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Can Classical Consensus Models deal with Large Scale Group Decision Making?

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***Abstract*—Consensus reaching processes (CRPs) in Group Decision Making (GDM) try to reach a mutual agreement among a group of decision makers before making a decision. To facilitate CRPs, multiple consensus models have been proposed in the literature. Classically, just a few decision makers participated in the CRP, however nowadays, the appearance of new technological environments and paradigms to make group decisions demand the management of larger scale problems that add new requirements to the solution of consensus. This contribution presents a study of a classical CRP applied to large-scale GDM in order to analyze its performance and detect which are the main challenges that these processes face in large-scale GDM. The analysis will be carried out in a java-based framework, AFRYCA 2.0, simulating different scenarios in large scale GDM.**

***Keywords*—Large-scale GDM; CRP; AFRYCA**

I. Introduction

Decision making processes are one of the most frequent activities in daily life and specifically, Group Decision Making (GDM), is essential in many societies and organizations in which multiple points of view are necessary. In Group Decision Making (GDM) problems, a set of individuals/experts with their own points of view try to find a common solution selecting the best alternative/s of a set of possible solutions. In real-world GDM problems, multiple situations might occur, such as cooperation or competitiveness among individuals, compatible or incompatible proposals, etc.

Classically, the resolution process of GDM problems, consisted in gathering the assessments of a few experts and choosing the best alternative/s. However, many real-world problems that affect groups or society might require consensual decisions. For this reason, consensus reaching processes (CRPs), in which individuals/experts discuss and modify their preferences to reach a collective agreement before making decisions, have become an increasingly prominent research topic in GDM problems [1].

Due to the expansion of technological paradigms, such as e-democracy [2], social networks [3], marketplace selection for group shopping [4] or crisis management [5], the so-called large scale GDM (LSGDM) problems, in which a higher number of experts participate in the decision process, have attracted the attention of the researchers.

Nowadays, most of the existing CRPs are focused on a classical view of GDM problems with few experts, however, in LSGDM problems the existence of disagreement between experts in the group is greater and, hence, the necessity of applying a CRP is higher [6]. Although proposals for CRPs in LSGDM have been introduced [6]–[8], no study about the performance of classical CRPs developed for GDM with few decision makers to evaluate their ability in the new contexts of LSGDM has been carried out.

In this study, our goals are:

1) Among the multiple CRP approaches dealing with classical GDM problems with a few number of experts, it is chosen one of the most widely used and representative approach to evaluate its performance in a LSGDM context.
2) Consider different aspects such as the experts' influence in the performance of the CRP or the possibility to achieve consensus with a classical consensus model in a LSGDM context.

Due to the complexity to deal with LSGDM problems, mainly because of the high number of decision makers who participate in the process, it is necessary a tool which facilitates the processing of these problems. AFRYCA 2.0 [9] is a framework that is able to simulate different scenarios and experts' behaviors for GDM. AFRYCA 2.0 will allow us to obtain the necessary results to carry out an analysis of the performance of a classical CRP in LSGDM and achieve the goals presented.

II. Preliminaries

In this section, GDM problems and main concepts related to CRPs are reviewed, as well as some main challenges detected in the CRP dealing with LSGDM problems.

A. Group decision making

GDM is a process which consists of achieving a common solution for a decision making problem, composed by a set of alternatives and the participation of multiple experts. When the number of experts is higher than 20 [10], these GDM problems could be so-called LSGDM problems.

A GDM problem is characterized by [11]:

1) A decision problem containing n alternatives, denoted by $X = \{x_1, x_2, \ldots, x_n\}$.

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2) A group of m experts, $E = \{e_1, e_2, \ldots, e_m\}$, express their preferences over the alternatives.
3) The experts try to reach a common solution.

In GDM, each expert $e_i \in E$ expresses his/her opinions over different alternatives by means of a preference structure. One of the most common preference structures in GDM is the so-called fuzzy preference relation [12]. A fuzzy preference relation associated to expert e_i it is noted as $P_i = (p_i^{lk})_{n \times n}$ and can be represented, for X finite, as an $n \times n$ matrix. Each assessment, $p_i^{lk} = \mu_{P_i}(x_l, x_k) \in [0, 1]$ represents the preference degree of e_i over x_l regarding $x_k, l, k \in \{1, \ldots, n\}, l \neq k$, such that if $p_i^{lk} > 0.5$ the preference of the expert e_i over x_l is greater than x_k and if $p_i^{lk} = 0.5$, x_k and x_l are indifference for e_i. In order to obtain the consistent preference relations, it is usual to assume the additive reciprocity property, i.e. $p^i_{lk} + p^i_{kl} = 1$ ($\forall l, k \in \{1, \ldots, n\}$).

