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First Look at MCDM: Choosing a Decision Method

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Abstract

More than four decades after the first Conference on *Multiple Criteria Decision Making (MCDM)* in 1972, this field has accomplished some maturity and has drawn closer to a turning point. Many publications, studies and applications around the world have showed how vast is the scope of MCDM.
The purpose of this paper is to shed some light on different aspects of MCDM in order to clarify notions and present the field in a holistic way. Its main goal is to serve as an entrance door to future students and researchers, supporting them with an easy and clear approach, which represents a quick survey on the field of decision support, and a guide to an effective and meaningful application of the methods in different areas of research and real world problems.

1. Introduction

Multiple Criteria Decision Making is a branch of *Operations Research (OR)*, also called *Management Science (MS)* or *Decision Science*, and mentioned sometimes as a sub-field of mathematics. According to *Hanne* [1], MCDM "deals with (mathematical) theory, methods and methodological issues and case studies (applications) for decision processes where multiple criteria (objectives, goals, attributes) have to be (or should be) considered".
After the World War II, with a prosperous economical and political scenario, Operations Research evolved promptly and extended its applications to other areas than the military, such as industry and logistics. The main objective of OR is to improve the decision making process by providing mathematical tools of analysis, modelling and optimization that aid making better decisions in empirical contexts. As a part of OR, MCDM also results from an interdisciplinary background, combining different areas like engineering, economics, psychology, computer science and of course, mathematics.
MCDM has changed along with OR since the early seventies becoming a very important asset to decision making processes nowadays. In its evolutionary process MCDM has turned from "a conceptual-theoretical enterprise of interests practiced by a limited number of disciplines and individuals to a universally embraced philosophy" [2]**.** Furthermore MCDM has transformed its paradigm to give voice to the decision maker (DM), we are no longer finding the optimal solution but a solution that satisfies more the DM [3].
The next sections of this paper present different aspects of MCDM as a discipline. In Section 2 we clarify some notations related to MCDM, and we also present the two main streams of thought developed around it. In Section 3 we describe the decision problem structure identifying its core characteristics. In Section 4 we introduce different approaches to choose the right decision method. Finally Section 5 gives some concluding remarks.

2. MCDM Classifications

In the MCDM literature one can find two main streams of thought sometimes called schools. The first to arise was the *French School* or also mentioned as the *European*

School, and it is famous for its connection to the *outranking methods* created and developed by *Roy*. In opposition the *American School* is associated with *multi-attribute value/utility theories (MAVT/MAUT)* motivated by the work of *Keeney and Raiffa* and made famous by one of the most studied and used methods worldwide, the *Analytic Hierarchy Process - AHP* by *Thomas L. Saaty* [4].
Along with these two different approaches also two distinct denominations emerged to define the discipline. The French practitioners dislike the acronym MCDM, as they think that the MCDM "approach is based on a misconception of the decision process and the way a decision analyst or a multicriteria decision method is involved into it" [1]. The word "making" is then replaced by "aid" on the tentative to step aside the role of the decision analyst from the one played by the Decision Maker (DM).
In some cases this field of studies is also mentioned as *Multi-criteria Decision Analysis*, a definition which tries to bring both MCDA and MCDM supporters to a consensus or is sometimes adopted by international teams gathering researchers from both schools.
Besides these two approaches there are still some major definitions which could be assigned to both MCDM and MCDA and were established to assist a methodical and structured research in the field.
Hwang and Yoon have proposed two main categories for grouping different MCDM problems according to their purposes and available information. The classes that were defined are *Multiple Attribute Decision Making (MADM)* and *Multiple Objective Decision Making (MODM)*. The later handles decision problems that consider a continuous decision space, and are usually related to design and planning. On the other hand, MADM problems are assigned to an evaluation component with a discrete decision space and a predetermined set of alternatives/potential actions normally considering information from the DM [5], [6].
Another classification used for MCDM methods is related to the quality of the available information. The application of MCDM to real world problems faces some issues related with imperfect knowledge from human evaluations, consequence of modelling complex real decision problems. Thus, the information is often catalogued as *Crisp*, when there is precise data or as *Fuzzy*, when it is incomplete or vague. In the same way MCDM methods are subdivided into *MADM/MODM* if they use crisp information or into *FMADM/FMODM (Fuzzy MADM/ Fuzzy MODM)* if they use fuzzy knowledge. One of the modelling and solution techniques to solve this kind of problems is *Fuzzy Set Theory* (see [7])**.**

3. Decision Process

The MCDM literature is divergent on the right approach to organize and define a decision making process or a Decision Making Situation (DMS). However a famous quote by *Albert Einstein* is largely used and points out the importance of this step, "The formulation of a problem is often more essential than its solution, which may be merely a matter of mathematical or experimental skill".
According to *Roy* [8] to best analyse and structure a decision aid process, three key concepts must be taken into account. Hence, the next three sub-sections present some important aspects related to *alternatives*, or generally potential actions, *criteria* and *problematic*, the main elements of the decision process pointed by the author. On the last subsection we analyse a possible structure for the decision process.

