decision making, group decision support systems, multiagent systems

1 | INTRODUCTION

Group decision support systems (GDSSs) have been studied over the last decades with the goal of providing support to decision-makers that may be involved in group decision-making processes.[1-3] According to the literature, we know that decisions made in group can achieve better results compared with individual decisions. Furthermore, most of the organizations' organigrams require this type of decision-making process.[4] Nowadays, due to the actual paradigm of globalization, many companies are becoming global and turning into multinational organizations. As a result, managers (the decision-makers) spend most of their time traveling around the world and staying in different countries with different time zones, and become unavailable to gather at the same place and time to make a decision.

To overcome this issue, GDSS have been adapted, and we can now find many GDSS that are web-based to provide support to decision-makers in many areas of society, such as healthcare, economy, gastronomy, logistics, and industry. For example Miranda et al[5] proposed a simulated medical practice scenario to deal with staging cancer. In their proposal, the decisions were made in group and allowed collaborative work. These authors also implemented a multiagent system (MAS) to represent and exchange information related to real participants. In the work proposed by Tavana et al,[6] a GDSS was developed to evaluate and manage oil and natural gas transportations using the alternative pipeline routes from the Caspian Sea to other regions. They represented decision-makers' beliefs using the strength, weakness, opportunity and threat (SWOT) analysis with the Delphi method. These believes were integrated using the preference ranking organization method for enrichment evaluation

(PROMETHEE) to find the better solution for pipeline routes. In the work proposed by Morente-Molinera et al,[7], the authors developed a decision support system composed of both web and mobile applications to support the selection of wines. This system allowed decision-makers to participate in the decision-making process even if they were geographically dispersed. They considered the use of different techniques such as a fuzzy wine ontology, group decision support algorithms, and a fuzzyDL reasoner. Yazdani et al[8] proposed a GDSS for the selection of logistic providers. Their model combines a quality function deployment and the multicriteria decision analysis algorithm technique for order preference by the similarity to ideal solution (TOPSIS) to optimize a French logistic agricultural distribution center. They proposed a model that approaches the decision problem considering two perspectives: the technical and customer perspectives. To select third-party logistic providers, the system acts as an interface between decision-makers and customer values. To support agricultural parties, the system uses fuzzy linguistic variables in uncertain situations.

Regardless of the potential offered by web-based GDSS, success and acceptance of these systems by the decision-makers have not been positive so far. Some of the known reasons are related to the resistance to change from employees and the difficulties in the configuration of the system, either in the creation and configuration of the decision problem or in the configuration of the preferences for each decision-maker. Another reason that makes web-based GDSS hard to accept is related with the fear of losing dialog and idea discussion that can be achieved in face-to-face meetings.[9-11]

In this work, we present a web-based GDSS to support groups of decision-makers independently of their location. Our GDSS supports the group decision-making process for dispersed groups with users that cannot gather at the same place and time. The system allows the creation of multicriteria problems and the configuration of the preferences, intentions, and interests of each decision-maker. All the information gathered in each iteration is combined and processed in a MAS, which uses virtual agents that represent each decision-maker and act according to his/her preferences and intentions. These agents interact and negotiate with each other to find a solution for the selected problem with the goal of maximizing the group satisfaction regarding the proposed solution. We believe that the proposed GDSS can contribute to an increase in the acceptance of this type of systems by promoting the interaction between the members of the group, through the exchange of arguments regarding the alternatives and the criteria of the problem. On the other hand, the configurations of the preferences of the decision-makers in each iteration, can be easily configured through the interfaces developed to maximize the usability of the system.

The remaining sections of the paper are organized as follows. In Section 2, we present the proposed system, where we perform a general description of the GDSS, the concepts related to the system, and the description of the system's domain model. Section 3 presents a description of the GDSS workflow starting with the meeting creation and finishing with the report of the generated results. Finally, in Section 4, the conclusions are presented, along with some guidelines about future work.

2 | THE PROPOSED WEB-BASED GDSS

Our GDSS enables the group decision-making for multicriteria problems. The idea was to develop a system that could resemble a virtual meeting room but using the same logic applied in social networks. The user interface was built as a web application that enables all the interactions between the user and the system through any kind of device (such as a PC, a tablet, or a smartphone).

To better understand how the systems works, it is important to be aware of the concepts used in the GDSS.

- *Meeting* is a representation of a real group decision-making meeting in which one multicriteria problem will be discussed.
- *Problem* is the multicriteria problem, composed by a set of alternatives to solve that problem which are differentiated according to a set of criteria.
- *Topic* is a conversation topic that can be related with criteria or alternatives or both at the same time. Each one of the decision-makers can create topics and respond and evaluate the topics and messages created by other decision-makers. This conversation is related to either a public conversation (where each decision-maker can participate in the conversation) and to a private conversation (between two decision-makers, while exchanging requests, where only these two decision-makers can participate in the conversation). This way of exchanging information (using public and private conversation topics) has been inspired by the social networks logic and has been explored in a previous work.[12,13]
- *Decision-maker* is a person who participates in the group decision-making process. This person has access to the meeting information and can evaluate the multicriteria problem (by defining different preferences for each considered criterion and alternative) and may also define other personal configurations, such as the desired style of behavior, expectancy credibility, and expertise. All these concepts have been studied in previous studies and represent the intentions and goals of the decision-maker for the selected meeting.[14-17]
- *Style of behavior* is the expected behavior or the desired behavior of the agent in the negotiation process. We have followed the work and concepts proposed by Carneiro et al[14], and we have identified five main styles of behavior, which are integrating, compromising, dominating, avoiding, and obliging. These five styles are differentiated in four dimensions that represent how the decision-maker intends to behave throughout the decision-making process. These dimensions are the concern for self (importance given towards self-interests and goals), concern for others (importance given towards other decision-makers' interests and goals), activity level (the participation effort that is related

to the probability to create conversation topics), and resistance to change (the probability to accept or refuse incoming requests to change preferences).

