Neurocomputing

Group Decision Support Systems for Current Times: Overcoming the Challenges of Dispersed Group Decision-Making

João Carneiro[1], Patrícia Alves[1], Goreti Marreiros[1] and Paulo Novais[2]

[1]GECAD – Research Group on Intelligent Engineering and Computing for Advanced Innovation and Development, Institute of Engineering, Polytechnic of Porto, 4200-072 Porto, Portugal.

[2]ALGORITMI Centre, University of Minho, Guimarães 4800-058, Portugal.

Correspondence should be addressed to:

João Carneiro

E-mail address: jrc@isep.ipp.pt

Full postal address: GECAD – Instituto Superior de Engenharia do Porto, R. Dr. António Bernardino de Almeida, 431, 4249-015 Porto, Portugal

Abstract

We are living a change of paradigm regarding decision-making. On the one hand, there is a growing need to make decisions in group at both professional and personal levels, on the other hand, it is increasingly difficult for decision-makers to meet at the same place and at the same time. The Web-based Group Decision Support Systems intend to overcome this limitation, allowing decision-makers to contribute to the decision process anytime and anywhere. However, they have been defined inadequately which has been compromising its success. This work discusses the current Group Decision Support Systems limitations in terms of challenges and possible impediments for their acceptance by the organizations and propose a conceptual definition of a Web-based Group Decision Support System that intends to overcome the existing limitations and help them to affirm as a reliable and useful tool. In addition, some crucial topics are addressed, such as communication and perception, that are essential and sometimes forgotten in the support of dispersed decision-makers. We concluded that there are still some limitations, mostly in terms of models and applications, that prevent the design of higher quality systems.

Keywords

Web-based Group Decision Support Systems, Dispersed Group Decision-Making, Microservices, Affective Computing, Cognitive Science

1. Introduction

A group decision-making process consists in a process in which a group of people act collectively in order to select one or more alternatives to solve a certain problem [1]. Today, in large organizations, most decision-making processes (strategic and operational) are carried out in a group. There are several reasons why this is so, such as: it is believed that it is possible to make better decisions in group [2, 3] and the current organizational structure of organizations demand it [4]. When a decision-making process is performed in group, the chance to detect a problem is higher, and subsequently, the decision-makers can work together to find a solution for that problem. This turns group decision-making into a more effective and fast process. To share workloads, to leverage the decision quality, to benefit from the stakeholders' support or help the less experienced group members are other pertinent reasons that justify making decisions in group [5-7]. Nevertheless, it is important to create the right conditions so the groups can take advantage of the group decision-making to perform certain tasks, such as generating ideas and solutions through the group interaction [8-10]. It is argued that members can enhance their ability to learn and stimulate their cognitive level with the group decision-making process [3, 11].

In a world that is increasingly global, it is difficult to bring together decision-makers in the same space at the same time, making it impossible to conduct face-to-face meetings and therefore, many benefits associated to the typical group decision-making process are lost. The Web-based Group Decision Support Systems (GDSS) have been studied since the beginning of the 21st century and they intend to support the group decision-making process anytime and anywhere [12]. They distinguish from conventional GDSS because they operate on the Web, which make them available by simply having an internet connection [13]. However, if the general opinion is that these systems are crucial for the current times, they have been struggling to impose, as is demonstrated by the low acceptance showed by the organizations [12]. The research under this area has been mostly oriented to study models that are capable of proposing solutions according to the decision-makers' preferences. However, a group decision-making process is much more than just an outcome [14]. In face-to-face meetings, decision-makers communicate (through verbal and nonverbal communication) in order to exchange perspectives, allowing them to reason, to argue, and to create new intelligence [15]. In addition, in face-to-face scenarios there is an implicit process that is respected and in which all the interaction occurs. That means, the process has a time dimension responsible for changing the state of the decision and of all those involved. It is all this interaction that composes the process that makes face-to-face meetings advantageous when compared with individual decision-making [16]. Therefore, a system that does not allow decision-makers to benefit from those advantages, will not be seen as a valuable asset and consequently as something worth to use. Even if just hypothetically, it is capable of proposing the best solution for a certain problem according to the decision-makers' preferences, but it is not capable of "explaining" the reasons behind that proposal, two things can happen: (1) the system will not be seen as reliable and the proposal can be seen as some kind of guess and (2) this behavior will impede the creation of new intelligence which annihilates all the advantages associated to conventional group decision-making.

In this work, two main contributions are made: the first one is the reflection on the current state of web-based group decision support systems, namely on what its limitations are and the possible impediments to their acceptance by the organizations, focusing on contexts with dispersed decision-makers. The second is the proposal of a conceptual Web-based GDSS especially designed for dispersed group decision-making, with a microservices-based architecture, which aims to address the problems identified in this work. The proposed approach presents a set of essential features we believe can help achieve the success and acceptability of the system. Considering these features, a set of strategies to implement them is also proposed. In addition, some important topics sometimes ignored under the group decision-making context are addressed.

The rest of the paper is organized in the following order: in the next Section, a brief history of Group Decision Support Systems is presented. Section 3 describes the current biggest challenges of GDSS. In Section 4 the Web-based Group Decision Support System conceptual model is presented, mostly in terms of features and architecture. Section 5 presents the discussion. Finally, some conclusions are put forward in Section 6, alongside with suggestions of work to be done hereafter.

2. A Brief History of Group Decision Support Systems

In 1984, DeSanctis and Gallupe [17] said that "an exciting new concept was emerging in the decision support area. It involved the development of computer systems for groups of people responsible for making decisions". These systems were called Group Decision Support Systems. These two researchers decided to study GDSS and their technological and functional requirements resulting in one of the first GDSS taxonomic approaches which categorized GDSS in four scenarios (decision room, teleconference, local area decision network and remote decision-making [17]). According to this categorization, the purpose and configuration of GDSS vary depending on the duration of the decision-making process and on the degree of physical proximity of the group members.

According to the authors, a decision-making group can be defined by two or more persons that together are responsible for: detecting a problem, finding the problem's origin, generating possible solutions, analyzing possible solutions, and perform strategies to implement the selected solutions. Although the group members may not be physically at the same place, they are aware of the existence of others, realizing they are part of a group that is making a decision.

The group needs and dynamics vary according to the factors of each situation. Literature on behavior of social sciences groups, as well as the investigation on electronic communication and group decision-making, suggests that the nature of the exchanged information and the decision-making results change when groups are extremely large, originating irregular communication [18]. Due to these factors, the group size and members' proximity during the meeting are the most critical aspects in the design of a

GDSS. Due to the difficulty in characterizing the groups size, these authors state that groups can be relatively small or relatively large.

As most part of technological innovations, GDSS appeared to facilitate the accomplishment of tasks long practiced by humans. Huber [6] defined GDSS as computer-based interactive systems that help to solve unstructured problems (problems with incomplete or ambiguous information), and, according to, Straub and Beauclair [19] that improves the decision quality. They assume a GDSS can help groups reach higher quality decisions, stimulating interactions in a more balanced and useful way, and reducing the negative aspects of small decision-making groups.

Thus, a GDSS can be seen as a specific decision support system, designed to provide tools and support decision-making in groups. It can be exemplified by systems such as video conference, and interactive software like forums and distributed networks. Throughout the history of development and growth of GDSS, there was a feeling that the quality of the decisions made by groups would become better with their use [19, 20]. The research in this area has always brought to light two main concerns: to improve the efficiency and effectiveness of a decision [21].

In the early 90's, the majority of existing GDSS were of synchronous type [22]. However, the interest in systems that do not restrict participants both in terms of decision and meeting time fostered the development and study of asynchronous GDSS. Cao and Burstein [23] referred that there was a major concern in investigating computerized support for group decision, where one of the main points of study was to support co-located people in space and time and they considered that there was a need for more research focused in asynchronous group decision support systems. It is also important to acknowledge that these research directions were introduced when important tools to build decision support systems emerged, such as: data warehouses, online analytical processing, data mining and web-based decision support systems [24]. In the beginning of the new millennium, studies that compare the two forms (synchronous and asynchronous) started to appear, seeking to understand which one brings more advantages to the decision process [24-26]. An asynchronous mean of discussion provides an environment where richer and with greater coordination discussions can occur. This can happen due to the asynchronous interaction self-nature, which allows reflecting upon, the generation of new ideas, and the discussion of more issues when compared to face-to-face meetings. The effort of asynchronous discussions is superior to the effort in synchronous systems since the participants need to accompany the process for a longer period. On the other hand, synchronous meetings are not so well structured, which sometimes makes it impossible to identify who came up with an idea or to justify the reason behind a particular decision. The GDSS approaches based on synchronous and asynchronous systems obviously have advantages and disadvantages, but they are not enough to fulfill all the needs by themselves. The markets globalization imposes decision-makers (like chief executive officers, managers, etc.) to scatter around the world in countries with different time zones [27]. This means that the group decision-making paradigm has changed so much that the need to support decision-makers anytime, anywhere and through almost any kind of device, is no longer an issue that is up for a pros/cons debate but rather a mandatory one.

