A Novel Mechanism of Multi-Criteria Decision Making: An Operations Research Approach

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Abstract: *The basic and important part of operations research is the development of approaches for optimal decision making. A prominent class of such problems is multi-criteria decision making (MCDM).Every complex problem now days require multi criteria decision making to get to the desired solution. Numerous Multi-criteria decision making (MCDM) approaches have evolved over recent time to accommodate various application. The purpose of this article is to systematically review the applications and methodologies of the MCDM techniques and approaches.*

Key words: *multiple criteria decision-making (MCDM),optimization, operations research. Pair wise comparisons*.

I.A General Overview of Multi-Attribute Decision Making:

Multiple criteria decision-making (MCDM) has grown as a part of operations research, concerned with designing computational and mathematical tools for supporting the subjective evaluation of performance criteria by decision-makers. This super class of models is very often called multi-criteria decision making (or MCDM). According to many authors (see, for instance, [Zimmermann, 1991]) MCDM is divided into Multi-Objective Decision Making (or MODM) and Multi-Attribute Decision Making (or MADM). **MODM** studies decision problems in which the decision space is continuous. A typical example is mathematical programming problems with multiple objective functions. **MADM** concentrates on problems with discrete decision spaces. In these problems the set of decision alternatives has been predetermined.

Although MADM methods may be widely diverse, many of them have certain aspects in common [Chen and Hwang, 1992]. These are the notions of alternatives, and attributes (or criteria, goals) as described next.

Multiple attributes:
Each MADM problem is associated with multiple attributes. Attributes are also referred to as *"goals"* or *"decision criteria"*. Attributes represent the different dimensions from which the alternatives can be viewed. In cases in which the number of attributes is large (e.g., more than a few dozens), attributes may be arranged in a **hierarchical** manner. That is, some attributes may be major attributes. Each major attribute may be associated with several sub-attributes. Similarly, each sub-attribute may be associated with several sub-sub-attributes and so on. Although some MADM methods may explicitly consider a hierarchical structure in the attributes of a problem, most of them assume a single level of attributes (e.g., no hierarchical structure).

Alternatives:
Alternatives represent the different choices of action available to the decision maker. Usually, the set of alternatives is assumed to be finite, ranging from several to hundreds. They are supposed to be screened, prioritized and eventually ranked.

Conflict among attributes:
Since different attributes represent different dimensions of the alternatives, they may conflict with each other. For instance cost may conflict with profit, etc.

Decision weights:
Most of the MADM methods require that the attributes be assigned weights of importance. Usually, these weights are normalized to add up to one.

Decision matrix:

A **decision matrix** is a list of values in rows and columns that allows an analyst to systematically identify, analyze, and rate the performance of relationships between sets of values and information. Elements of a **decision matrix** show **decisions** based on certain **decision** criteria.

An MADM problem can be easily expressed in matrix format. A decision matrix **A** is an ($M \times N$) matrix in which element a_{ij} indicates the performance of alternative A_i when it is evaluated in terms of decision criterion C_j, (for i = 1,2,3,..., M, and j = 1,2,3,..., N). It is also assumed that the decision maker has determined the weights of relative performance of the decision criteria (denoted as W_j, for j = 1,2,3,..., N). This information is best summarized in figure 1. Given the previous definitions, then the general MADM problem can be defined as follows [Zimmermann, 1991]:

Definition 1-1:

Let $A = \{ A_i$, for i = 1,2,3,... ,$M\}$ be a (finite) set of decision alternatives and $G = \{g_i$, for j = 1,2,3,..., $N\}$ a (finite) set of goals according to which the desirability of an action is judged. Determine the optimal alternative A^* with the highest degree of desirability with respect to all relevant goals g_i.