- *Credibility* is defined in this work as the possibility for each decision-maker to select which other decision-makers he/she considers to be credible for the corresponding meeting. This selection is related to concepts such as trust, reliability accuracy, quality or even authority, reputation, and competence. We have explored this concept in more detail in a previous work.[18]
- Expectancy – in this work, we have defined expectancy as the perception that the decision-maker has regarding the acceptance of his preferences by other decision-makers. This expectation can influence satisfaction and may have a negative, positive, or neutral impact depending on whether the expectations are achieved, exceeded, or not achieved. We have explored this concept with more detail in a previous work.[19]
- *Satisfaction* is related to the perception of the quality of the decision. We have studied this concept in previous works,[19,20] and it can be measured according to the decision-maker's expectations, style of behavior, emotional changes, and mood variation.
- *Expertise* corresponds to the decision-maker's self-evaluation of his/her expertise level for the corresponding meeting. This concept has been studied in (including credibility and expertise), and we have identified five levels of expertise, which are expert, high, medium, low, and null.[18]
- *Available time* indicates the time needed for a decision-maker to analyze the problem. This corresponds to the availability specified by the decision-maker towards the decision-making process and whether he/she intends to receive detailed information by the system. If the available time is low, the information provided by the system should be more specific and oriented to the interests of the decision-maker, while if the available time is high, this information may not be only related to the decision-maker's self-interests but also related to the interests of other decision-makers. We have explored this concept with more detail in the work of Carneiro et al[21]

The system is composed by a MAS, and for each decision-making process, a group of agents will be used where each agent will act according to the decision-maker' preferences that it represents. Furthermore, each agent will try to obtain a solution for the multicriteria problem using an argumentation-based dialog model. Agents use deliberative dialogs tp identify the most consensual decision that brings the highest satisfaction to all decision-makers (which could correspond to the selection of one or more alternatives as a proposed solution for the problem). In addition to that, agents can also use other kind of dialogs, such as negotiation persuasion and information seeking.[16,17]

2.1 | Domain model

Figure 1 shows a high-level representation of the domain model of the application without any implementation details. The main concept in the application is obviously the meeting, everything else in the application, aside from user account management, revolves around the meeting. Since a group decision-making process is an iterative process, the system allows each meeting to have several iterations, where each iteration can have

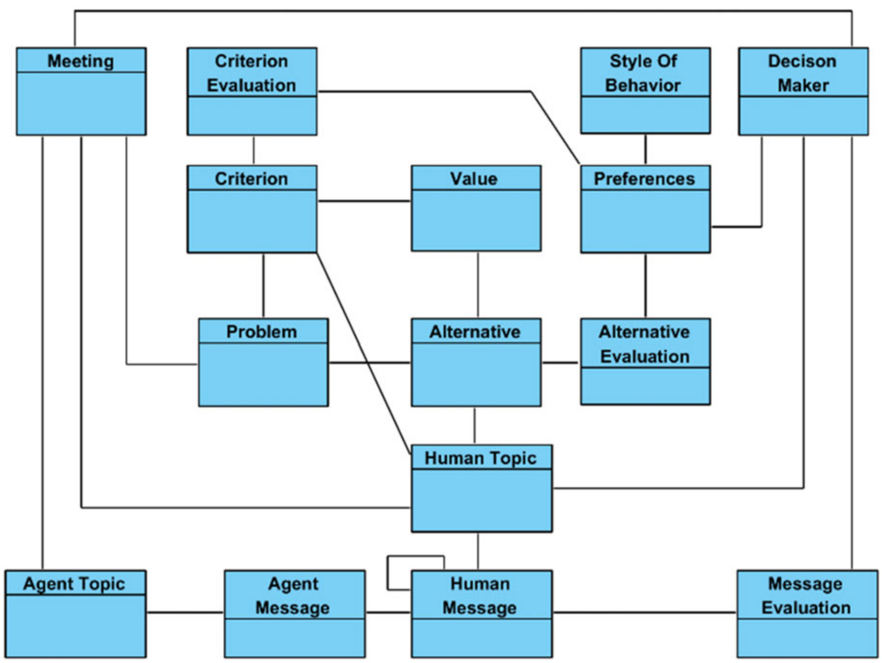

FIGURE 1 The proposed system's domain model

different problem configurations as well as different decision-makers. This way the system will be able to deal with situations where one or more decision-makers may abandon the decision-making process in the end of one iteration and before the meeting is concluded. Likewise, the system will be able to in include new decision-makers in the decision-making process if it is necessary.