Seeking to address this new decision-making paradigm in an era in which the internet access has been massified, the Web-based GDSS emerged as the silver bullet. The Web has become an important milestone in the history of the GDSS. At the beginning of the 21st century, the Web-based GDSS became the main focus of study within the theme of decision-making support. Basically, a Web-based GDSS is a GDSS that provides support to the decision-making by means of a Web browser [28]. With the study of Web-based GDSS it was not long before solutions for different kinds of devices started to appear (via browser), such as: tablets, smartphones and desktops.

3. Group Decision Support Systems: Current Challenges

For more than three decades that GDSS have being widely studied to support groups in the decision-making process. However, (especially) large organizations have passed through an immense globalization in the last twenty years, forcing many decision-makers to be geographically dispersed and in different time zones [29, 30]. As a consequence, it is particularly complex to support a group decision-making process, since further issues can arise like: failing to capture contextual information, communication misunderstandings, unevenly distributed information and the difficulty to interpret the sense of silence

[31]; and temporal issues, which can originate: ambiguity, conflicting temporal interests and requirements, and scarcity of temporal resources [32, 33]. Like mentioned previously, to provide an answer and try to operate correctly in this type of scenarios, the traditional GDSS have evolved to what is identified today as Web-based GDSS [34-36].

In this section, some of the most important challenges and issues currently faced by GDSS are discussed in the light of four major topics: the decision-making process, the decision-makers representation, the kind of information provided by GDSS to decision-makers and the GDSS evaluation.

3.1. The Decision-Making Process

The decision-making process consists in the selection of one or more alternatives as the solution for a certain problem [4]. As we have seen, most decision-making processes that occur in large organizations are performed by groups. It is proven that groups achieve qualitatively and quantitatively superior performances than individuals [2, 3, 37], but obviously, there are disadvantages associated to the group decision-making process, such as the time used by decision-makers to discuss social and personal issues [38-40]. It is also important to be aware that the benefits associated with a group decision-making process are not guaranteed. For a group to generate ideas and solutions through the group interaction, which are important tasks in a group decision-making process [9, 10], stimulating the members' cognitive level and ability to learn [3, 11], appropriate conditions are necessary. So, it is important to be aware of what the word "process" means and represents in this context. According to the Cambridge Dictionary, a process consists in "a series of actions that you take in order to do something". This implies a time dimension associated to the group decision-making process. It is in this timeframe that the decision-makers analyze the other decision-makers' opinions/preferences, reflect, clarify doubts, change their own preferences, etc. So, it follows that many of the benefits associated to the group decision-making process come along the process.

Two main approaches have been implemented in GDSS to support groups in the group decision-making process: (1) the classical approaches, based on preferences aggregation and (2) the consensus-based approaches. The former consists in an aggregation phase that combines the experts' preferences, followed by the selection of one alternative [41, 42]. The latter extends the former through an iterative process in order to achieve consensus [43-46]. Classical approaches cannot benefit from the advantages associated to the face-to-face group decision-making, while consensus-based approaches have the potential to do so. It is crucial to be aware of the importance of the process, especially when systems or models are planned to support dispersed decision-making. The developers should be aware of the non-monotonic self-nature of the process. Ideally, a system/model should be capable of potentiating the process. That means sometimes the best option may not be to achieve a decision at a certain instant of time (in the form of consensus or another), because decision-makers do not yet have enough conditions to do so. To force a decision can lead to a not so solid outcome, i.e., can result in an outcome with a low decision quality, since the quality of the decision-making process influences the quality of the decision [14]. Also, richer processes should have the ability to help decision-makers understand the other decision-makers' preferences, as individuals and as a group, in a way that they can understand the reasons behind those preferences. If a process includes the justifications/reasons for certain perspectives/preferences, they can be used as valuable information, like to document the reasons why a certain decision was undertaken. This knowledge can be valuable for future decisions and to help organizations understand why certain decisions were made. Following this line of thought, we verified the existence of big gaps between the existing systems (in terms of their functioning) and what would be desirable. The richness of the process provided by a GDSS can have a tremendous impact in the degree of consciousness upon which decision-makers will act. It is also important to remember that in a group decision-making process supported by a GDSS, the number of configurations and interactions cannot condition the usability of the system and consequently the user-experience of the decision-makers.

3.2. Representing the Decision-Makers

To rephrase, Doyle, Cummins and Pollock [47], AI is the discipline aimed at understanding intelligent beings by constructing intelligent systems. In 1998, Castelfranchi [48] said "AI is the science of possible forms of intelligence, both individual and collective". It is therefore necessary to first know the human being (its functioning) before using that knowledge in the development of intelligent systems. So, in the context of group decision-making, the decision-makers are the ones that need to be studied and understood. “GDSS intend to support decision-makers”. This seems so obvious that sounds odd to write it. However, most of the existing approaches are still focused on the problem rather than on the decision-makers. The ability to represent decision-makers has a great impact on the system’s success, and therefore, in the aptitude to potentiate decision quality [49].

In this work, we address the GDSS regarding their ability to support dispersed decision-makers in the decision-making phase (in the selection of one or more alternatives to solve the problem). To consider the decision-makers’ preferences is the most common way of representing them. In this type of context, it is “mandatory” for decision-makers to express their preferences so that the system may be able to propose solutions based on those preferences. However, to only consider the decision-maker’s preferences to accurately represent him/her is not enough, and it is not difficult to recognize that a poor representation can lead to deficient processes and, as a consequence, to decisions of lower quality. Most of the current approaches in GDSS only consider the preferences of decision-makers, forgetting what their intentions and objectives are (widely used in the famous BDI architectures [50]). To consider the intentions of a decision-maker can radically affect the outcome of the decision. Intentions may even conflict with preferences. For example: if a group wants to choose a restaurant to organize a dinner, and if Decision-maker DM1 prefers restaurant R1, it is assumed that if the chosen alternative is R1, Decision-maker DM1 will achieve its goals and therefore will be satisfied. However, this may not be exactly true. Real contexts sometimes are a lot more complex. For instance, Decision-maker DM1 may prefer Restaurant R1, but his/her main intention could be to please Decision-maker DM2 (who happens to be the birthday person and prefers Restaurant R2). This means that if this decision was exclusively made through a GDSS that only considered the preferences of the decision-maker, the presented solution could not reach the expected level of satisfaction. To include strategies to allow decision-makers not only to model their preferences but also their intentions is of a great importance in a system supporting decisions in dispersed contexts.

Nowadays, there are many proposals that intend to model human aspects in agents, such as: personality [51, 52], emotions [53-55], cognitive styles [56], etc. [57, 58], some of which are already being adapted to GDSS [59-61]. The inclusion of cognitive/affective aspects in the decision-making process is an idea shared by several authors. Though, to the best of our knowledge, most of them are to be used in simulated environments. The most used models to model agents are the FFM [62, 63], OCC [63] and PAD [64]. However, these models may not satisfy all the future computational models’ needs and we believe the usage of such techniques in real systems can bring some disadvantages. “A real me” can be a bad approach if my persona is less persuasive, intelligent or capable than others. From our point of view, the models showing potential of adaptation to represent decision-makers, whether they are simulators or real systems, are those from Kilmann and Thomas [65], Howard and Howard [62] and Rahim [66]. However, the styles proposed in those models do not provide operating values, i.e., there are no conditions to compute those models. The same cannot be said of the model proposed by Carneiro, Saraiva, Conceição, Santos, Marreiros and Novais [14], which is specifically adapted to the group decision-making context and provides actuation level values allowing its computation.

