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A new fuzzy linguistic approach to qualitative Cross Impact Analysis

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ABSTRACT

Scenario Planning helps explore how the possible futures may look like and establishing plans to deal with them, something essential for any company, institution or country that wants to be competitive in this globalize world. In this context, Cross Impact Analysis is one of the most used methods to study the possible futures or scenarios by identifying the system's variables and the role they play in it. In this paper, we focus on the method called MICMAC (Impact Matrix Cross-Reference Multiplication Applied to a Classification), for which we propose a new version based on Computing with Words techniques and fuzzy sets, namely Fuzzy Linguistic MICMAC (FLMICMAC). The new method allows linguistic assessment of the mutual influence between variables, captures and handles the vagueness of these assessments, expresses the results linguistically, provides information in absolute terms and incorporates two new ways to visualize the results. Our proposal has been applied to a real case study and the results have been compared to the original MICMAC, showing the superiority of FLMICMAC as it gives more robust, accurate, complete and easier to interpret information, which can be very useful for a better understanding of the system.

1. Introduction

How will the future look like? How to be prepared for possible future situations? Finding good answers to these kind of questions is essential for any company, institution or country that wants to be competitive in the current globalized world, as evidenced by the large number of foresight agencies, organizations and departments operating around the world.[1] Events such as climate change, global warming, the current financial crisis or the emerging economies of countries as China, Brazil or Russia give even more importance to these studies.

Many methods to address the above questions can be found in the literature. One of the most employed approaches is Scenario Planning [1–5]. It is widely understood as a family of methods to help managers imagine possible futures by stimulating creative thinking in order to consider a wide variety of scenarios in a systematized way [5]. These scenarios are coherent descriptions of alternative hypothetical futures that reflect different perspectives on past, present and future developments, which can serve as a basis for action [6].

Broadly speaking, the diversity of techniques employed in Scenario Planning can be classified into qualitative and quantitative, based on the nature of the procedures they employ [5]. Among the most popular quantitative methods [5], we find Interactive Cross Impact Simulation [7], Interactive Future Simulation [8], Fuzzy Cognitive Maps (FCM) [9], Trend Impact Analysis (TIA) [10] and Cross Impact Analysis (CIA) [11]. Both TIA and CIA use probabilities given by human experts. They represent probabilities of deviation from a model that has been fitted to historical data, in the former, and prior conditional probabilities of the events involved [12], in the latter (in its original conception). Finally, FCMs capture causal relationships in a weighted directed graph that enables the study of loops and indirect relations. The use of FCMs in developing scenarios is very recent [9].

In this work we focus on Cross Impact Analysis (CIA) [11]. In the initial proposal by Gordon [13], experts are asked about probabilities (conditional or marginal) of the *factors* that constitute a scenario, that are later operated to obtain the probability of the scenario. However, a lot of different variants of CIA have been proposed since then in the literature, some of which do not necessarily make use of probabilities. Roughly, they can be classified in four groups [14]: deterministic [15,16], probabilistic [13,17], equation-based [18], and fuzzy [14,19,20]. One well-known variant of CIA method

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[1] http://www.globalforesight.org/foresight-organizations/orgs—top-foresight.

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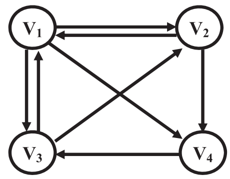
1568-4946/



(a)

	V_1	V_2	V_3	V_4	Global Influence Ranking
V_1	-	VW	VW	VW	1
V_2	VW	-	-	VW	2
V_3	VW	VW	-	-	2
V_4	-	-	VW	-	4

(b)

	V_1	V_2	V_3	V_4	Global Influence Ranking
V_1	-	VS	VS	VS	1
V_2	VS	-	-	VS	2
V_3	VS	VS	-	-	2
V_4	-	-	VS	-	4

(c)

Fig. 1. (a) Example of an influence interrelation network: $V_i \rightarrow V_j$ indicates that V_i influences V_j. (b) System where these interrelations are very weak (VW). (c) System where these interrelations are very strong (VS). MICMAC provides the same output in both cases.

proposed by Duperrin and Godet is MICMAC [4,15]. Godet suggests applying MICMAC at the first stage of the Scenario Planning process, when the experts define the main variables of the system and their interactions in order to identify the role they play in the system. MICMAC analyses the importance of a given set of variables through a matrix that contains the influence that each variable has on the others. The influence is not expressed with probabilities but using integer values between 0 and 3. The main characteristic feature of this procedure lies on its ability to uncover both global direct and indirect influence/dependence among variables.