3.1. Alternatives or Potential actions

The concepts of *alternatives* and *potential actions* come together as they represent the main goal of the decision process, or the possible choices for the DM.
Different decision problems require different modelling approaches, which points out the difference between alternative and potential action.

An action is called *potential* when it is possible to implement or it has something to add to the decision process. On other hand, an alternative results from modelling situations where two potential actions are mutual exclusive, so they are expected to operate separately [8]. Therefore, when referring to the best alternative to a problem, one can think of it as the only potential action to implement from the initial set. It is also essential to mention that a set of potential actions can change through the decision process as more information is gathered, leaving out some actions.

3.2. Family of Criteria and Performance Table

The concept of *criteria* is connected to both the notions of *attribute* and *objective*, as we already observed when describing MADM and MODM. *Eldrandaly et al.* refer that an attribute measures the system performance regarding an objective, whereas the objective is a statement of the desired situation of the system [9].
A *criterion*, that we denote by $\boldsymbol{g_j}$, represents one of the possible dimensions from which the alternatives or possible actions can be evaluated, according to a defined point of view, in general the DM's angle.
The criteria measures how well a potential action is performing towards the goals of the problem. It is important that the criteria are descriptive of the goals in order to understand the performance of each alternative under those goals. Thus, we denote by $\boldsymbol{g_j(a_i)}$ the *performance* of an alternative $\boldsymbol{a_i}$ regarding a certain criterion $\boldsymbol{g_j}$. This indicator assesses the level of fulfilment of a certain goal, and also allows the comparison of different alternatives concerning a given criterion.
Depending on the decision method, criteria can be expressed under two data types, *qualitative or quantitative*, these types can be found either together or separately [10]**.** To better perform the judgment of alternatives the definition of a scale is needed. The most common options mentioned across the literature are: *the nominal, the ordinal, the ratio, the absolute, and the interval.* (see [8], [11], [12]).
A large number of decision methods use *criteria weighting* in order to favour a certain aspect of the decision makers' preferences. A well known example is the *AHP* [13].
Choosing the right criteria for the problem situation in hands is very important, and it can shorten the number of alternatives or assure a consistent evaluation of the set of actions (see [6], [8], [14]). On the definition of the criteria, situations of *independence*, *cooperation*, or *conflict* can happen, so it is also relevant to analyse the way criteria interact.

3.3. Problematic

This last concept is related to the expected outcome of the decision problem and represents a major role in choosing the right method for the DMS under consideration.
Bernard Roy [15] categorised the decision making situations according to four major problematics, and the way the Decision Aid (DA) should be envisaged:

The Description problematic $(\boldsymbol{P.\delta})$ **–** DA focuses in providing an appropriate set of actions and a suitable family of criteria, without making any recommendation.
The Choice Problematic $(\boldsymbol{P.\alpha})$ **–** The aid intends to narrow down the number of actions to find a single alternative or a possible smaller subset (usually containing the most fulfilling actions to the predefined goals).
The Sorting Problematic $(\boldsymbol{P.\beta})$ **–** In this problematic the aid seeks to assign each action a category from a set defined a priori. These categories can be related with the feasibility of the actions and the possibility of their implementation.
The Ranking Problematic $(\boldsymbol{P.\gamma})$ **–** The DA results in a complete or partial preorder of the set of alternatives, after comparing them with each other.

These are the most common problematics, yet others could be considered (see [16]).

3.4. Structure of a Decision Process

For the purpose of this paper we followed the model proposed by *Guitouni* [17], which focus the DMS on a *Multiple Criteria Aggregation Procedure (MCAP)* approach.
The most applied decision methods rely on MCAP, on other words they use mathematical and algorithmic procedures, which given a set of alternatives, and considering a certain problematic, lead to the desired solution. It is often mentioned that a universal MCAP does not exist, meaning that a single MCAP is not likely to be used in all DMS. Each MCAP is associated to an approach. The considered possibilities are: *the single synthesizing criterion approach*, *the outranking synthesizing approach* and *the interactive approach.*
According to Guitouni and Martel [3] the multi-attribute utility/value theory considers a set of attributes denoted by $\boldsymbol{A}$, while the outranking methods consider a family of criteria denoted by $\boldsymbol{F}$. This leads to a classical model $\mathbb{A} - \boldsymbol{F/A} - \mathbb{E}$ that can be used to describe any DMS. Although the model is considered incomplete (see [18]) it is representative for the purpose of this study.
The $\mathbb{A} - \boldsymbol{F/A} - \mathbb{E}$ model, regards the set of alternatives $\mathbb{A}$, of a discrete decision space, the family of criteria/attributes $\boldsymbol{F/A}$, and adds a new concept of *Performance Table* $\mathbb{E}$, also called *Decision Matrix*. In this table the rows represent the alternatives, as the columns represent the criteria. A value on the intersection of a certain $\boldsymbol{i^{th}}$ alternative with a $\boldsymbol{j^{th}}$ criterion is the performance indicator $\boldsymbol{g_j(a_i)}$ denoted by $\boldsymbol{e_{ij}}$ on the performance table.