In GDM problems, the selection process for achieving a solution containts two phases [13] (see Fig. 1): (i) Aggregation phase: experts' preferences are aggregated, (ii) exploitation phase: an alternative or a subset of alternatives will be selected as solution for the problem.

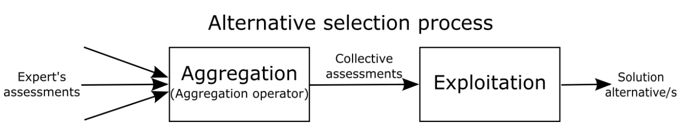

Fig. 1. Selection process for the solution of GDM problems

B. Consensus reaching process

When a GDM problem is solved only by the selection process, the agreement between experts cannot be guaranteed, hence, experts can feel that their individual opinions have not been taken into consideration [14]. To resolve this inconvenient, CRPs were introduced as an additional phase in the GDM problems resolution. CRP is a dynamic and iterative process in which experts change their initial preferences, in order to make their preferences closer to each other and reach a high agreement level after several rounds of discussion [14], [15]. The concept of consensus has been interpreted from various perspectives, from unanimity to some more flexible interpretations considering different degrees of partial agreement [16]. The concept of *soft consensus* is one of the most accepted and flexible interpretations of consensus, which is defined as "most of the important individuals agree as to almost all of the relevant opinions", introduced by Kacprzyk et al. [11]. A general CRP scheme consists of four main phases (see Fig. 2):

1) Gathering preferences: The preferences of each expert are provided and collected in this phase.
2) Consensus measurement: The group consensus degree is estimated. Different consensus measures can be applied by means of aggregation operators or computing distances between preferences [17].
3) Consensus control: The consensus degree obtained is compared with a *threshold value* $\mu \in [0, 1]$, which represents the minimum value of acceptable agreement. If the consensus degree exceeds the threshold value, μ, the group moves into the selection process; otherwise, another discussion round would be carried out. It should be noted that, another threshold value $maxrounds \in \mathbb{N}$, which indicates the maximum number of allowed rounds can be introduced in order to prevent a never ending process.
4) Consensus progress: To increase the level of agreement throughout the discussion rounds of the CRP, a procedure is carried out. This procedure is classified into two categories [17]:
   - Procedure with a feedback process, in which the farthest preferences from consensus are detected and then advises experts to modify them to increase the consensus degree in the following rounds.
   - Procedure without a feedback process, in which the experts' preferences can be updated automatically to increase consensus.

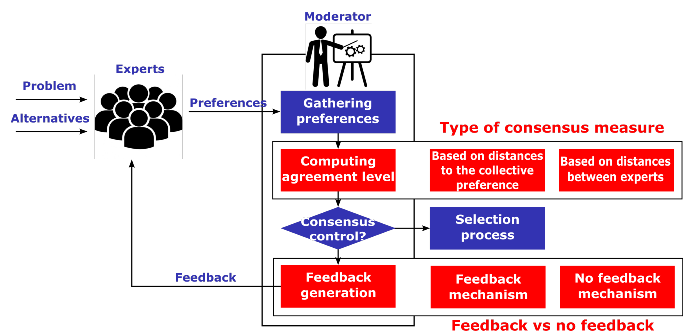

Fig. 2. General CRP scheme

Multiple consensus approaches have been proposed during the past decades and different criteria have been used to classify different consensus approaches. This paper utilizes the classification introduced in [17] shown in Table I and the most widely used model from Q_1 (due to limit of pages) is selected for further research. The selected model was proposed by Herrera-Viedma et al. in [18] and it has been selected because:

1) It is one of the most widely used and studied consensus models in the literature.
2) It follows the soft consensus view [1].
3) The first attempt to use proximity measures.
4) Both consensus measures and proximity measures are based on the comparison of the individual preferences and the collective preference.
5) The alternatives are compared considering their position for each preference, knowing the real consensus in each round during the consensus process.