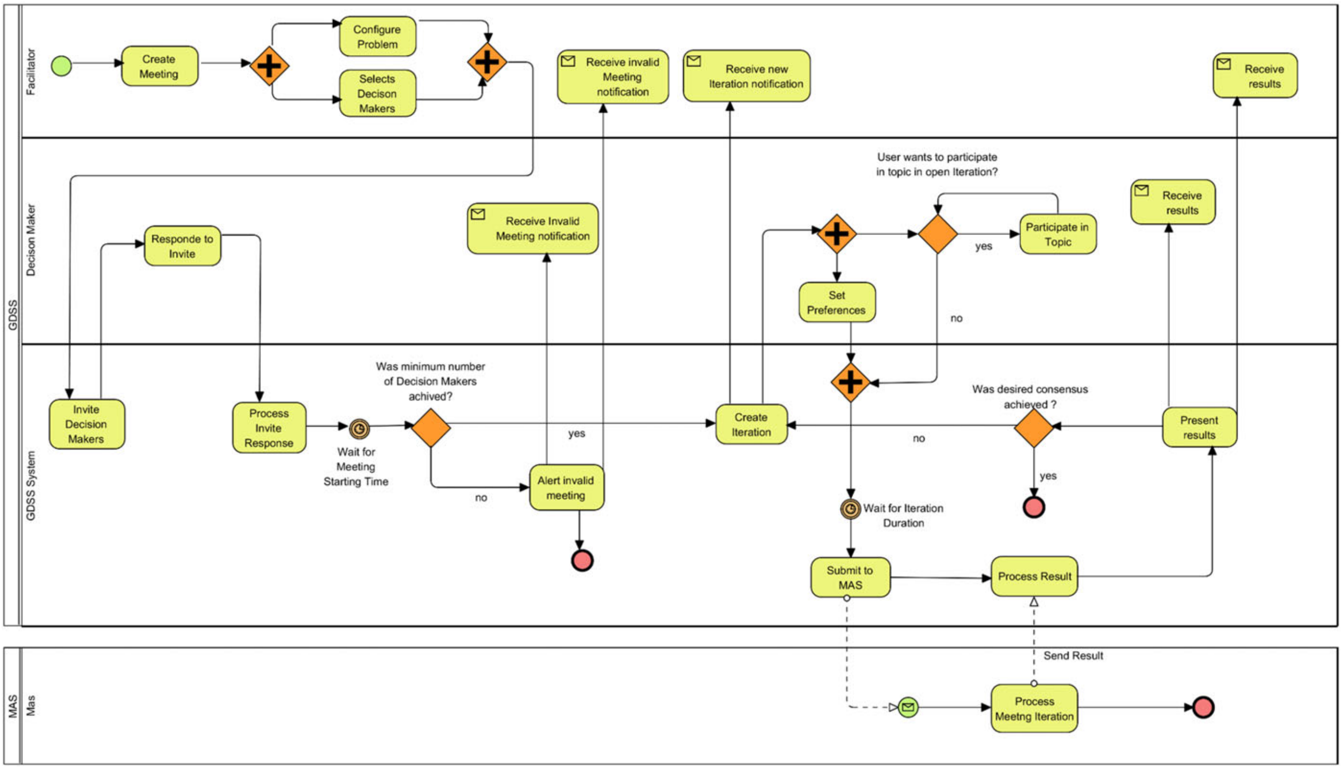

FIGURE 2 BPMN diagram of GDSS

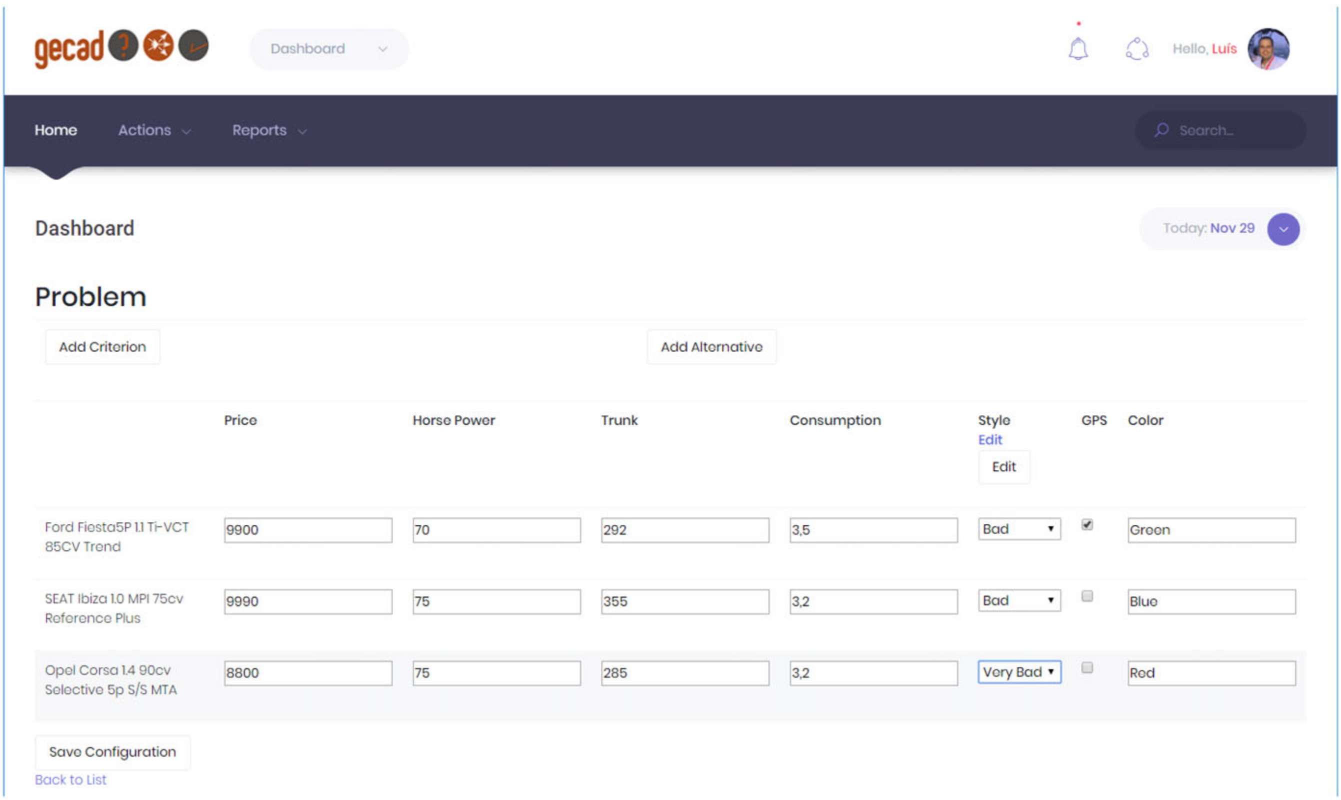

FIGURE 3 Problem configuration interface

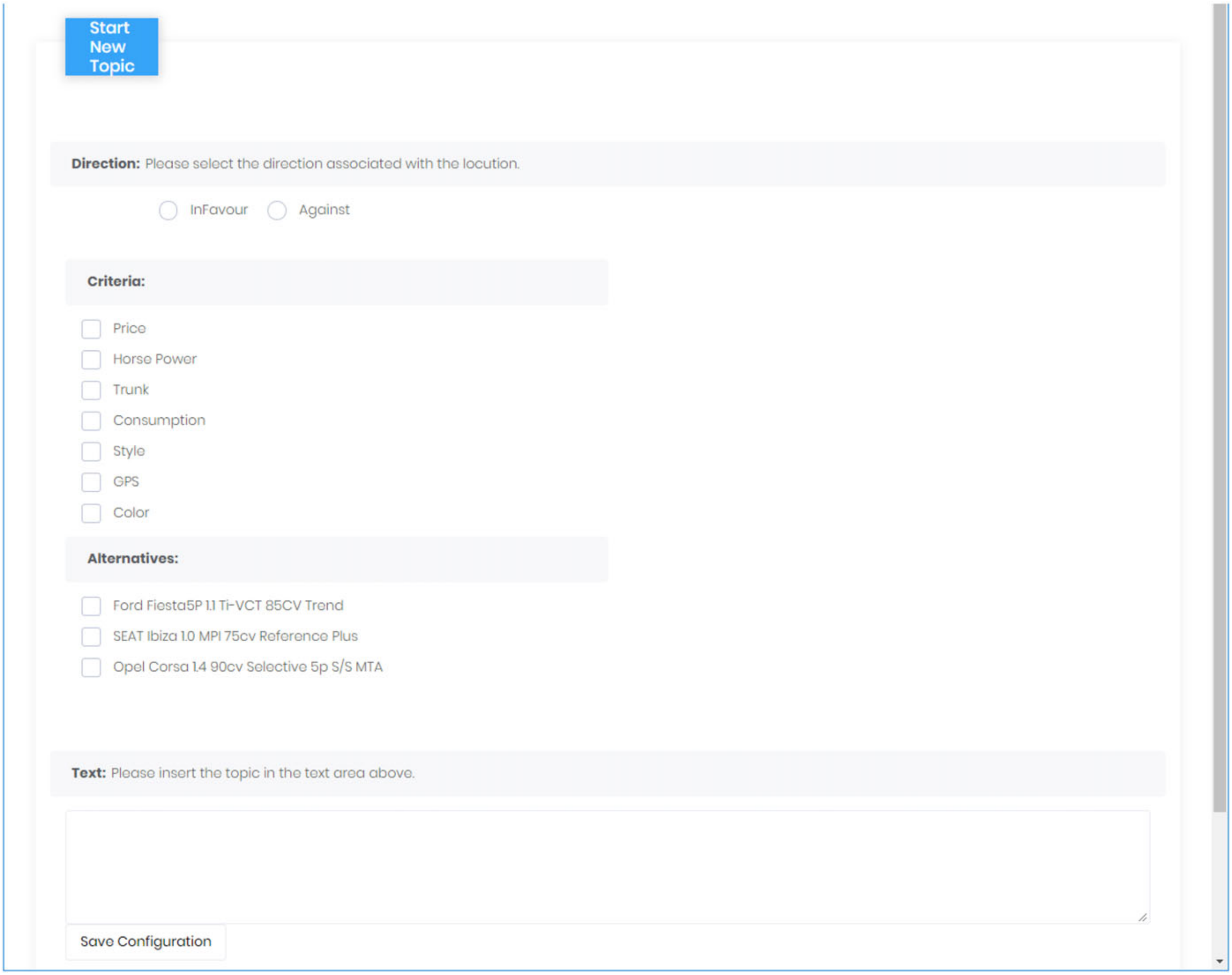

FIGURE 4 Topic creation interface

FIGURE 5 Respond to message interface

The meeting contains all the information related with each decision-making process, of which we highlight the following: a definition of the Problem, a group of decision-makers, a list of decision-makers' conversations, and a list of agents' conversations.

The problem model defines the multicriteria problem as a set of criteria and a set of alternatives. To complete the problem definition, it is also necessary to specify the relation between the criteria and the alternatives, which corresponds to the value that each alternative has in each criterion. It should be noticed however that the system can handle criteria from various types such as subjective, numeric, Boolean, and classificatory. In addition to that, greatness is associated to each criterion, which can be of maximization or minimization. For example, if we want to minimize the prize criterion, then the cheapest product would be the most beneficial solution.

As for the decision-maker, it will have his/her own preferences for each iteration. The preferences are in turn the decision-maker's expectancy regarding the selected alternative, the style of behavior, the decision-maker's expertise level, the available time, and credible decision-makers. Finally, preferences may also include the decision-makers' evaluation for the alternatives and criteria.

The human topic represents a conversation between decision-makers about one or more criteria and/or one or more alternatives. A human topic is created by a decision-maker and contains the initial human message for that human topic. As for human messages, they will either be an opening message or responses in a topic. Whenever a human message is included in the topic, it will be associated with the message it is responding to, as well as a message evaluation to that message.

Finally, we have agent topics, which represent the dialogs created by the MAS (messages exchanged between agents). If an agent message is derived from a human message, the agent message will inherit the characteristics of the corresponding human message.

The MAS used in this GDSS uses a framework that encapsulates the JADE framework with the intention of representing or virtualizing the interaction between decision-makers in face-to-face meetings, allowing the implementation of different dialog models and agents' behaviors.[22] This framework implements a type of communication between agents that guarantees that, at any given moment of time, all agents are in possession of the same knowledge and are therefore capable of simulating what could happen in a face-to-face meeting (in this case, whenever a decision-maker decides on a subject, all participants receive this information at the same instant of time). This approach uses a social network logic in which conversations are maintained in the form of topics where each agent creates a new topic for each subject, and then, other agents in the group can argue regarding that topic. The process ends whenever all involved agents withdraw from the discussion, which corresponds to them not wanting to discuss new topics nor responding to existing topics.

3 | WORKFLOW OF A GROUP DECISION-MAKING PROCESS

Assuring usability was a mandatory requirement throughout the development process of this GDSS, to simplify as possible the use of the system by a decision-maker. To better describe the workflow of this application, we used a business process model and notation (BPMN) diagram that is represented in Figure 2.