Besides the decision-makers’ preferences and intentions, there is another important issue related to the decision-makers representation: to represent the impact of the process on the decision-makers. The information with which decision-makers are confronted throughout the process affects their emotional system. The most recent studies indicate that emotions play an essential role in decision-making, perception, learning and in a variety of other cognitive functions [67]. The emotional aspects are not limited to art, entertainment and social interaction; they strongly influence rational thinking mechanisms. Common sense emphasizes that excessive emotionality may impair the decision-making process, but other scientific evidences show that the absence of emotions is also prejudicial [68]. So, it is important to anticipate the impact of the process on the decision-makers.

There is still much to be done regarding the decision-makers’ representation. However, this will turn, for sure, into a hot topic in the near future.

3.3. Information Analysis or Intelligent Reports

Most of the works published under the GDSS area consist on methods/algorithms to support group decision-making processes [69, 70]. Also, there are some works concerning which statistical data formats are more appropriate for the different forms of decision [71]. In a context where decision-makers are dispersed, first and foremost due to the strategies used to report information throughout the process, special attention should be given to the interaction between them and the system. However, few studies explore which information should be reported, in what format and how the reported information should be adapted to the decision-makers' needs, i.e., personalized. An Intelligent Report can be a solution for this problem, by reporting information adapted to the specific needs of each decision-maker. Thus, in order to develop Intelligent Reports, some important factors should be considered:

- Expertise Level: The information reported, in terms of detail and complexity, should be adapted to the capacities and knowledge of each decision-maker [72, 73];
- Time: The level of effort the decision-maker can spend in the process should be considered. This should affect the report's detail level [74, 75];
- Intentions: The decision-maker's intentions should be considered in order to provide appropriate information. For instance, the fact that decision-makers can have a higher/lower concern for self or/and concern for others should be weighted in the information shown [76].

In addition, in order to develop Intelligent Reports, researchers should pay attention to other aspects, such as: the data (kind of information, format and complexity) [71, 77], affective issues (emotional issues, anxiety, stress and sadness) [78, 79], relationships (credibility, seniority, hierarchy, reputation, expertise and friendship) [80, 81], interpersonal conflicts and psychological aspects (engagement in the decision process, personality, behavior and strategy) [82, 83] and usability (user interface, interaction and graphics) [84, 85].

3.4. Evaluation

From a scientific perspective, one of the major challenges faced by GDSS is how can they be evaluated? How can we affirm that one GDSS produces higher quality results compared to another? At the present moment, we cannot. Researchers have been evaluating these systems/models through mathematical proofs, number of rounds or seconds to propose or reach a solution, among others [86]. However, these techniques do not say much in terms of decision quality. It becomes impossible to compare how much more one model/system is capable of enhancing the quality of the decision as opposed to another. Surely, the decision quality cannot be measured in the end of a group decision-making process because the impact resulting from that decision is still unknown.

Some strategies that try to study the perceived "quality" have been proposed. However, most of them are focused in the system usability and in the satisfaction with the meeting [87-89], although some preliminary approaches regarding decision satisfaction, i.e., the perception of the decision quality, exist [90, 91]. From our point of view, the ability to predict satisfaction with a reasonable accuracy has many uses. Let's suppose a GDSS with a multiagent system, where each decision-maker is represented by an agent. First, each agent can "work" in a way that seeks to maximize the satisfaction of the decision-maker it represents, which means that the agent, besides acting according to the preferences of the decision-maker, can also have a metric to compare the impacts of different solutions. Second, agents can cooperatively use that metric to maximize the group satisfaction, or the satisfaction of other agents they wish to "please". Third, it can be used as a metric to evaluate the ability of different models and systems to enhance satisfaction. Some important works like the ones of Higgins [92] and Carneiro, Saraiva, Conceição, Santos, Marreiros and Novais [14] can help researchers study satisfaction in the context of GDSS.

As can be seen, perhaps due to the number of variables that need to be considered, and because there is a lack of knowledge regarding what strategies to use in order to deal with some of those variables, studies on satisfaction and perception of the decision quality in the context of GDSS are scarce. From the decision quality standpoint, classifying or comparing GDSS is still a big challenge.

4. The Conceptual Model

This work distinguishes essentially by the way how the problematic of supporting group decision-making is addressed. Rather than idealizing the system around a model capable of proposing a solution according to certain configurations, our focus is to allow decision-makers to benefit from the typical advantages associated with face-to-face group decision-making processes.

We propose a Web-based GDSS inspired in the behavior of a social network like Facebook or LinkedIn. That means, the system should potentiate the interaction between decision-makers. The issues are discussed in the form of topics and everyone can add comments and replies. The system main features are (Figure 1): the ability to foster communication between decision-makers; the ability to represent decision-makers in terms of preferences, intentions, goals, desires, interests, beliefs, social standing, credibility and expertise; to help decision-makers perceive the process in terms of how the decision and everything that composes the context evolves over time; and finally, a set of strategies to support decision-makers through proposals, recommendations, predictions, relevant information, among others. These features intend to overcome (theoretically) the limitations and challenges previously described.

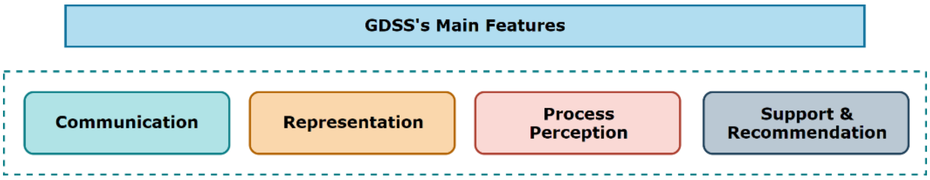

Figure 1. Main features of the proposed Web-based GDSS.

4.1. Conceptual flow

Communication is the key ingredient of a group decision-making process. Thus, we propose a system that potentiates the communication between decision-makers. Obviously, it is different to communicate in face-to-face contexts and through an online application [93, 94]. So, the communication should be more structured than the one practiced in presential contexts. With a more structured type of communication the system will be able to use the conversations made by decision-makers to support the decision-making process and for autocomplete purposes, for instance, in the definition of multi-criteria problems or/and in the identification of alternatives and criteria. Another important aspect is that internet users are already used to social networks, which facilitates the understanding that each subject should be debated on a different topic. Other important strategies such as the use of "Likes (thumbs up)" and other forms of expression can also be used, since it is something that people are already used to and can serve as strategies that allow to better understand the level of acceptance of different ideas and the level of importance of the different subjects. Figure 2 represents (in a non-formal format) the activities carried out by decision-makers in the use of our conceptual proposal. As can be seen, decision-makers can communicate even if they are not (yet) involved in a decision-making process. Considering that the identification of a problem occurs in a normal dialogue, this is the first step to start a decision-making process. After that, a decision-maker can create a new problem or submit a ticket asking a facilitator to create the group decision-making (GDM) problem. When a problem is created and the participants are added to the process, each participant can then start by some initial configurations. This is the first time that decision-makers (in general) interact with the new decision-making process and where they can define important stuff such as: their expertise level, their intentions and point other decision-makers as experts in that topic. In this way, they are modelling their representation and helping the system to understand the context. All these steps can be revisited at any time and decision-makers can perform many reconfigurations as they want. In fact, the system can make use of these changes to better understand the process and consequently to create intelligence. After that, and if alternatives and relevant criteria are not yet defined, the system should provide conditions to perform the idea generation step. The most structured type of communication used by the means of the system will help in the organization of different ideas, in the identification of alternatives and of the most important criteria.