C. LSGDM: Challenges for CRP

Nowadays, technological and societal demands have given place to new GDM problems in which a high number of participants take part, these problems are so-called LSGDM.

TABLE I
OVERVIEW OF CONSENSUS MODELS REVIEWED IN THE TAXONOMY

	Consensus measures based on distances to the collective preferences	Consensus measures based on distances between experts
Feedback mechanism	(Q_1) Herrera Viedma et al. [18], Parreiras [19]	(Q_2) Mata et al. [20], Chiclana et al. [21]
No feedback mechanism	(Q_3) Xia et al. [22], Wu and Xu [23]	(Q_4) Palomares et al. [6], Zhang et al. [24]

There are two main differences between classical GDM and LSGDM [7]: i) the number of decision makers and the amount of information in LSGDM is much larger, ii) discussion and time needed in LSGDM to achieve a final decision is longer. Taking into account these differences, our aim is to evaluate the performance of a classical CRP in LSGDM however, CRPs have to face new challenges in LSGDM. Some of these challenges are the following ones:

1) *Non-cooperative behaviors*: The amount of decision makers is higher and with different points of view. As a consequence, the experts might not cooperate to reach an agreement and have a non-cooperative behavior. Two classical non-cooperative behaviors in LSGDM problems are:
   - *Refuse behavior*: Experts might refuse to change their preferences.
   - *Defense behavior*: Experts might change their preferences in an opposite direction to agreement.

   This contribution also considers the cooperative behavior, *accept behavior*, which indicates the experts follow the suggestions to reach the consensus.
2) *Subgroup behaviors*: In large-scale contexts, there might exist some subgroups of experts who have similar interests that do not want to change their initial preferences, breaking the collaboration contract [16].
3) *Minority opinions*: Xiong et al. [25] talked about the importance of taking into account minority opinions in the CRPs.
4) *Supervision*: The supervision for preferences during the CRP will be more complex in a LSGDM problem [6], [26].
5) *Time cost*: Time can be critical in different situations since LSGDM demands more time.

This contribution focuses mainly on behavior challenges. Several behaviors will be taken into account in our study, *refuse behavior*, *defense behavior* and *accept behavior*, studying their influence in the CRP in a LSGDM context. Such an influence also can be related to time cost since, a non-cooperative behavior can negatively affect to CRP process.

III. AFRYCA 2.0: A FRAMEWORK FOR CONSENSUS ANALYSIS APPROACHES IN GDM

Our contribution aims to analyze the performance of a classical consensus model in LSGDM problems, hence, a suitable tool which allows to simulate the performance of consensus models and the experts' behaviour who take part in the CRP, is essential. For this reason, this section revises briefly a software so-called AFRYCA, *A Framework for the analYsis of Consensus Approaches* [17], that will be utilized to carry out the study of CRP in LSGDM problems by using a selected consensus model proposed in the literature. Furthermore, the latest version AFRYCA 2.0 [9], is able to simulate different experts behavior patterns during the CRP.

In technological terms, AFRYCA is a component-based application which has been developed by using Eclipse Rich Client Platform (Eclipse RCP) [27], a platform to build and deploy desktop rich client applications easy to maintain and extend. AFRYCA 2.0 [9] uses more than 40 components which are grouped in six types (see Fig. 3):

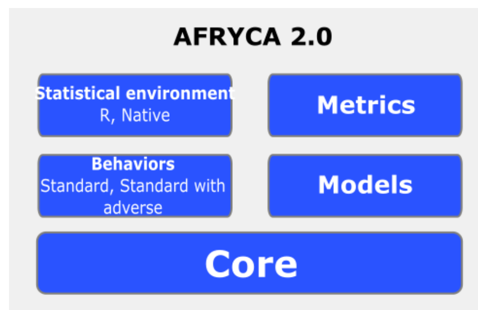

Fig. 3. AFRYCA 2.0 architecture

- *Graphical User Interface (GUI)*: Components which allow to interact with the framework.
- *Statistical environments*: Two statistical environments are included in AFRYCA 2.0, R[1] and a native statistical environment. They are able to carry out Multi-Dimensional Scaling (MDS) of the preferences and the simulation of behavior patterns by means of probability distributions.
- *Metrics*: Components to analyze several consensus models and the CRPs performance.
- *Behavior patterns*: Components which simulate expert's behavior regarding the advice received. AFRYCA 2.0 includes two behavior patterns: 1) the *standard behavior pattern*, which simulates behaviors of experts accept /refuse suggestions; 2) the *standard with adverse behavior pattern*, which allows to simulate behaviors of experts accept/refuse/defense recommendations.
- *Models*: Components which implement consensus models proposed in the literature.