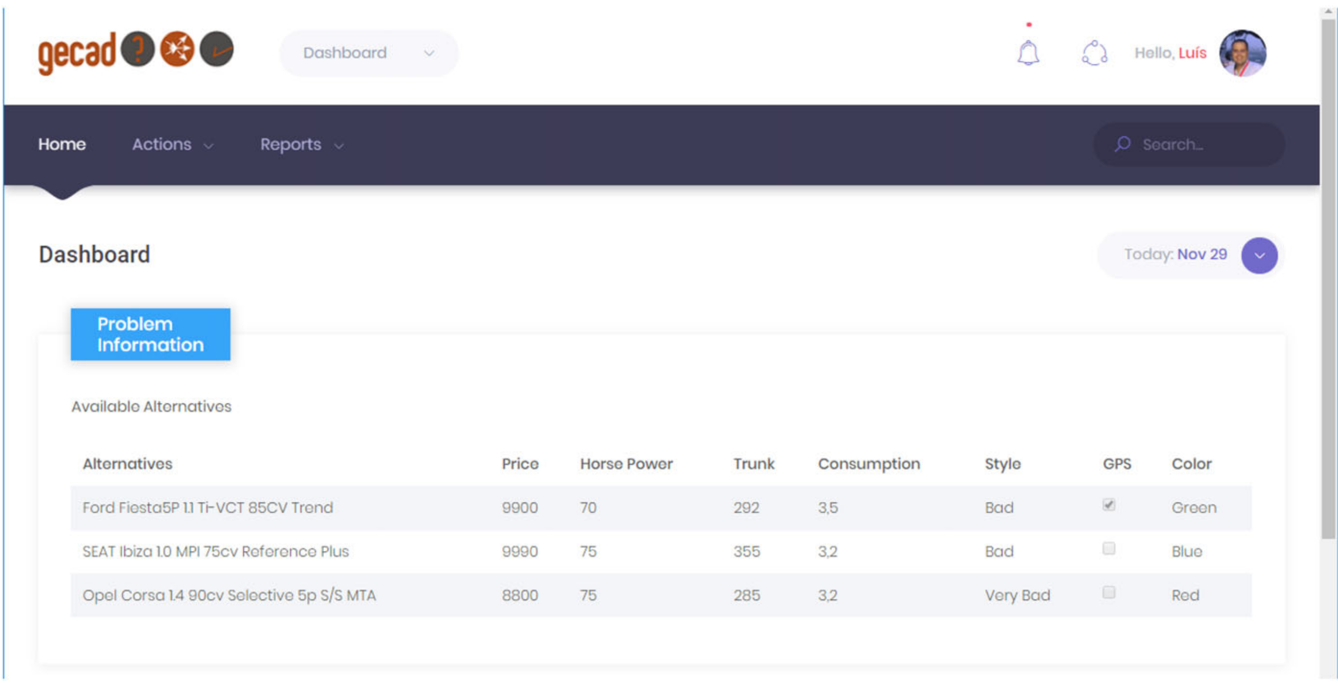

FIGURE 6 Decision-maker preference configuration (problem information) interface

The process begins when a user creates a meeting and consequentially becomes the meeting facilitator for the newly created meeting. The facilitator is then responsible for making the problem configuration, namely the specification of criteria and alternatives, as shown in Figure 3. It is important to notice that the facilitator can easily add new criteria or alternatives to the problem matrix simply by clicking in the "Add Criterion" or "Add Alternative" buttons available on the top of the table. In addition to that, facilitator also needs to invite other users to participate as decision-makers in the meeting. The invited users will receive a notification requesting their participation in the meeting and will then be able to accept or decline the invitation.

After each intended user is invited to participate in the meeting, the system will wait until the meeting starting time is ready. The system will then verify if the minimum amount of required decision-makers for the meeting was achieved, and in this case, the process will proceed to the iterative decision phase. Otherwise, if the number of decision-makers is below the minimum, then the process will terminate, and the system will notify the facilitator and the invited users that the meeting was invalid.

When starting an iteration, both the facilitator and the available decision-makers will be notified. From this moment on, all decision-makers can create discussion topics regarding alternatives or criteria (as shown in Figure 4). To create a new topic, the decision-maker must first select the direction associated with the locution, then select the criteria and/or alternatives that are related with the topic, and finally write the locution to conclude the topic creation. When a new topic is created, the system will notify all the available decision-makers who are participating in the decision-making process. After that, all the available decision-makers can respond to the topics and assess their importance.

As shown in Figure 5, a response message indicates the message that a user is responding to and its direction (if the response is in favor or against that message), as well as if that message is related with the criteria, alternatives, or both. In the response, the decision-maker needs