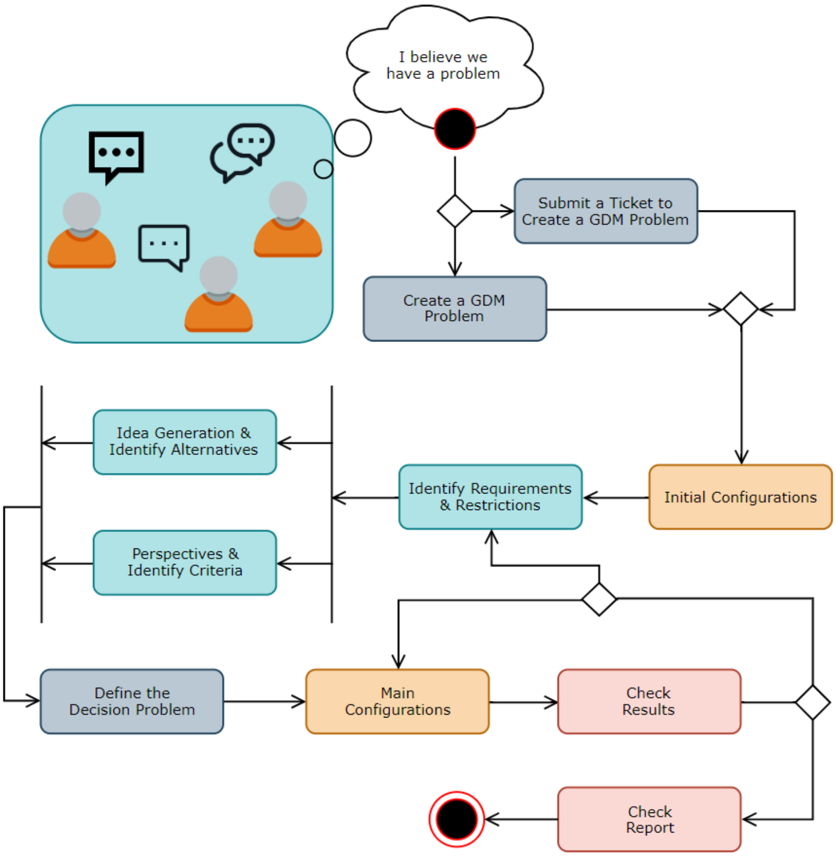

Figure 2. Representation of the activities carried out by decision-makers in the use of the system.

After all the different possible alternatives are identified, the decision problem should be defined. For that, artificial intelligence techniques, like techniques to extract knowledge, can make use of the dialogues performed by decision-makers in the previous steps. The definition of the decision problem should not be costly because the different alternatives were in majority referred before, such as the most important criteria. When the decision problem is defined, decision-makers can then configure their preferences regarding not only alternatives and criteria, but also regarding limitations, desires, goals and their group position in terms of opinion. This seems complex but it can be done through simple "clicks" using configuration templates with high usability. Right after decision-makers perform their configurations, different artificial intelligence techniques can be used to propose solutions, to search inconsistencies, to present relevant information and to support/recommend decision-makers. Decision-makers do not need to be aware of this level of complexity, but the strategy used to present the information to them is vital. That means, the communication between the system and each decision-maker should be adapted to his/her preferences and interests, and the system should be capable of understanding how much each decision-maker is involved in the process. Obviously that the capacity to propose solutions is intrinsic to this kind of systems, but in this conceptual proposal the major objective is the walk to find the solution. The system should be aware of the process importance, which means that the system should be intelligent enough to understand how important to mature ideas, to exchange perspectives and to reflect is, in order to potentiate the decision quality. 100% consensus after the first round may sound good but at the same time be indicative of a hasty decision. Several stopping criteria can be used, combined or not (e.g., end date, maximum number of rounds, minimum consensus needed, minimum group satisfaction, minimum participant satisfaction and alternatives consistency). When a consensus is reached or the satisfaction level attained is enough, the process ends, and a final report is presented. Otherwise, the previous steps can be revisited. Finally, the system should be capable of using all the data generated during the process, to document the reasons that led the group to make that decision and the impact that each decision-maker had in the process. This will turn into valuable information for the organizations because they can, in the future, understand the reasons that made them take those decisions and the responsibility/contribution that each decision-maker had (either for the good or bad decisions). Also, artificial intelligence techniques can be used in these reports to learn from past experiences in order to make better predictions and recommendations.

4.2. Architecture

The literature is not rich in terms of architectures for Web-based GDSS, though in a first instance, a Web-based GDSS differs from a conventional GDSS mostly because of its architecture. In this work, a microservices-based architecture (Figure 3) is proposed, because it empowers a lot of benefits for the context of the proposed system (group decision-making with dispersed participants) and for the current context of the major organizations. If we think in terms of the number of features a system like this has to provide (and the number of different algorithms and models used), a microservices-based architecture allows to: get a better faults isolation, perform continuous delivery, have components spread across multiple servers, be easily understood since they represent small pieces of functionality, etc.; and from the organizations perspective it allows to: organize the code around business capabilities, use complement cloud activities, write code in different languages, get an easy integration, perform automatic deployment, etc. .

Figure 3 represents the conceptual Web-based GDSS proposed in this work. It uses a standard microservices architecture. There is an API Gateway that works as a single-entry point into the system, which allows the internal system architecture to be encapsulated and to provide an API tailored to each client. In addition, functionalities such as authentication, monitoring, load balancing, among others, are also of the API Gateway responsibility.

In this conceptual proposal, it is considered the existence of a set of possible microservices/services to satisfy the organization’s business (accounts, products, etc.) and a set of microservices that intends to support the decision. Several artificial intelligence strategies are considered and will be explored later. Each strategy has special needs and can be implemented using different programming languages. Thereby, a microservices-based architecture becomes even more relevant because each service is independently deployable, loosely coupled, highly maintainable and testable, easier to understand and is relatively small.

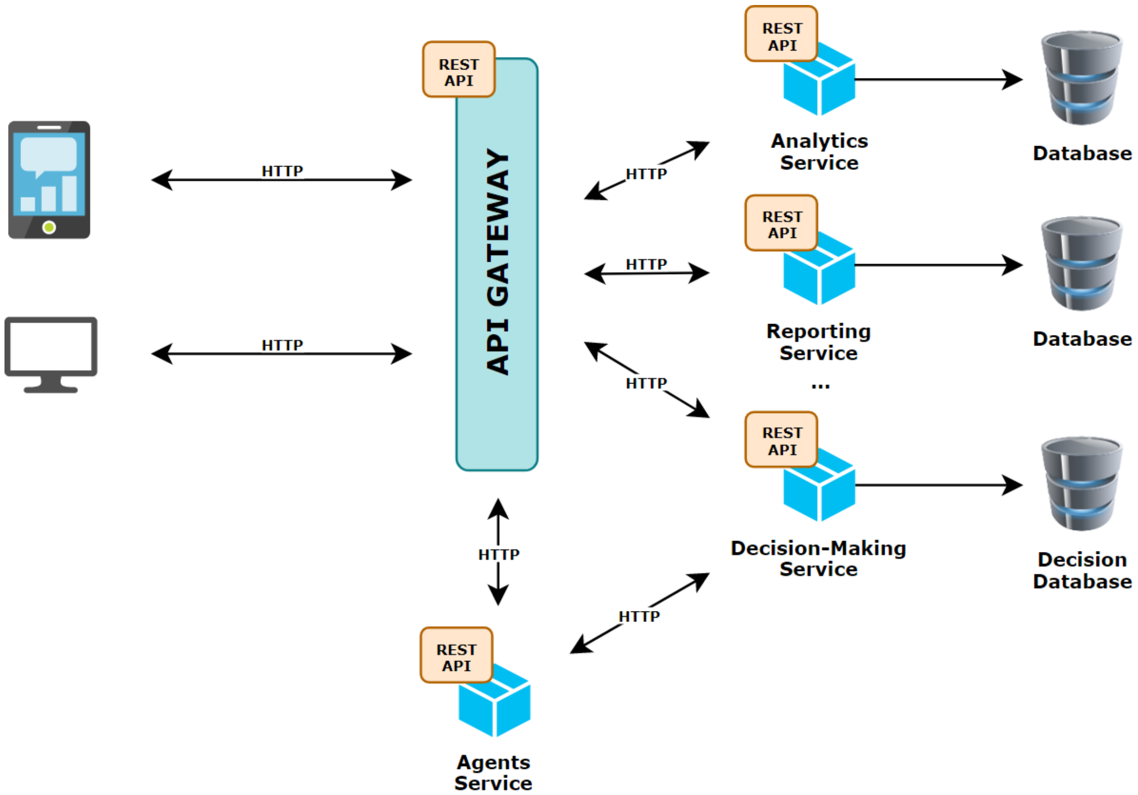

Figure 3. The Group Decision Support System’s Conceptual Architecture.

A special attention is payed to the “Agents Service” and to the “Decision-Making Service”. The “Agents Service” is the microservice that encapsulates the Multi-Agent System existent in the Web-based GDSS and where the main agents platform stands (in 2019, some authors presented solutions to encapsulate Multi-Agent Systems in microservices [95, 96]). In the “Agents Service”, the information that circulates in the system is analyzed and processed when necessary by the agents. The “Decision-Making Service” uses strategies to automatically propose solutions and is where another agents platform, to work with contextual agents (or clones like will be seen later), exists. Although not represented in Figure 3, the Decision-Making Service can, in turn, consume other microservices that implement different decision strategies/algorithms/models.