Critrria

	C_1	C_2	C_3	...	C_N
$Alt.$	W_1	W_2	W_3	...	W_N
A_1	a_{11}	a_{12}	a_{13}	...	a_{1N}
A_2	a_{21}	a_{22}	a_{23}	...	a_{2N}
A_3	a_{31}	a_{32}	a_{33}	...	a_{3N}
.	.	.	.	...	.
.	.	.	.	...	.
.	.	.	.	...	.
.	.	.	.	...	.
A_M	a_{M1}	a_{M2}	a_{M3}	...	a_{MN}

Figure 1: A Typical Decision Matrix.

Very often, however, in the literature the goals g_i are also called decision criteria Therefore, the terms MADM and MCDM have been used very often to mean the same class of models (i.e., MADM). For these reasons, in this paper we will use the terms MADM and MCDM to denote the same concept.

2 . Classification of MCDM Methods

There are many MADM methods available in the literature. Each method has its own characteristics. There are many ways one can classify MADM methods. One way is to classify them according to the type of the data they use. That is, we have **deterministic**, **stochastic**, or **fuzzy** MADM methods (for an overview of fuzzy MADM methods see [Chen and Hwang, 1992]). However, there may be situations which involve combinations of all the above (such as stochastic and fuzzy data) data types.

Another way of classifying MADM methods is according to the number of decision makers involved in the decision process. Hence, we have **single** decision maker MADM methods and **group** decision making MADM (for more information on the later class, the interested reader may want to check the journal of **Group Decision Making**).In this paper we concentrate our attention on single decision maker deterministic MADM methods.

The Multi criterion Decision-Making (MCDM) are gaining importance as potential tools for analyzing complex real problems due to their inherent ability to judge different alternatives (Choice, strategy, policy, scenario can also be used synonymously) on various criteria for possible selection of the best/suitable alternative (s). These alternatives may be further explored in-depth for their final implementation.

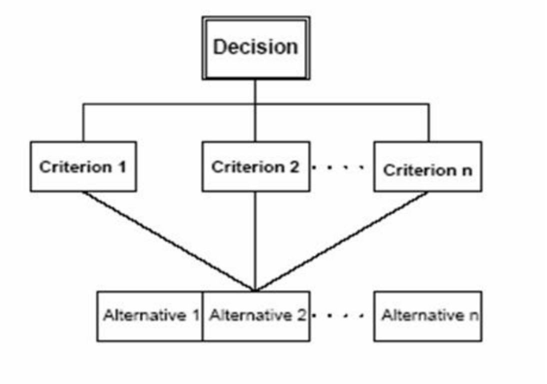

Figure 2: Multi criteria decision making (MCDM) Tree

Multi criterion Decision-Making (MCDM) analysis has some unique characteristics such as the presence of multiple non-commensurable and conflicting criteria, different units of measurement among the criteria, and the presence of quite different alternatives. It is an attempt to review the various MCDM methods and need was felt of further advanced methods for empirical validation and testing of the various available approaches for the extension of MCDM into group decision-making situations for the treatment of uncertainty.

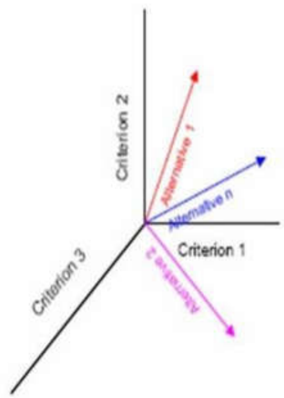

Figure 3: Multi-dimensions of MCDM

The weighted sum model (WSM) is the earliest and probably the most widely used method. The weighted product model (WPM) can be considered as a modification of the WSM, and has been proposed in order to overcome some of its weakness. The analytic hierarchy process (AHP), revised AHP, WPM, and TOPSIS methods are the ones which are used mostly in practice today and are described in later sections. Finally, it should be stated here that there are many other alternative ways for classifying MADM methods [Chen and Hwang, 1992]. However, the previous ones are the most widely used approaches in the MADM literature.