[1] https://www.r-project.org/

- *Core*: Main features of AFRYCA 2.0.

AFRYCA 2.0 also provides important information such as initial consensus degree, final consensus degree, ranking of alternatives and final solutions.

IV. Performance of a classical CRP in LSGDM

According to Section II-B, this contribution intends to study the performance of the classical CRP model presented in [18] in a LSGDM context by using AFRYCA 2.0. To clarify all the elements which are part of the study, this section describes the performance of the selected consensus model and the conditions of the simulation process including the experts' behavior which will participate in the decision making.

A. Herrera Viedma's CRP

The classical consensus model selected to analyse its performance in LSGDM is the proposed by Herrera-Viedma et al. in [18]. The ranking of alternatives are obtained from individual fuzzy preference relations by computing the quantifier-guided dominance and non-dominance degrees for each alternative. Such preferences ranking are compared with a collective preference ranking to compute the consensus degrees. The model also includes a feedback mechanism, based on proximity measures and a set of directions rules to suggest to experts how to modify their preferences.

The Herrera-Viedma et al.'s consensus model uses several parameters which are briefly introduced here:

- β: parameter to control the OR-LIKE of the aggregation operator that computes the global consensus degree.
- Aggregation quantifiers: parameters of the linguistic quantifier used to compute the collective preference by means of the OWA operator.
- Exploitation quantifiers: parameters of the linguistic quantifier used to compute dominance and non-dominance degrees and conduct preferences of experts into preference ranking.

B. Simulation: Data and process

This section describes the simulation of the classical CRP model presented in Section IV-A in a LSGDM case study. The value of the parameters used in the simulation, both the model and the consensus process, the different scenarios simulated depending of the experts' behavior and the results obtained are also exposed.

Let us suppose the following LSGDM problem: the Academy of Motion Picture Arts and Sciences of EEUU organizes a special committee which is composed of 30 members $E = \{e_1, e_2, \ldots, e_{30}\}$, to make the decision of what film deserve the Oscar for the best film in the recent year. There are four candidate films: $X = \{x_1$: La La Land, x_2: Moonlight, x_3: Fences, x_4: Manchester by the sea$\}$.

All preferences are expressed as consistent fuzzy preference relations, the corresponding data sets are available in the public access of AFRYCA website[2]. The consensus threshold is $\mu = \mathbf{0.85}$ and $maxround = 30$ ($maxround$ has been selected for sake of clarity but usually it is much smaller).

[2] http://sinbad2.ujaen.es/afryca/

Another important issue to consider in the simulation and one of the most important challenges in LSGDM problems is the different behaviors which appear in the CRP, due to the large numbers of experts involved in it. For this reason three different *scenarios* with different behaviors are simulated:

- *Scenario 1*: All experts accept all the recommendations. This kind of scenario is the *ideal* one but not very common in real world problems.
- *Scenario 2*: 80% of experts accept all the recommendations and 20% present a defense behavior.
- *Scenario 3*: 70% of experts accept all the recommendations, 20% refuse the suggestions and 10% present a defense behavior.

For each simulation, the consensus model has been configured with the parameter values shown in Table II. Results of the simulations are shown in Table III.

TABLE II
HERRERA-VIEDMA PARAMETERS [18]

$\mu = 0.85$
$\beta = 0.8$
$Aggregation\ quantifier = F_{most}$
$Exploitation\ quantifier = F_{as\ many\ as\ possible}$

V. Analysis of results

Once defined the framework parameters and scenarios, AFRYCA 2.0 carried out the different simulations obtaining the results graphically shown in Fig. 4. Some comments and analyses are provided below.

- Simulation results: Logically, those scenarios with non-cooperative behaviors imply more discussions rounds. The ranking and the solution set of alternatives are the same in all the scenarios, hence, the model is robust and coherent in their consensus process.