MICMAC has been successfully applied in many fields. Some recent examples are listed next. In [21], the authors employ this method to categorize the drivers and barriers of mobile banking (also known as M-Banking) in India. In [22], MICMAC was used to identify factors that represent a major threat for the dynamic loosening, under soft foot conditions, of a bolted joint. Another interesting application is found in [23], where it was used to assess the driving power and dependence of supply chain risks. In [24], MICMAC was employed to analyse the effect and dependence among the overall design components, and to consider the relationship network graph of distribution of components in the system. A recent study by Guo et al. [25] employed a four-stage novel approach for analysing and developing a structured hierarchy framework for students' usage of computer-mediated communication media in learning contexts. In this work, the authors used MICMAC to analyse the driver and dependence power for each media use reason and identify the hidden and indirect relationships among all reasons. Diabat and Govindan [26] presented a model of green supply chain management. The model developed was validated on a case study by applying MICMAC.

MICMAC and some other CIA methods, despite being very successful tools, still exhibit some drawbacks. First, the information is given by various experts through opinion pools, panels, etc. Such information is vague due to the subjective character of the data, imprecision on the opinions, not enough consensus among the experts, etc. This vagueness in the information is not properly addressed by these methods since they model and aggregate experts' opinions using integer numbers, which cannot cope with uncertainty. Another drawback caused by the same fact is the low interpretability of the results, which are numerical values that lack a deep meaningfulness. Furthermore, much of the information provided by MICMAC is relative. For example, consider two systems with the same influence interrelation network among variables (Fig. 1(a)). In one of them, all interrelations are very weak (Fig. 1(b)) and in the other, they are very strong (Fig. 1(c)). MICMAC gives the same output in both cases, since it only provides relative information, expressed as rankings. This issue also arises when displaying the results: the same plot is obtained for the two situations. For a good understanding of the system, it is important to provide the user with both relative and absolute measures of the importance of the variables.

The drawbacks mentioned above might lead to a distorted view of the system and therefore, of future scenarios. In order to overcome these problems and obtain a more robust approach, we introduce Computing with Words (CW) techniques taken from the Soft Computing field. To be precise, the use of linguistic labels and fuzzy sets to represent the information allows establishing linguistic assessments (e.g., *high, medium, low*) of mutual influence relations and, at the same time, captures the uncertainty behind such judgments in a satisfactory way. Moreover, systems designed following the CW paradigm both give and receive linguistic data, which makes the information closer to human language and thus, easier to interpret. This approach has been recently applied with success in other fields as selection of personnel [27,28], risk assessment [29], product design and development [30–32], quality service evaluation [33,34] or renewable energies [35,36].

Based on this idea, we aim at developing an improved version of MICMAC that overcomes these problems, as well as presenting novel ways to visualize the linguistic results. This new method is called Fuzzy Linguistic MICMAC (FLMICMAC) and has shown good results in preliminary studies with an earlier version [37]. The particular objectives we pursue with this method are the next:

- Allow the user to input data in linguistic format.
- Address the inherent vagueness present in foresight and forecast studies.
- Show linguistic output information to the user at different granularity levels.
- Give the decision-maker information in both relative and absolute terms to check the role of the variables and the real strength of their impact in the system.
- Provide new graphical representations to achieve a better understanding of the system.

The contribution is structured as follows. We start describing the MICMAC methodology in Section 2. Then, our proposal is presented in Section 3. Section 4 deals with the application of our method to a real case-study, and the comparison of the results with those obtained by the original method. Finally, Section 5 is devoted to conclusions and further work.

2. MICMAC

2.1. Description of the methodology

The MICMAC method for structural analysis is aimed at determining the most important variables within a system among a set of variables, initially specified by an expert committee, and establishing their role in the system. This is accomplished by studying the influence relation among the variables. Basically, MICMAC consists in the following three steps:

1. *Define relevant variables*. The variables of the system are defined basing on the opinion of several experts, brainstorming and literature review. An unsorted list of variables is given as an output in this phase. Let n be the number of variables identified.
2. *Specify the relations between the variables*. The experts provide a $n \times n$ integer matrix that states the influence that each variable