3 Some MCDM Application Areas

Some of the industrial engineering applications of MCDM include the use of decision analysis in integrated manufacturing [Putrus, 1990], in the evaluation of technology investment decisions [Boucher and McStravic, 1991], in flexible manufacturing systems [Wabalickis, 1988], layout design [Cambron and Evans, 1991], and also in other engineering problems [Wang and Raz, 1991]. Most widely used MCDM
technique is AHP, developed by Saaty and inspired by the intelligent behavior of human beings. Since judgments given by decision makers are relative, any change in the relative values of the choices may significantly change the weights of affected choices, resulting in a problem known as Rank Reversal [Y.-M. Wang and Y. Luo].The problem of imprecision and subjectivity in the weight calculation process is not handled in AHP and these problems can be overcome by using Revised AHP. Software Engineering has always been an area of concern for researchers because of its real time applications in the era of computer science. In most of the applications the final decision is dependent on the outcome ranking of alternatives in respective to criterion . Software development and evolution is characterized by multiple objectives and constraints. Nowadays the problems have been become more and more complex and depend upon multiple factors. A decision should also
consider issues such as: cost, performance characteristics (i.e., CPU speed, memory capacity, RAM size, etc.), availability of software, maintenance, expendability, etc. These may be some of the decision criteria for this problem. In the above problem we are interested in determining the **best alternative** (i.e., computer system). In some other situations, however, one may be interested in determining the relative importance of all the alternatives under consideration.

Multi-criteria decision-making (MCDM) plays a critical role in many real life problems. It is not an exaggeration to argue that almost any local or federal government, industry, or business activity involves, in one way or the other, the evaluation of a set of alternatives in terms of a set of decision criteria. Very often these criteria are conflicting with each other. Even more often the pertinent data are very expensive to collect.

4. Literature Review

4.1**. Review of Multiple-Criteria Decision-Making (MCDM) Methods:**

A focused study of MCDM over the few years illustrated the effectiveness of applying these methods in the areas of sustainable and renewable energy applications [Mardani, A.; Jusoh, A.; Zavadskas, E.K.; Cavallaro, F.; Khalifah, Z.]. The development of MCDM methods has been widely reported in the literature throughout the years. MCDM methods have also been applied in various engineering problems due to their clarity and robustness after years of study [12,13].

For the purpose of this paper, several methods have been reviewed, and eventually, the following ones have been selected, as they are the most widely applied in multi-criteria analysis problems for energy applications: WSM, WPM, TOPSIS, AHP. In the next paragraphs, a brief review is given with indicative applications of each of them in the literature.

Despite the disadvantages of WSM and WPM, i.e., sensitivity to units' ranges and exaggeration of specific scores, there are numerous applications in the literature that employ either of them primarily due to their straightforward implementation. Pilavachi et al. [7] have used an MCDM method according to a statistical estimation of weighted factors, while technical, social and economic features have also been considered. The method has been employed on the problem of risk identification and assessment within the tidal energy sector, as can be seen in [18], also introducing a comparison between the TOPSIS and WSM methods and showing results with good agreement. Among many methods, TOPSIS is used extensively in different areas of research. Lozano-Minguez et al. [12] employed this deterministic methodology on the selection of the most desirable support structure of an offshore wind turbine, among three design options, under the consideration of a combination of multiple qualitative and quantitative criteria.

4.2 Methodology:

4.2.1An Overview of Selected MCDM Methods:

There are three steps in utilizing any decision-making technique involving numerical analysis of alternatives:

1) Determining the relevant criteria and alternatives.

2) Attaching numerical measures to the relative importance of the criteria and to the impacts of the alternatives on these criteria.

3) Processing the numerical values to determine a ranking of each alternative.

This section is **only** concerned with the effectiveness of the four methods in performing step 3. The central decision problem examined in this paper is described as follows. Given is a set of M alternatives: $A_1, A_2, A_3, \ldots, A_M$ and a set of N decision criteria $C_1, C_2, C_3, \ldots, C_N$ and the data of a decision matrix as the one described in Figure 1. Then the problem is to rank the alternatives in terms of their total preferences when all the decision criteria are considered simultaneously.