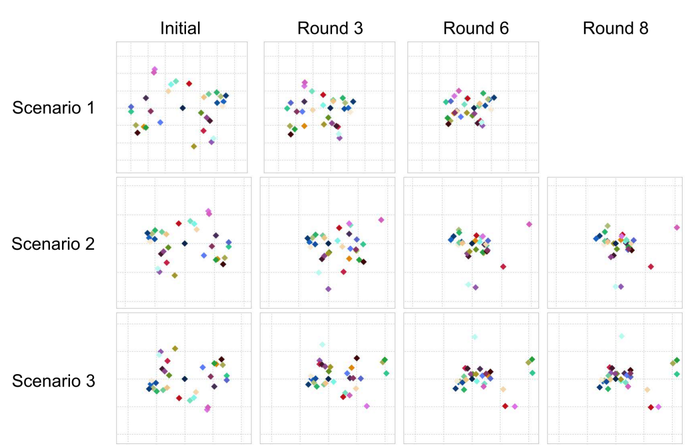

Fig. 4. MDS visualization of CRP using Herrera-Viedma et al.'s model [18]

TABLE III
CRP SIMULATIONS RESULTS WITH HERRERA-VIEDMA ET AL.'S MODEL [18]

Herrera-Viedma et al. [18]	Initial consensus degree	Final consensus degree	Number of rounds	Ranking	Solution
Scenario 1	0.60	0.88	6	$x_2 \succ x_1 \succ x_3 \succ x_4$	x_2
Scenario 2	0.60	0.87	8	$x_2 \succ x_1 \succ x_3 \succ x_4$	x_2
Scenario 3	0.60	0.86	8	$x_2 \succ x_1 \succ x_3 \succ x_4$	x_2

- Analysis: It should be noted that, this model weights the alternatives for computing the consensus measure by means of S-OWA OR-LIKE operator [28], by using a parameter β, that limits the impact of non-cooperative behaviors to a certain degree. For this reason the simulation results in all scenarios have similar performances. However, the experts' consensus degree on each alternative is based on an average operator that does not weight expert's behavior in the CRP process. Hence, the impact of non-cooperative behavior is limited to some extent but not in a general way. If we look at Fig. 4 some experts, in scenarios 2 and 3, are quite far away from mutual agreement. Therefore, the good performance of the model is limited. A new simulation was carried out in which the consensus threshold was $\mu = 0.9$, in such a case the scenario 2 did not reach consensus after $maxrounds = 30$ (see Fig. 5), due to the averaging process.

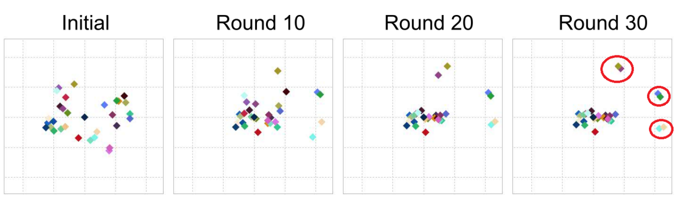

Fig. 5. MDS visualization of CRP using Herrera-Viedma et al.'s model [18] with a consensus threshold 0.9

Based on previous analysis, in order to guarantee a robust and correct performance of this model in LSGDM, it would be necessary the weighting of the set of alternatives and include some penalization in the computation of the consensus degree to decrease the impact of behaviors in scenarios 2 and 3. In short, some advantages and disadvantages of this CRP model in LSGDM are:

- Advantages:
  - Refuse and defense behaviors can be managed by using S-OWA OR-LIKE operator but not always.
  - Decision results are robust in different scenarios.
  - Discussion rounds are relatively small (taking into account the LSGDM problem).
- Disadvantages:
  - Even though the model reaches consensus, some experts are far away from the mutual agreement, hence, consensus achieved could not take into account the opinion of some experts.
  - The weighting of alternative set versus the weighting of experts regarding their behavior can lead to deadlock situations in which agreement is not reaching.

VI. CONCLUSIONS

Due to the high number of experts involved in LSGDM problems, disagreement in the group is more possible and hence, CRP is necessary. Although a few specific proposals of CRPs for LSGDM have been done, no study about the performance of a classical CRP model designed for GDM problems with few experts within LSGDM problem. Therefore this paper, by using the consensus simulation framework AFRYCA 2.0, has carried out a study of a classical CRP in different scenarios that are similar to the ones that can be found in real-world LSGDM to analyze such a performance.

From the obtained results, a conclusion is clear, the use of a classical consensus model to LSGDM is not always suitable, and it should be adapted to deal with LSGDM with some improvements that have been pointed out in the analysis.

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