$$\mathbb{A} = \{\boldsymbol{a_1}, \dots, \boldsymbol{a_i}, \dots, \boldsymbol{a_m}\}$$
$$\boldsymbol{F/A} = \{\boldsymbol{g_1}, \dots, \boldsymbol{g_j}, \dots, \boldsymbol{g_n}\}$$
$$\mathbb{E} = \{\boldsymbol{e_{ij}} = \boldsymbol{g_j(a_i)}\ \boldsymbol{i} = \boldsymbol{1}, \dots, \boldsymbol{m}; \boldsymbol{j} = \boldsymbol{1}, \dots, \boldsymbol{n}\}$$

The $\mathbb{A} - \boldsymbol{F/A} - \mathbb{E}$ model is included on the first stage of a five step decision-making process seen as recursive and non linear, with de decision maker and the decision analyst providing information and changes to the loop. Thereby, we consider the following steps of the process developed by *Guitouni* [17]:

I. **Structuration** – structuring of the DMS (alternatives, criteria and Performance Table)
II. **Preferences Articulation and Modelling** – determination of criteria relative importance, inter-criteria information, value and utility functions, thresholds, etc.
III. **Preferences Aggregation** – establishment of a preference relational system
IV. **Exploitation** (depends on each MCAP)
V. **Recommendation –** the output of the process

4. Choosing the right Method for a Decision Making Situation

Many attempts have been made to define a framework that links each DMS to the most suitable decision method. This is an exhaustive, thorough, and nearly impossible procedure that must take into consideration all the decision process dimensions, the DM's role, not to mention the extensive number and variety of methods, and the information available. However it is unquestionable that the selection problem is primal to the success of the process [9], which explains some of the meticulous studies in this area (see [3], [18]).
As above mentioned, *Hwang and Yoon* [19] organized some decision methods on a diagram tree according to the available information, providing the decision analysts and the decision makers with a simple tool to choose a method. Nevertheless, it is a restricted approach and leaves out important aspects of the decision process as well as powerful methods, not considered in the definition of the tree.

A study conducted by *Baker et al.* [12] presented a state of the art of the existing approaches to select MCDM methods. This study considered nine different approaches and compared them with each other regarding their characteristics. It also pointed out four major facets and their inner features, which according to the authors guarantee the characterization of the decision problem in the selection context. Those facets are:

The Problem facet – type of decision problematic, problem scale *(workplace, department, enterprise, corporation…)*.
The Potential Action facet – number of alternatives, ability to consider new alternatives, incompatibility and conflict, organization of the alternatives, nature of the alternatives set *(discrete, continuous)*.
The Criteria facet – data type, measure scale, criteria weighting, criteria interaction.
The Usage facet – tool *(Software)*, Approaches for giving partial and final evaluations, Easiness of use, cost for implementing *(purchasing the tool, costs for training)*, decision maker preferences *(DM understanding, skills and habits).*

Guitouni and Martel proposed seven guidelines to help choosing an appropriate decision method within twenty-nine possible MCAP [3]:

G1: Determine the stakeholders of the decision process.
G2: Consider DM's "cognition" when choosing a particular preference evaluation mode.
G3: Determine the decision problematic pursued by the DM.
G4: Choose the MCAP that can handle properly the input information**.**
G5: Consider the compensation degree of the MCAP method
G6: Consider the fundamental hypothesis of the method
G7: Consider the decision support system

The guidelines supported the designing of a typological tree of discrete MCAP. The DM or the analyst only needs to follow the branches of the tree according to the guidelines and one or several decision methods will be presented as possibilities for the DMS under consideration. This means that not always an unequivocal choice is the result of its use. Still it represents a powerful tool for guiding the method selection and can be improved by adding new methods to the list, or new branches to the tree following for example the four facets above or other relevant characteristics of the DMS.

5. Conclusion

Over recent years, MCDM has proven to be part of the decision making in various components of a society that grows in complexity. Thanks to that, the decision support has turned into a more solid, organized and widely used process.
The approaches presented in this paper to develop a method selection technique reveal important accomplishments. However the process of selecting a method needs more attention from the decision making community. All the above mentioned issues, regarding the selection topic, delay a wider and more effective use of MCDM in real problems [9]**.**
The definition of a database where all the existing decision methods can be catalogued and organized could support future research and streamline the application of the methods.
It is a common denominator to all the method selection studies the fact that, even though some of them are very extensive and accurate, none of them is able to encompass all the methods and all the DMS. This problem could be solved with a standard tabulation for all the methodologies, creating a universal taxonomy. A massive enterprise like that needs efforts worldwide and takes time for negotiation, research and evaluation. Consensus and collaboration are the key words for solving this problem, and that means putting aside favouritisms and join forces for the future of MCDM and its worldwide application.

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