4.2.2.The Weighted Sum Model:

The weighted sum model (or WSM) is probably the most commonly used approach, especially in single dimensional problems. If there are M alternatives and N criteria then, the best alternative is the one that satisfies (in the maximization case) the following expression [Fishburn, 1967]:

$$A^*_{WSM} = \max \sum_{i,j=1} q_{ij} w_j, \text{ for } 1,2,3\ldots,N$$

where: A_{WSM}* is the WSM score of the best alternative, N is the number of decision criteria, a_{ij} is the actual value of the *i-th* alternative in terms of the *j-th* criterion, and W_j is the weight of importance of the *j*-th criterion.The assumption that governs this model is the **additive utility assumption.** That is, the total value of each alternative is equal to the sum of products given as. In single-dimensional cases, in which all the units are the same (e.g., dollars, feet, seconds), the WSM can be used without difficulty. Difficulty with this method emerges when it is applied to multi-dimensional decision-making problems. Then, in combining different dimensions, and consequently different units, the additive utility assumption is violated and the result is equivalent to *"adding apples and oranges"*.

4.2.3.The Weighted Product Model:

The weighted product model (or WPM) is very similar to the WSM. The main difference is that instead of addition in the model there is multiplication. Each alternative is compared with the others by multiplying a number of ratios, one for each criterion. Each ratio is raised to the power equivalent to the relative weight of the corresponding criterion. In general, in order to compare the alternatives A_K and A_L, the following product (Bridgman [1922] and Miller and Starr [1969]) has to be calculated:

$$R(A_k / A_L) = \prod_{J=1}^{N} (a_{Kj} / a_{Lj})^{w_j},$$

where: N is the number of criteria, a_{ij} is the actual value of the *i-th* alternative in terms of the *j-th* criterion, and W_j is the weight of importance of the *j-th* criterion. If the term $R(A_K / A_L)$ is greater than to one, then alternative A_K is more desirable than alternative A_L (in the maximization case). The best alternative is the one that is better than or at least equal to all the other alternatives. The WPM is sometimes called **dimensionless analysis** because its structure eliminates any units of measure. Thus, the WPM can be used in single- and multi-dimensional decision-making problems. An advantage of the method is that instead of the actual values it can use relative ones. This is true because:

$$\frac{a_{Kj}}{a_{Lj}} = \frac{a_{Kj} / \sum_{i=1}^{N} a_{Kj}}{a_{Lj} / \sum_{i=1}^{N} a_{Li}} = \frac{a'_{Kj}}{a'_{Lj}}$$

A relative value a'_{kj} is calculated by using the formula: $a'_{Kj} = a_{Kj} / \sum_{i=1}^{N} a_{Ki}$ where the a'_{kj} s are the actual values.

4.2.4:The AHP method:

The Analytic Hierarchy Process (AHP) decomposes a complex MCDM problem into a system of hierarchies. The final step in the AHP deals with the structure of an m*n matrix (Where m is the number of alternatives and n is the number of criteria). The matrix is constructed by using the relative importance of the alternatives in terms of each criterion. Analytic Hierarchy Process (AHP) is an MCMD method based on priority theory. It deals with complex problems which involve the consideration of multiple criteria/alternatives simultaneously. Its ability to incorporate data and judgment of experts into the model in a logical way, to provide a scale for measuring intangibles and method of establishing priorities to deal with interdependence of elements in a system to allow revision of judgments in a short time to monitor the consistency in the decision-maker's judgments to accommodate group judgments if the groups cannot reach a natural consensus, makes this method a valuable contribution to the field of MCDM.