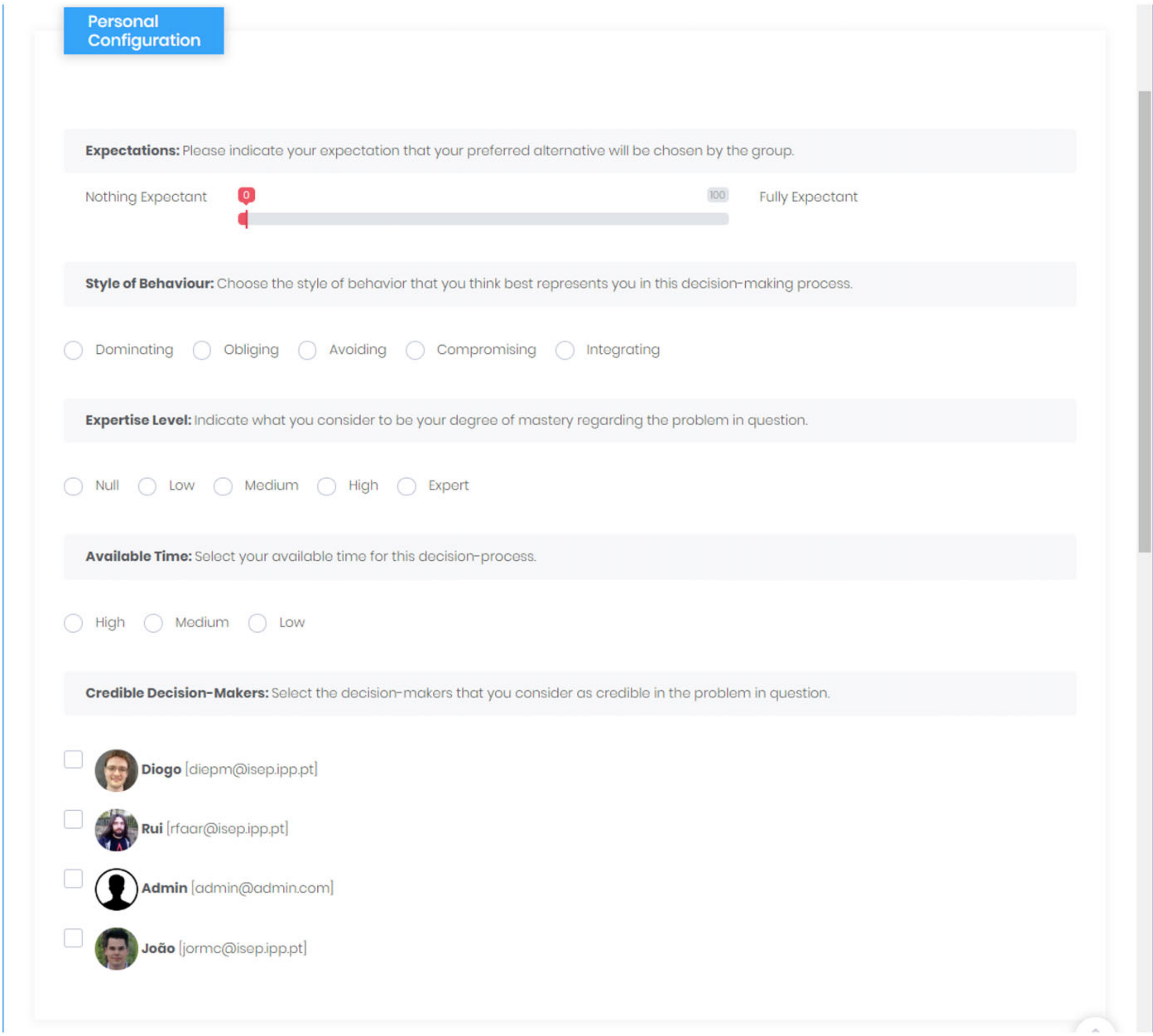

FIGURE 7 Decision-maker preference configuration (personal configuration) interface

to evaluate the message. There are three possible outcomes associated to this evaluation, the first being related to an evaluation greater than zero (in this case, the response will be a reinforcement to the original message, and then he can write a response reinforcing that message). The second case is related to an evaluation lower than zero (and in this case, the response will be an attack to the original message). The third and final outcome is related to evaluations equal to zero, and in this case, the system will not allow the introduction of a response message because it is considered that the decision-maker does not have an opinion about the original message.

Alongside the creation of discussion topics and responses to messages, decision-makers must also configure their preferences. The preference configuration interface was designed according to a template that was developed specifically for a web-based GDSS and that demonstrated high usability and configuration speed for the decision-makers.[11] This interface is composed of three main sections: problem information, personal configuration, and problem configuration. The problem information section presents the multicriteria problem to the decision-maker allowing the

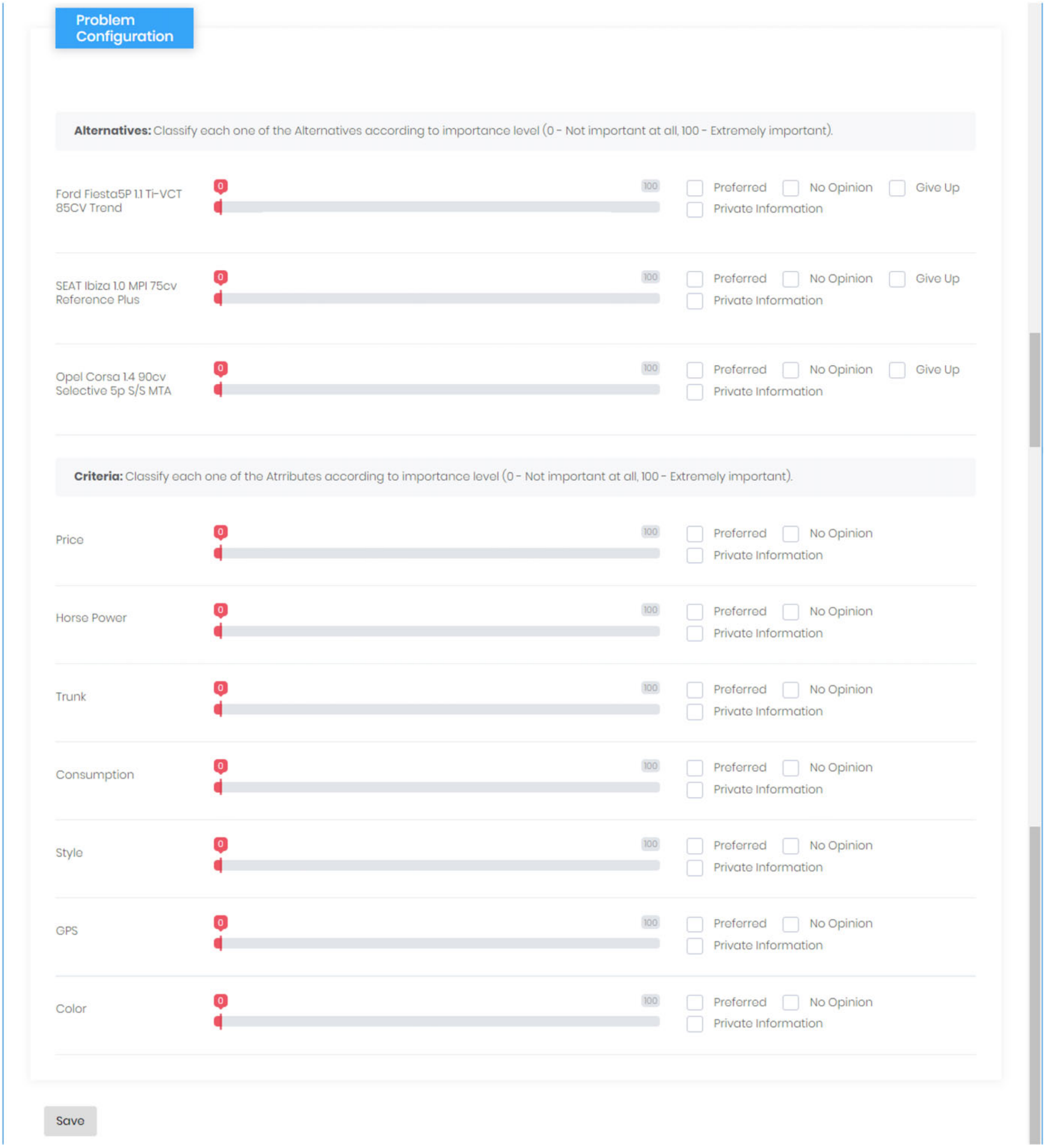

FIGURE 8 Decision-maker preference configuration (problem configuration) interface

analysis of the alternative's values for each criterion (see Figure 6). In the personal configuration section (see Figure 7), the decision-maker needs to indicate its expectations regarding his preferred alternative to be the one chosen by the group, the desired style of behavior for the agent that will represent him in the negotiation process, the level of expertise concerning the subject of the decision problem, the available time to spend in the process (analyzing results, etc), and finally the decision-maker must also indicate which decision-makers it deems credible among the others regarding the problem being discussed. The last section of the interface is the problem configuration section that is related with the evaluation of criteria and alternatives (see Figure 8). This evaluation is done in a range between 0 and 100. To evaluate each one of the criteria and alternatives, the decision-maker can easily slide or click on the slide bar. By presenting all the evaluations together on top of one another while the user is performing the evaluations, it will allow him/her to easily compare each evaluation and assign his/her preferences more accurately.