4.3. Decision-Makers Representation

In this conceptual approach, some aspects regarding the decision-makers representation are considered. A multi-agent system is used, where each decision-maker is represented by an agent, called as participant agent from now on. That means a participant agent should be modelled with the characteristics of the decision-maker he represents in order to represent him/her accordingly. However, there are three aspects that affect exponentially the complexity of modeling agents in this context. First, decision-makers behave differently according to the situation characteristics (for instance, how much a decision problem means to them) [97], second, these different behaviors are always affected by the decision-makers’ personality traits (which are more constant) and third, the decision-makers’ knowledge evolves over time.

Previously, it was referred that the multi-agent system is part of the “Agents Service”, however, this is not the only agents platform in the proposed Web-based GDSS. The existence of another agents platform in the “Decision-Making Service” is also considered. So, the participant agents in the “Agents Service” represent decision-makers in terms of what they are, more specifically, these agents are modelled with personality traits of the decision-makers they represent and each one has a knowledge base, where the history of everything that matters is saved. It is considered that the participant agents in the “Agents Service” are always active and can be working even when the decision-makers they represent are not involved in any process. They can be processing the decision-makers dialogues, for instance, to study relationships, the evaluations made by other decision-makers to their comments, who usually support them, who usually criticized them, among others. Regarding the agents in the “Decision-Making Service”, they represent decision-makers in a context, and they are alive only during the existence of that process. These agents can be modelled with other characteristics, such as: the decision-maker’s intentions, which other decision-makers they consider credible, decision problem preferences, etc. These agents can use other artificial intelligence techniques in order to better understand the process impact, such as an emotional model. In terms of flow, when a decision-maker is added to a new decision problem, a new participant agent is created in the “Decision-Making Service”. This participant agent is a clone of the participant agent existent in the “Agents Service”. This approach presents several benefits because it avoids problems when a decision-maker is involved in too many decision problems at the same time, it separates the impact that each process has in the participant agent and makes it easier to manipulate the temporary knowledge and the knowledge that should be persistent.

4.4. Group Support and Recommendation: Possible Perspectives

Support and recommendation go hand in hand in terms of systems capable of helping users attaining something better. Decision support techniques and recommendation techniques can both be used to help decision-makers during the process. In this proposal, a set of different techniques to support decision-makers in the group decision-making process are considered. However, due to the nature of the proposed architecture, the system is prepared to grow up and new strategies can be included over time. Moreover, as the proposed architecture is microservices-based, it becomes a lot easier, in terms of scalability and reusability, to work with containers and to monitor them.

As seen before, a Web-based GDSS should provide good enough conditions so decision-makers can communicate. In this conceptual proposal, this is accomplished through the natural interaction existent in a social network.

Besides communication, there are other tasks that the system should be able to facilitate, such as the creation of new problems. It is known that to define a new decision problem is complex and time-consuming. There are always several alternatives, different criteria types, several decision-makers, etc. So, it is important to use at least 2 different strategies for this purpose: (1) text analytics, to automatically suggest based on the previous dialogues, alternatives, criteria and decision-makers, and (2) algorithms such as case-based reasoning, to predict the possible alternatives and criteria types based on previous problems.

Regarding the strategies to automatically propose a solution to the group, in a first instance a dialogue-based argumentation model is considered and in a second instance, a multi-criteria decision analysis (MCDA) model. The former intends to be capable of proposing solutions and at the same time, due to its self-nature characteristics, to be capable of explaining the reasons that lead to the proposition of those solutions. This allows decision-makers to feel part of the process and to understand it accordingly. As they understand the motifs behind the proposed solutions, they can reason about those motifs and consequently it becomes easier to accept or to reject the proposed solutions. The considered dialogue-based argumentation model has a high level of expressiveness, that means, the participant agents can behave according to different intentions in the same dialogue. In addition, the participant agents can use the same locution for different purposes (for instance, to persuade or to deliberate) and the identification of these intentions is a responsibility of the other participant agents. The latter intends to work as a detector of inconsistencies. It is extremely important to perceive if the preferences configuration made by each decision-maker makes sense. For instance, let us imagine a decision-maker that considers the price as the most important criterion, but at the same time his/her preferred alternative is the most expensive; it is important to understand if there are not major price differences between alternatives or if he/she made a mistake in the configuration process or if there are subjective reasons behind his/her configuration. A MCDA model can be extremely helpful in the detection of these inconsistencies.

Considering the number of messages exchanged in a system like this, it is fundamental to study the produced dialogues. For that, two main strategies are considered: text analytics and natural language processing. In this way, the system can study the dialogues and produce important information regarding not only the dialogues structure but mostly in terms of their meaning and the sentiment existent in them. In addition, classic algorithms from the social networks' literature can be used to understand the impact/importance of each message/topic. This information can be used by each agent in the dialogues to better represent their decision-makers' needs/intentions.

It is important to use strategies that allow to learn, classify, predict and recognize patterns. For that, machine learning algorithms are considered, more specifically, deep learning and reinforcement learning algorithms. With these algorithms each participant agent (in the "Agents Service") will be capable of presenting important information about other decision-makers, about the decision processes (previous and actual) and about things that generally matter to the decision-maker it represents.

Finally, the participant agents should be capable of using different services according to the situation needs. Moreover, the participant agents should be capable of recognizing the different decision-making stages in order to understand the maturity of the decision.

5. Discussion

Concerning the limitations of GDSS intended for dispersed groups, as well as their low acceptance by organizations [12], we believe that there are flaws in the way this problem has been addressed and interpreted. It is true that sometimes group decision-making is a mandatory process, for example due to most organizational charts of today's organizations. However, there are several benefits associated with the group decision-making process that go well beyond these "policy" issues. So, what would be the interest of a decision-maker in using a GDSS that does not allow him/her to take advantage of such benefits? What trust would he/she put into a proposed solution that discards the existence of a process altogether and of everything that a process allows for? How frustrating can a system that does not allow for the insertion of new knowledge be? And not less important, how adequate for a high-level executive or top manager will a system be if, albeit ensuring the best results, requires tens/hundreds of time-consuming configurations?

In this work, we have verified that current approaches cannot take advantage, at least in full, of the benefits associated with face-to-face group decision-making. However, before entering a more critical analysis, one must be aware that there are certain decision contexts in which this obsession with the benefits associated to group decision-making may not make sense. There may be constraints, such as temporal issues, group typology and/or decision format/configuration, that may benefit from the low level of interaction associated with dispersed groups.

There is a certain distance between researchers working on the development of methods that can be applied to Web-GDSS and researchers who have studied the impact of GDSS on organizations (in an application logic). This separation makes the latter not focusing on the impact that the used method(s) has(have) in the process and consequently in the success of the GDSS. The non-success of the GDSS is clear, it is an evidence, and it is something that cannot be hidden behind the scientific success of the many methods applied to them. It is important to note that already in 1988, Watson, DeSanctis and Poole [98], carried out a study comparing the impact of using a GDSS with groups using only paper and pencil, and groups that did not use any type of support. The conclusion was that there were no advantages in using a GDSS. They assumed that the failure of the GDSS could be because it was a recent type of application and even went as far as stating that "More work on GDSS design and group instructions (learning) is needed before abandoning the idea of having groups use GDSS on their own without technical or other assistance". In an even older study, the researchers found that the use of computerized conferencing mode made it more difficult to reach consensus [99]. Later, in 1997, Warkentin, Sayeed and Hightower [100] compared virtual teams with face-to-face teams in what was their ability to interact through the use of Web-based conference systems, and the scenario did not change. They concluded that "the findings of the present study provide several insights into the communication process of virtual groups. First, the pros of collaboration technologies may now consistently outweigh their cons. While collaboration technologies have the capability of creating a communication environment for virtual partners who are separated by time and/or space, they may prevent the development of a strong sense of cohesion and satisfaction with the group's interaction process. Second, the strength of relational links is positively associated with the effectiveness of information exchange." More recently the story remains, in 2016 van Hillegersberg and Koenen [12] studied precisely the reasons why organizations take long to adopt the use of GDSS. They concluded that there are currently no motives for organizations to invest in GDSS as there is no evidence of their actual benefits. In addition, they found that the existence of a facilitator is crucial for the system to be successful, but that it brings too much costs, making GDSS that are used for more generic decision environments more difficult to thrive. On the other hand, GDSS like spatial decision support systems are more likely to succeed due to their more specific context [101].

