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A consensus model for Delphi processes with linguistic terms and its application to chronic pain in neonates definition☆

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ABSTRACT

This paper proposes a new model of consensus based on linguistic terms to be implemented in Delphi processes. The model of consensus involves qualitative reasoning techniques and is based on the concept of entropy. The proposed model has the ability to reach consensus automatically without the need for either a moderator or a final interaction among panelists. In addition, it permits panelists to answer with different levels of precision depending on their knowledge on each question. The model defined has been used to establish the relevant features for the definition of a type of chronic disease. A real-case application conducted in the Department of Neonatology of Máxima Medical Center in The Netherlands is presented. This application considers the opinions of stakeholders of neonate health-care in order to reach a final consensual definition of chronic pain in neonates.

1. Introduction

Delphi technique is a well-known group decision-making method involving a structured interaction among a panel of experts or stakeholders, which anonymously tries to reach consensus on the significant features of a certain topic [25]. Since its introduction in the 1960s, it has been used to attain convergence of expert opinion in a variety of fields of knowledge such as program planning, needs assessment, policy determination and resource utilization [11,19,22,35].

The Delphi method has proved to have some functional advantages over other consensus-building methods, such as brainstorming, dialectical inquiry and nominal group [14,22,24,25,35]. The moderator in these group decision-making techniques conducts the group communication and consensus processes through several rounds. However handling uncertainty and linguistic terms in group assessments is one of the main problems of this type of methods.

To handle the uncertainty and linguistic information inherent to human consensus processes, many group decision-making techniques have been developed and are available in the academic literature [2,7,13,14,16,17]. In [18] a review of consensus models in a fuzzy environment can be found. There is, nowadays, a wide range of areas of application for these methods, from managerial to medical or engineering [6,8,10,30]. In particular, some fuzzy Delphi approaches have been proposed to deal with uncertainty and linguistic information [9,12,27]. Although, through these approaches, participants use a set of ordered linguistic labels, they are unable to use different levels of precision in their assessments. In addition, these fuzzy Delphi approaches share with original Delphi technique the absence of a definition of a degree of consensus. These have been considered as significant drawbacks by Delphi technique users.

The new approach to the Delphi method developed in this paper, not only includes the use of linguistic information, with different levels of precision, but also computes a degree of consensus in each round of the Delphi process. It permits each participant to utilize linguistic terms that reflect more adequately the level of uncertainty intrinsic to his evaluation, and to be dynamically aware of their agreement in each round.

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To this end, the new Delphi approach is based on qualitative reasoning techniques [34]. Participants' assessments through linguistic terms are considered qualitative labels in an absolute order-of-magnitude qualitative space [31]. Different levels of precision are used to reflect the distinctions required by evaluators' reasoning processes. Techniques based on order-of-magnitude qualitative reasoning have provided theoretical models that permit operating in conditions of insufficient or non-numerical data [34]. One of the advantages of qualitative reasoning is its ability to tackle problems in such a way that the principle of relevance is preserved, i.e., each variable involved in a real problem is valued with the level of precision required.

The paper comprises six sections. Section 2 introduces the main features of Delphi processes. The theoretical framework for this new approach is then presented in Section 3. In Section 4 the new approach for Delphi processes, based on a group consensus measure with linguistic terms is explained. A real case example in the health-care sector is presented in Section 5 to show the performance of this new approach. Finally, the main conclusions and lines of future research are discussed in Section 6.

2. Delphi processes: overview and key points

Dalkey and Helmer and the Rand Corporation developed the Delphi technique in 1963 [11]. This technique is usually used for determining the set of possible alternatives, finding implicit assumptions conducting to different judgements, exploring new solutions for a specific problem, or reaching consensus about a specific topic from a panel of experts or stakeholders.

A Delphi process is generally designed through 3–4 rounds of questions. In the first round, in order to gather panelists' opinions, open-ended questions are used. The results of this first round are classified into statements which are then valued by the panelists in a second round. In the consecutive rounds the panelists are showed the values of the total panel and are asked to re-assess their own values in the light of the group's opinion. Frequently, this type of iteration leads to a consensus on the group of significant statements.

The main weaknesses or limitations on the Delphi method are the absence of a definition of a degree of consensus, the difficulty of dealing with the uncertainty involved in panelists' opinions, and the way in which some opinions are suppressed during the consensus process.