After each decision-maker provides their preferences and configurations, the system will wait again until the iteration is completed. After this, the system will send all the meeting data to the MAS. At this point, the MAS will start the negotiation process with the received data. When the process ends, the MAS will send back the results to the GDSS. These results include all the messages exchanged between the agents during the negotiation process, as well as the achieved consensus with the results of the negotiation process and the satisfaction level measured for each one of the decision-makers regarding the selection of each one of the alternatives.

After all the results are generated and received from the MAS, the system will notify the decision-makers to consult them and will also verify if the desired level of consensus was achieved. If it was achieved, then the iterative decision process will finish, and the system will notify the facilitator and the decision-makers with the final meeting results. Otherwise, the iterative decision process will continue, and each decision-makers will be able to review the current results and reconfigure his/her initial preferences. The conditions mentioned previously will be verified again to start a new iteration, and this process will be repeated until a consensus is achieved.

Decision-makers can access the results of each iteration through a dashboard that presents intelligent reports. In this dashboard, the information presented is directed to the decision-maker and can vary according to three factors: level of expertise, available time, and the level of interest in the process.[21,23] Figure 9 presents a dashboard with the results of an iteration. The results are presented in two main sections. The first section presents statistical data where the decision-maker can analyze the support of alternatives and criteria, as well as the most consensual alternative at the end of the iteration, his/her satisfaction regarding the selected alternative, and the group satisfaction with the selection of that alternative. In addition to that, in the left chart, the decision-maker can observe the support of each one of the alternatives and the corresponding group

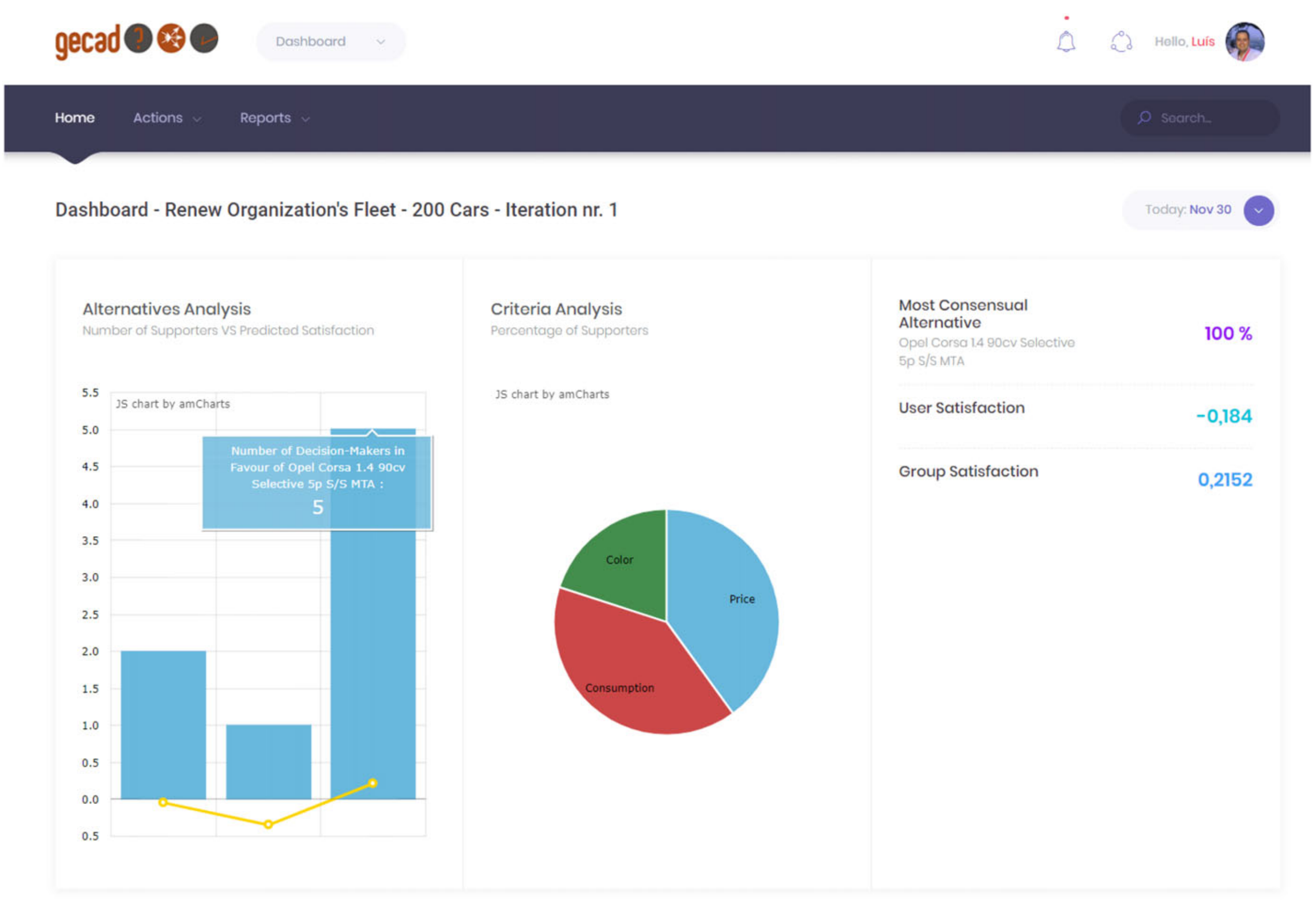

FIGURE 9 Iteration results report (Part 1)