Therefore, it is important that the researchers rethink some of the strategies that have been developed to support groups, mainly (and according to what is the purpose of this work) to support dispersed groups and that in the limit have no other form of interaction other than the system. Supporting group decision-making in what is a typical human process requires more than what the knowledge of methods is. It fundamentally requires an awareness of what the process and group decision-making is so that those methods with their different strategies will address the needs of those who are the central elements of the problem: the decision-makers. To meet the needs of the decision-makers, it is necessary to respect the decision-making process and to realize that in the timeframe in which the whole process occurs, it is not only the state of the decision that undergoes changes and mutations, but also the decision-makers who adapt and evolve in terms of what their ideas and preferences are. For this, it is necessary to be aware of how sometimes time is the key factor for reaching this maturation and therefore to obtain higher quality decisions.

The quality of the decision is one of the key points for the success of a GDSS, being closely related to what the satisfaction of the decision-makers is in respect to the decision process. There is no evidence (to the best of our knowledge) of how they correlate. Yet, we know that the dissatisfaction with the process obviously leads to the rejection of the system, even if the quality of the decision is excellent (which cannot be previously known by the user). Therefore, if the quality of the decision was not measured after the selected alternatives had already been applied as a solution, it would be the perfect metric to sell a GDSS. One possibility would be to work on the perception of the quality of the decision (or the decision-makers' satisfaction) as a metric that would be considered by the system itself and made available to the decision-makers along the process. It is therefore important to use strategies for the decision-makers to understand how the process, that is being supported by the GDSS, allows to reach higher quality decisions.

It becomes apparent that the ability to consider in a more detailed way what is the process and all the inherent variables will allow the decision-makers to feel more comfortable with its execution. This does not mean that this increasingly complex approach is perceived by decision-makers so that it does not affect their user-experience. Finally, it is important to note that, taking into account the approach presented in this paper, the recent quantum-cognition theory proposals also have the potential to be applied to GDSS in the future [102, 103].

6. Conclusions and Future Work

Web-based GDSS have been studied in the last years in order to develop solutions capable of supporting decision-makers anytime and anywhere. They differentiate from conventional GDSS because they operate on the web and so, decision-makers only need to have an internet connection to use them. However, GDSS in general are having problems to establish and to be recognized as a useful tool by organizations. We believe this is due to the way they have been addressed, which is focusing in the outcomes rather than in the decision-makers' needs.

This work introduces a refreshing look over the topic of GDSS. Some of the key challenges of today were discussed in light of what the benefits of group decision-making are. The work presented here focused on the support for group decision-making with dispersed elements (ubiquitous contexts) and was particularly concerned with looking at the decision process as something that occurs in a temporal window, which means that the decision undergoes mutations throughout the process as well as the preferences/beliefs/intentions of the decision-makers involved.

As a starting point, it was possible to realize that many of the existing approaches do not take into consideration the benefits of making group decisions, leading to the question: What are the necessary conditions to take advantage of group decision-making and achieve those benefits? This results in many of the existing systems/methods being able to produce excellent scientific results, but that still would have little or no chance of survival in real contexts. One of the clearest examples is the association that exists between the number of configurations a decision-maker needs to make in order to model a multi-criteria problem using some Multi Criteria Decision Analysis methods and his/her lifestyle (e.g., with an extremely busy schedule). There has been little concern invested in evaluating the impact that different approaches have on end-users (decision-makers), both on the level of acceptance and on the ability of decision-makers to make use of the approach.

A certain lack of sensitivity in respect to what the process represents in group decision-making was also identified. Understanding the fact that in many scenarios, decisions reached in a shorter time can be beneficial, there are other situations in which (as shown in the literature) the existence of the process allows to reach higher quality decisions. This means that the strategies used must be able (in the appropriate contexts) to encourage the process and to understand when there are conditions to propose certain solutions.

The methods that can be applied to GDSS present certain limitations that compromise the success of the system. The fact that a GDSS supports such a traditionally human process means that there is a high discrepancy between the decision-makers' expectations and what their user-experience is. Three aspects that point out a particular weakness in what the decision-maker's interaction with the GDSS is were identified and need to be studied in the future:

- Expressiveness: Strategies that allow decision-makers to express/model their preferences towards the problem (and the context) are still seldom debated. Surely, there has been a great study of linguistic strategies, but they are only a part of what may constitute the whole modeling of the decision-maker's preferences. Relevant examples: expertise levels, credible decision-makers, preference of alternatives, importance of criteria, public/private information, expectations, etc. The fact that the decision-maker experiences limitations in expressing aspects that he deems relevant can lead to disbelief in the application's ability and in turn, preclude its success;
- Representativeness: This point extends the previous point to another level. If on the one hand there is the modeling of the problem, on the other hand there is the system's ability to represent the intentions/goals of the decision-makers, who may be (in a real context) in conflict with their

preferences. This makes us realize the importance of a system that may support decisions in dispersed contexts to include strategies that allow decision-makers not only to model their preferences but also their intentions;

- Interaction: Another point that has also been less studied is the interaction of the decision-makers with the GDSS, particularly the way information is made available to them. There is a need to study mechanisms of intelligent reporting to allow the information that an agent reports to the decision-maker it represents, to be structured, organized and oriented according to the interests and intentions of that decision-maker.

Additionally, we proposed a conceptual Web-based GDSS that intends to enable decision-makers to benefit from the typical advantages associated to face-to-face decision-making. Our approach (theoretically) allows decision-makers to interact as people do in social networks, which naturally promotes the communication and the interaction between them. In addition, our proposal is based in a microservices architecture that demonstrates a lot of benefits in a system where so many different artificial intelligence techniques can be implemented. However, some limitations that impede to presently implement an approach like this were found, such as: rudimentary tools to develop multi-agent systems, lack of psychological models that can be computerized, and dialogue-based argumentation models not intelligent enough.

A lot still needs to be done in order to develop successful Web-based GDSS. Their relevance and the need for these type of systems by organizations of today and tomorrow are an absolute certainty. Researchers who explore this topic should be aware of the relationship between the methods they develop and what is the context of group decision-making.

As future work, we want to continue digging under the topic of GDSS. After identifying a set of issues that are compromising the GDSS success and a set of possible solutions, the main goals are to make this conceptual model real, and to develop dialogue-based argumentation models in which not only the messages exchanged by the agents are perceptible to decision-makers, but also the intentions behind the messages.

Funding

This work was supported by the GrouPlanner Project (POCI-01-0145-FEDER-29178) and by National Funds through the FCT – Fundação para a Ciência e a Tecnologia (Portuguese Foundation for Science and Technology) within the Projects UIDB/00319/2020 and UIDB/00760/2020.

References

1. Liu, W., Dong, Y., Chiclana, F., Cabrerizo, F.J., Herrera-Viedma, E.: Group decision-making based on heterogeneous preference relations with self-confidence. Fuzzy Optimization and Decision Making 16, 429-447 (2017)
2. Shaw, M.E.: A comparison of individuals and small groups in the rational solution of complex problems. The American Journal of Psychology 44, 491-504 (1932)
3. Lamm, H., Trommsdorff, G.: Group versus individual performance on tasks requiring ideational proficiency (brainstorming): A review. European journal of social psychology 3, 361-388 (1973)
4. Tindale, R.S., Winget, J.R.: Group decision-making. Oxford Research Encyclopedia of Psychology, (2019)
5. Bell, D.E.: Disappointment in decision making under uncertainty. Operations research 33, 1-27 (1985)
6. Huber, G.P.: Issues in the design of group decision support sytems. MIS quarterly 195-204 (1984)
7. Kaner, S.: Facilitator's guide to participatory decision-making. John Wiley & Sons (2014)
8. O'Neill, T.A., McLarnon, M.J.: Optimizing team conflict dynamics for high performance teamwork. Human Resource Management Review 28, 378-394 (2018)