Several fuzzy Delphi approaches have been developed in the literature to solve these issues. The application of fuzzy theory to the Delphi method by means of linguistic variables was initially introduced in [27]. A fuzzy Delphi method considering pessimistic, moderate and optimistic assessments of experts via triangular fuzzy numbers was introduced in [23]. Using triangular fuzzy numbers to model the experts' judgments, in [21] consensus is reached in only one round thanks to the implementation of the max–min fuzzy Delphi method and a new Delphi method via fuzzy integration. After reviewing the previous fuzzy Delphi works, a new approach using fuzzy statistics is proposed in [9]. An application of fuzzy Delphi method to obtain the critical factors of the regenerative technologies by using fuzzy AHP to find the importance degree of each factor is introduced in [20]. A web based consensus support system for group decision making problems and incomplete preferences was introduced in [2]. The method is similar to Delphi technique but it does not rely on the use of questionnaires and the moderator tasks can be replaced. An extension of the recent literature and an implementation of fuzzy Delphi for the adjustment of statistical forecast can be found in [12]. This study presents a fuzzy Delphi adjustment process to improve accuracy and introduced an empirical study to illustrate its performance.

A new approach for Delphi processes is proposed in this paper. It is based on a definition of a degree of consensus that can be used when experts' answers (as from round 2) are given with linguistic terms. Linguistic terms are handled by means of order-of-magnitude qualitative reasoning techniques. [31,32] offer a detailed application of these methods to group decision-making and consensual processes.

3. Order-of-magnitude reasoning framework

In this section, we briefly review the basic concepts of the qualitative absolute order-of-magnitude model which will be used in the next sections [1,31,34]. This paper relies on the use of linguistic terms based on this model. This allows the imprecision involved in panelists' opinions in Delphi processes to be managed.

The qualitative absolute order-of-magnitude model of granularity n considers a finite set of *basic* qualitative labels, $\mathbb{S}_n^* = \{B_1, \ldots, B_n\}$, which is totally ordered: $B_1 < \ldots < B_n$ [1,31,33].

In general, each basic qualitative label corresponds to a linguistic term, for instance for $n = 5$: B_1 = "Strongly disagree" < B_2 = "Disagree" < B_3 = "Neither agree nor disagree" < B_4 = "Agree" < B_5 = "Strongly agree".

The *complete universe of description* for the absolute order-of-magnitude space with granularity n, is the set $\mathbb{S}_n$:

$$\mathbb{S}_n = \mathbb{S}_n^* \cup \{[B_i, B_j] \mid B_i, B_j \in \mathbb{S}_n^*, i < j\},$$

where the *non-basic* label $[B_i, B_j]$ with $i < j$ is defined as the set $\{B_i, B_{i+1}, \ldots, B_j\}$, whereas $[B_i, B_i] = B_i$ [1,31].

Following with the above-mentioned set of $n = 5$ linguistic terms, the non-basic label $[B_1, B_2]$ represents the linguistic term ["Strongly disagree", "Disagree"]. The linguistic term "Unknown" is represented by ["Strongly disagree", "Strongly agree"], i.e., $[B_1, B_5]$. This least precise qualitative label is denoted by the symbol ?, i.e., in $\mathbb{S}_n$, $[B_1, B_n] \equiv \alpha$.

This structure permits working with all different levels of precision from the basic labels $B_1, \ldots, B_n$ to the ? label (see Fig. 1).

In addition, we also review the concept of extended measure in $\mathbb{S}_n$ and the connex union and intersection operations introduced in [31]:

A normalized measure μ is considered in the set of basic qualitative labels, $\mu : \mathbb{S}_n^* \to [0, 1]$ such that $\sum_{B_i \in \mathbb{S}_n^*} \mu(B_i) = 1$. This measure is directly extended to $\mathbb{S}_n$ by defining $\mu([B_i, B_j]) = \sum_{k=i}^{j} \mu(B_k)$.

In order to define the degree of consensus among a set of panelists' opinions, the connex union and the intersection between qualitative labels are also considered [31]. Given two qualitative labels $[B_{i_1}, B_{j_1}], [B_{i_2}, B_{j_2}] \in \mathbb{S}_n$, their connex union is the label $[B_{i_1}, B_{j_1}] \sqcup [B_{i_2}, B_{j_2}] = [B_{\min(i_1,i_2)}, B_{\max(j_1,j_2)}]$. When $[B_{i_1}, B_{j_1}] \cap [B_{i_2}, B_{j_2}] \neq \emptyset$, their intersection is the qualitative label $[B_{i_1}, B_{j_1}] \cap [B_{i_2}, B_{j_2}] = [B_{\max(i_1,i_2)}, B_{\min(j_1,j_2)}]$.

Finally, an *iterative relaxation process* is initiated in order to reach a non-empty intersection among the set of qualitative labels when this intersection is initially empty (see a detailed explanation in

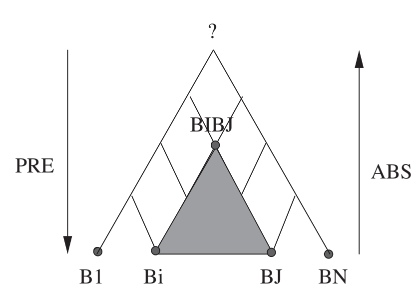

Fig. 1. The complete universe of description $\mathbb{S}_n$ [31].

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