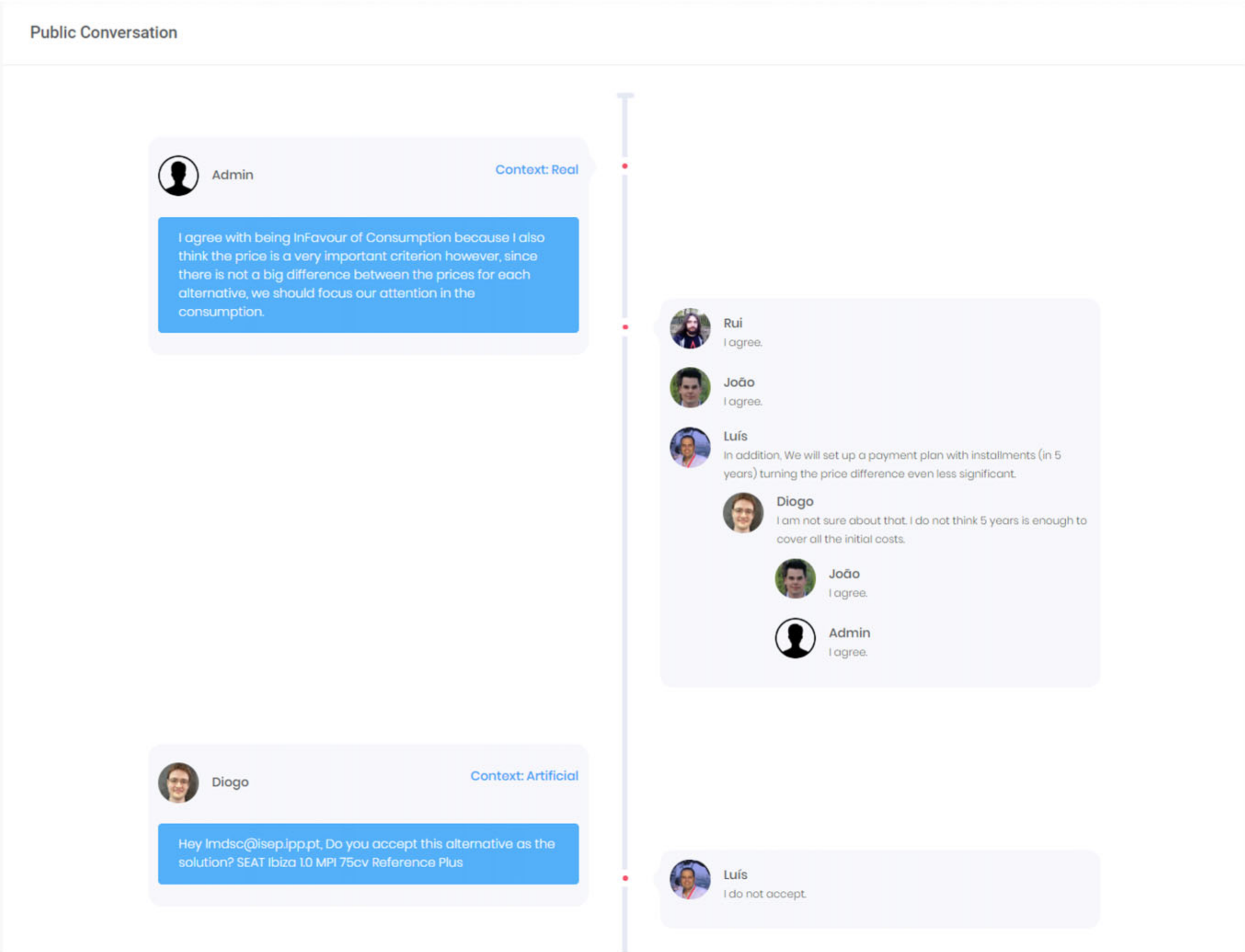

FIGURE 10 Iteration results report (Part 2)

satisfaction (yellow line) in case each one of those alternatives were to be selected as the decision for that iteration. The pie chart indicates the support towards each considered criterion.

The second section (see Figure 10) presents nonstatistical data, which include all the messages exchanged during the negotiation process performed by the MAS for that iteration. The MAS is able to use and understand the topics created by the decision-makers, which correspond to real-context messages, and generates new messages (such as requests) that corresponds to an artificial-context message.

4 | CONCLUSIONS AND FUTURE WORK

In a world that increasingly becoming more global, we are now observing remarkable changes in today's society and in many different traditional and conventional processes such as the decision-making process. What was once a more individualistic process which then evolved into a group decision-making process is now outdated due to arising constraints of this globalization. It no longer makes sense to gather decision-makers at the same time and place to make decisions, and the process must evolve to support decision-makers spread around the world, staying in different countries with different time zones. As a result, we are now dealing with a new type of decision support systems, also known as web-based GDSS.

A lot of work and efforts should be taken before web-based GDSS are accepted, mostly related with the resistance to change and the capability to correctly model the intentions and preferences of the decision-maker while preserving the advantages that are inherent to face-to-face meetings. In this work, we deal with these aspects, and we have presented a web-based GDDS to support the group decision-making process for dispersed groups with users that cannot gather at the same place and at the same time. The system allows the creation of multicriteria problems and the configuration of the preferences, intentions, and interests of each decision-maker. The system makes use of a MAS to combine and process this information, using virtual agents that represent each decision-maker and act according to his/her configurations. These agents interact and negotiate with each other to find a solution for the selected problem.

The GDSSs that we referenced in Section 1 were mostly developed to support the decision-making of a specific problem; in this work, the proposed GDSS allows the configuration of any multicriteria problem, namely its alternatives and the criteria that make it possible to value each of the alternatives. We believe that with this approach, we will proceed in the refinements of a successful GDSS to correctly support decision-makers while preserving the valuable intelligence and knowledge that can be generated in face-to-face meetings. Furthermore, the high level of usability that the system provides will contribute to an easier acceptance and adoption of this kind of systems.

For future work, we aim to study and develop models using machine learning techniques to extract knowledge from argumentative-based dialog models performed by both decision-makers and agents. IN particular, it is intended to model argumentative processes in GDSS, using MASs, considering the decision-makers' objectives and understanding the decision process. Furthermore, with this work, we intend to create models to analyze, classify, and process these data to potentiate the generation of new knowledge that will be used by both agents and decision-makers.

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