9. Hackman, J.R., Morris, C.G.: Group tasks, group interaction process, and group performance effectiveness: A review and proposed integration. Advances in experimental social psychology 8, 45-99 (1975)
10. Watson, W.E., Michaelsen, L.K., Sharp, W.: Member competence, group interaction, and group decision making: A longitudinal study. Journal of applied psychology 76, 803 (1991)
11. Osborn, A.: Applied Imagination-Principles and Procedures of Creative Writing. Read Books Ltd (2012)
12. van Hillegersberg, J., Koenen, S.: Adoption of web-based group decision support systems: experiences from the field and future developments. International journal of information systems and project management 4, 49-64 (2016)
13. Zaraté, P., Liu, S.: A new trend for knowledge-based decision support systems design. (2016)
14. Carneiro, J., Saraiva, P., Conceição, L., Santos, R., Marreiros, G., Novais, P.: Predicting satisfaction: perceived decision quality by decision-makers in web-based group decision support systems. Neurocomputing 338, 399-417 (2019)
15. Hellmann, A., Ang, L., Sood, S.: Towards a conceptual framework for analysing impression management during face-to-face communication. Journal of Behavioral and Experimental Finance 100265 (2020)
16. Michaelsen, L.K., Watson, W.E., Black, R.H.: A realistic test of individual versus group consensus decision making. Journal of Applied Psychology 74, 834 (1989)
17. DeSanctis, G., Gallupe, B.: Group decision support systems: a new frontier. ACM SIGMIS Database: the DATABASE for Advances in Information Systems 16, 3-10 (1984)
18. Leduc, N.F.: Communicating through computers: Impact on a small business group. Telecommunications Policy 3, 235-244 (1979)
19. Straub, D.W., Beauclair, R.A.: Current and future uses of GDSS technology: report on a recent empirical study. Twenty-First Annual Hawaii International Conference on System Sciences. Volume III: Decision Support and Knowledge Based Systems Track, vol. 3, pp. 149-158. IEEE (1988)
20. Gallupe, R.B.: The impact of task difficulty on the use of a group decision support system. (1987)
21. Pearson, J.M., Shim, J.: An empirical investigation into DSS structures and environments. Decision Support Systems 13, 141-158 (1995)
22. Turban, E.: Decision support and expert systems: management support systems. Prentice Hall PTR (1993)
23. Cao, P.P., Burstein, F.V.: An asynchronous group decision support system study for intelligent multicriteria decision making. Proceedings of the 32nd Annual Hawaii International Conference on Systems Sciences. 1999. HICSS-32. Abstracts and CD-ROM of Full Papers, pp. 9 pp. IEEE (1999)
24. Shim, J.P., Warkentin, M., Courtney, J.F., Power, D.J., Sharda, R., Carlsson, C.: Past, present, and future of decision support technology. Decision support systems 33, 111-126 (2002)
25. Benbunan-Fich, R., Hiltz, S.R., Turoff, M.: A comparative content analysis of face-to-face vs. asynchronous group decision making. Decision Support Systems 34, 457-469 (2003)
26. Fjermestad, J.: An analysis of communication mode in group support systems research. Decision Support Systems 37, 239-263 (2004)
27. Shum, S.B., Cannavacciuolo, L., De Liddo, A., Iandoli, L., Quinto, I.: Using social network analysis to support collective decision-making process. International Journal of Decision Support System Technology (IJDSST) 3, 15-31 (2011)
28. Power, D.: Decision Support Systems Glossary: Key Decision Support Systems Terms. (2014)
29. Grudin, J.: Group dynamics and ubiquitous computing. Communications of the ACM 45, 74-78 (2002)

30. Chen, M., Liou, Y., Wang, C.-W., Fan, Y.-W., Chi, Y.-P.J.: TeamSpirit: Design, implementation, and evaluation of a Web-based group decision support system. Decision Support Systems 43, 1186-1202 (2007)
31. Bjørn, P., Esbensen, M., Jensen, R.E., Matthiesen, S.: Does distance still matter? Revisiting the CSCW fundamentals on distributed collaboration. ACM Transactions on Computer-Human Interaction (TOCHI) 21, 1-26 (2014)
32. McGrath, J.E.: Time, interaction, and performance (TIP) A Theory of Groups. Small group research 22, 147-174 (1991)
33. Légaré, F., Witteman, H.O.: Shared decision making: examining key elements and barriers to adoption into routine clinical practice. Health affairs 32, 276-284 (2013)
34. Morente-Molinera, J.A., Wikström, R., Herrera-Viedma, E., Carlsson, C.: A linguistic mobile decision support system based on fuzzy ontology to facilitate knowledge mobilization. Decision Support Systems 81, 66-75 (2016)
35. Siddiqui, A.W., Raza, S.A., Tariq, Z.M.: A web-based group decision support system for academic term preparation. Decision Support Systems 114, 1-17 (2018)
36. López, J.C.L., Carrillo, P.A.Á., Chavira, D.A.G., Noriega, J.J.S.: A web-based group decision support system for multicriteria ranking problems. Operational Research 17, 499-534 (2017)
37. Hill, G.W.: Group versus individual performance: Are N+ 1 heads better than one? Psychological bulletin 91, 517 (1982)
38. Mintzberg, H.: The nature of managerial work. (1973)
39. Argyris, C., Schon, D.A.: Theory in practice: Increasing professional effectiveness. Jossey-bass (1974)
40. Hoffman, L.R.: Applying experimental research on group problem solving to organizations. The Journal of Applied Behavioral Science 15, 375-391 (1979)
41. Wu, J., Xiong, R., Chiclana, F.: Uninorm trust propagation and aggregation methods for group decision making in social network with four tuple information. Knowledge-Based Systems 96, 29-39 (2016)
42. Wang, J., Wang, J.-q., Zhang, H.-y., Chen, X.-h.: Multi-criteria group decision-making approach based on 2-tuple linguistic aggregation operators with multi-hesitant fuzzy linguistic information. International Journal of Fuzzy Systems 18, 81-97 (2016)
43. Zhang, Y., Xu, Z., Liao, H.: A consensus process for group decision making with probabilistic linguistic preference relations. Information sciences 414, 260-275 (2017)
44. Dong, Q., Cooper, O.: A peer-to-peer dynamic adaptive consensus reaching model for the group AHP decision making. European Journal of Operational Research 250, 521-530 (2016)
45. Xia, H., Huang, T.-Z., Shao, J.-L., Yu, J.-Y.: Group consensus of multi-agent systems with communication delays. Neurocomputing 171, 1666-1673 (2016)
46. Yu, F., Ji, L., Yang, S.: Group consensus for a class of heterogeneous multi-agent networks in the competition systems. Neurocomputing (2019)
47. Doyle, J., Cummins, R., Pollock, J.: The foundations of psychology: A logico-computational inquiry into the concept of mind. Philosophy and AI: Essays at the Interface 39-78 (1991)
48. Castelfranchi, C.: Modelling social action for AI agents. Artificial intelligence 103, 157-182 (1998)
49. Barkhi, R., Kao, Y.-C.: Psychological climate and decision-making performance in a GDSS context. Information & Management 48, 125-134 (2011)
50. Singh, D., Padgham, L., Logan, B.: Integrating BDI agents with agent-based simulation platforms. Autonomous Agents and Multi-Agent Systems 30, 1050-1071 (2016)
51. Dimuro, G.P., da Rocha Costa, A.C., Gonçalves, L.V., Hübner, A.: Centralized regulation of social exchanges between personality-based agents. International Workshop on

Coordination, Organizations, Institutions, and Norms in Agent Systems, pp. 338-355. Springer (2006)
52. Padgham, L., Taylor, G.: A system for modelling agents having emotion and personality. International Workshop on Intelligent Agent Systems, pp. 59-71. Springer (1996)
53. Ball, G., Breese, J.: Emotion and personality in a conversational agent. Embodied conversational agents 189-219 (2000)
54. Gmytrasiewicz, P.J., Lisetti, C.L.: Emotions and personality in agent design and modeling. International Workshop on Agent Theories, Architectures, and Languages, pp. 21-31. Springer (2001)
55. Dias, J., Paiva, A.: Feeling and reasoning: A computational model for emotional characters. Portuguese conference on artificial intelligence, pp. 127-140. Springer (2005)
56. Frank, A.U., Bittner, S., Raubal, M.: Spatial and cognitive simulation with multi-agent systems. International Conference on Spatial Information Theory, pp. 124-139. Springer (2001)
57. Novais, P., Carneiro, D.: The role of non-intrusive approaches in the development of people-aware systems. Progress in Artificial Intelligence 5, 215-220 (2016)
58. Dias, J., Mascarenhas, S., Paiva, A.: Fatima modular: Towards an agent architecture with a generic appraisal framework. Emotion modeling, pp. 44-56. Springer (2014)
59. Recio-García, J.A., Quijano, L., Díaz-Agudo, B.: Including social factors in an argumentative model for group decision support systems. Decision Support Systems 56, 48-55 (2013)
60. Palomares, I., RodríGuez, R.M., MartíNez, L.: An attitude-driven web consensus support system for heterogeneous group decision making. Expert Systems with Applications 40, 139-149 (2013)
61. Palomares, I., Martinez, L., Herrera, F.: A consensus model to detect and manage noncooperative behaviors in large-scale group decision making. IEEE Transactions on Fuzzy Systems 22, 516-530 (2013)
62. Howard, P.J., Howard, J.M.: The Big Five Quickstart: An Introduction to the Five-Factor Model of Personality for Human Resource Professionals. (1995)
63. McCrae, R.R., John, O.P.: An introduction to the five-factor model and its applications. Journal of personality 60, 175-215 (1992)
64. Mehrabian, A.: Pleasure-arousal-dominance: A general framework for describing and measuring individual differences in temperament. Current Psychology 14, 261-292 (1996)
65. Kilmann, R.H., Thomas, K.W.: Interpersonal conflict-handling behavior as reflections of Jungian personality dimensions. Psychological reports 37, 971-980 (1975)
66. Rahim, M.A.: A measure of styles of handling interpersonal conflict. Academy of Management journal 26, 368-376 (1983)
67. Bechara, A., Damasio, H., Damasio, A.R.: Emotion, decision making and the orbitofrontal cortex. Cerebral cortex 10, 295-307 (2000)
68. Picard, R.W.: Affective computing: challenges. International Journal of Human-Computer Studies 59, 55-64 (2003)
69. Kou, G., Chao, X., Peng, Y., Xu, L., Chen, Y.: Intelligent collaborative support system for AHP-group decision making. Studies in Informatics and Control 26, 131-142 (2017)
70. Khiat, S., Djamila, H.: A temporal distributed group decision support system based on multi-criteria analysis. Int. J. Interact. Multimedia Artif. Intell. 5, 7-21 (2019)
71. Brase, G.L.: Which statistical formats facilitate what decisions? The perception and influence of different statistical information formats. Journal of Behavioral Decision Making 15, 381-401 (2002)
72. McGrath, J.E.: Groups: Interaction and performance. Prentice-Hall Englewood Cliffs, NJ (1984)
73. Shanteau, J.: How much information does an expert use? Is it relevant? Acta psychologica 81, 75-86 (1992)

74. Fisher, C.W., Chengalur-Smith, I., Ballou, D.P.: The impact of experience and time on the use of data quality information in decision making. Information Systems Research 14, 170-188 (2003)
75. Diederich, A.: Dynamic stochastic models for decision making under time constraints. Journal of Mathematical Psychology 41, 260-274 (1997)
76. Rahim, M.A., Magner, N.R.: Confirmatory factor analysis of the styles of handling interpersonal conflict: First-order factor model and its invariance across groups. Journal of applied psychology 80, 122 (1995)
77. Simon, H.A.: Bounded rationality in social science: Today and tomorrow. Mind & Society 1, 25-39 (2000)
78. Raghunathan, R., Pham, M.T.: All negative moods are not equal: Motivational influences of anxiety and sadness on decision making. Organizational behavior and human decision processes 79, 56-77 (1999)
79. Loewenstein, G., Lerner, J.S.: The role of affect in decision making. Handbook of affective science 619, 3 (2003)
80. Dubrovsky, V.J., Kiesler, S., Sethna, B.N.: The equalization phenomenon: Status effects in computer-mediated and face-to-face decision-making groups. Human-computer interaction 6, 119-146 (1991)
81. Levy, G.: Decision making in committees: Transparency, reputation, and voting rules. American economic review 97, 150-168 (2007)
82. Shanteau, J.: Psychological characteristics and strategies of expert decision makers. Acta psychologica 68, 203-215 (1988)
83. John, O.P., Srivastava, S.: The Big Five trait taxonomy: History, measurement, and theoretical perspectives. Handbook of personality: Theory and research 2, 102-138 (1999)
84. Juristo, N., Moreno, A.M., Sanchez-Segura, M.-I.: Analysing the impact of usability on software design. Journal of Systems and Software 80, 1506-1516 (2007)
85. Rafla, T., Robillard, P.N., Desmarais, M.: Investigating the impact of usability on software architecture through scenarios: A case study on Web systems. Journal of Systems and Software 79, 415-426 (2006)
86. Marreiros, G., Santos, R., Ramos, C., Neves, J.: Context-aware emotion-based model for group decision making. IEEE Intelligent Systems 25, 31-39 (2010)
87. Briggs, R.O., de Vreede, G.-J., Reinig, B.A.: A theory and measurement of meeting satisfaction. 36th Annual Hawaii International Conference on System Sciences, 2003. Proceedings of the, pp. 8 pp. IEEE (2003)
88. Paul, S., Seetharaman, P., Ramamurthy, K.: User satisfaction with system, decision process, and outcome in GDSS based meeting: an experimental investigation. 37th Annual Hawaii International Conference on System Sciences, 2004. Proceedings of the, pp. 37-46. IEEE (2004)
89. Tian, X., Hou, W., Yuan, K.: A study on the method of satisfaction measurement based on emotion space. 2008 9th International Conference on Computer-Aided Industrial Design and Conceptual Design, pp. 39-43. IEEE (2008)
90. Carneiro, J., Santos, R., Marreiros, G., Novais, P.: Evaluating the perception of the decision quality in web-based group decision support systems: A theory of satisfaction. International Conference on Practical Applications of Agents and Multi-Agent Systems, pp. 287-298. Springer (2017)
91. Husain, A.: New satisfying tool for problem solving in group decision-support system. Applied Mathematical Sciences 6, 5403-5410 (2012)
92. Higgins, E.T.: Making a good decision: value from fit. American psychologist 55, 1217 (2000)
93. Carneiro, J., Martinho, D., Marreiros, G., Jimenez, A., Novais, P.: Dynamic argumentation in UbiGDSS. Knowledge and Information Systems 55, 633-669 (2018)

94. Carneiro, J., Martinho, D., Marreiros, G., Novais, P.: Arguing with behavior influence: a model for web-based group decision support systems. International Journal of Information Technology & Decision Making (IJITDM) 18, 517-553 (2019)
95. Carneiro, J., Alves, P., Marreiros, G., Novais, P.: A Conceptual Group Decision Support System for Current Times: Dispersed Group Decision-Making. International Symposium on Distributed Computing and Artificial Intelligence, pp. 150-159. Springer (2019)
96. W. Collier, R., O'Neill, E., Lillis, D., O'Hare, G.: MAMS: Multi-Agent MicroServices. Companion Proceedings of The 2019 World Wide Web Conference, pp. 655-662 (2019)
97. Carneiro, J., Saraiva, P., Martinho, D., Marreiros, G., Novais, P.: Representing decision-makers using styles of behavior: an approach designed for group decision support systems. Cognitive Systems Research 47, 109-132 (2018)
98. Watson, R.T., DeSanctis, G., Poole, M.S.: Using a GDSS to facilitate group consensus: Some intended and unintended consequences. Mis Quarterly 463-478 (1988)
99. Hiltz, S.R., Johnson, K., Turoff, M.: Experiments in group decision making communication process and outcome in face-to-face versus computerized conferences. Human communication research 13, 225-252 (1986)
100. Warkentin, M.E., Sayeed, L., Hightower, R.: Virtual teams versus face-to-face teams: an exploratory study of a web-based conference system. Decision sciences 28, 975-996 (1997)
101. Keenan, P.B., Jankowski, P.: Spatial decision support systems: three decades on. Decision Support Systems 116, 64-76 (2019)
102. Asano, M., Ohya, M., Tanaka, Y., Basieva, I., Khrennikov, A.: Quantum-like model of brain's functioning: Decision making from decoherence. Journal of Theoretical Biology 281, 56-64 (2011)
103. Busemeyer, J.R., Bruza, P.D.: Quantum models of cognition and decision. Cambridge University Press (2012)