The methodology is capable of Breaking down a complex, unstructured situation into its Component parts, Arranging these parts into a hierarchic order (criteria, sub-criteria, alternatives etc.) Assigning numerical values from 1 to 9 to subjective judgments on the relative importance of each criterion based on the characteristics Synthesizing the judgments to determine the overall priorities of criteria/sub-criteria/ alternatives. Eigenvector approach is used to compute the priorities/weights of the criteria/ sub criteria/ alternatives for the given pair wise comparison matrix. In order to fully specify reciprocal and square pair wise comparison matrix, N (N-1)/2 pairs of criteria/sub criteria/alternatives are to be evaluated. The Eigen vector corresponding to the maximum Eigen value (λ MAX) is required to be computed to determine the weight vectors of the criteria/sub-criteria/alternatives. Small changes in the elements of the pairwise comparison matrix imply a small change in λ MAX and the deviation of λ MAX from N is a deviation of consistency. This is represented by Consistency Index (CI). i.e. (λ MAX –N)/(N-1). Random Index (RI) is the consistency index for a randomly-filled matrix of size. Consistency ratio (CR) is the ration of CI to average RI for the same size matrix. A CR value of 0.1 or less is considered as acceptable. Other wise, an attempt is to be made to improve the consistency ny obtaining additional information. Prof. Thomas L. Saaty (1980) originally developed the Analytic Hierarchy Process (AHP) to enable decision making in situations characterized by multiple attributes and

alternatives. AHP is one of the Multi Criteria decision making techniques. AHP has been applied successfully in many areas of decision-making. In short, it is a method to derive ratio scales from paired comparisons.

Four major steps in applying the AHP technique are:

Step1: Develop a hierarchy of factors impacting the final decision. This is known as the AHP decision model. The last level of the hierarchy is the three candidates as an alternative.

Step2:Elicit pair wise comparisons between the factors using inputs from users/managers

Step3: Evaluate relative importance weights at each level of the hierarchy

Step4: Combine relative importance weights to obtain an overall ranking of the three candidates.

4.2.5.TOPSIS Method

TOPSISwas first presented by Yoon (1980) and Hwang and Yoon (1981), for solving Multiple Criteria Decision Making (MCDM) problems based on the concept that the chosen alternative should have the shortest Euclidian distance from the Positive Ideal Solution (PIS) and the farthest from the Negative Ideal Solution (NIS). For instance, PIS maximizes the benefit and minimizes the cost, whereas the NIS maximizes the cost and minimizes the benefit. It assumes that each criterion require to be maximized or minimized. TOPSIS is a simple and useful technique for ranking a number of possible alternatives according to closeness to the ideal solution.

The TOPSIS procedure is based on an intuitive and simple idea, which is that the optimal ideal solution, having the maximum benefit, is obtained by selecting the best alternative which is far from the most unsuitable alternative, having minimal benefits. The ideal solution should have a rank of _1‘ (one), while the worst alternative should have a rank approaching _0‘ (zero). As ideal cars are not probable and each alternative would have some intermediate ranking between the ideal solution extremes. Regardless of absolute accuracy of rankings, comparison of number of different cars under the same set of selection criteria allows accurate weighting of relative car suitability and hence optimal car selection.

Mathematically the application of the TOPSIS method involves the following steps.

Step 1: Establish the decision matrix. The first step of the TOPSIS method involves the construction of a Decision Matrix (DM).

$$DM = \begin{array}{c|cccc} & C_1 & C_2 & \dots & C_n \\ L_1 & X_{11} & X_{12} & \dots & X_{1n} \\ L_2 & X_{21} & X_{22} & \dots & X_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ L_m & X_{m1} & X_{m2} & \cdots & X_{mn} \end{array} \quad \text{------------------(1)}$$

Where ‗i‘ is the criterion index (i = 1 . . . m); m is the number of potential sites and ‗j‘ is the alternative index (j= 1 . . . n). The elements C1, C2…, Cn refer to the criteria: while L1, L2…, Ln refer to the alternative locations. The elements of the matrix are related to the values of criteria i with respect to alternative j.

Step 2: Calculate a normalised decision matrix

The normalized values denote the Normalized Decision Matrix (NDM) which represents the relativeperformance of the generated design alternatives.

$$NDM = R_{ij=} \frac{X_{ij}}{\sqrt{\sum_{i=1}^{m} X^2{}_{ij}}} \quad \text{---------------(2)}$$

Step 3: Determine the weighted decision matrix

Not all of the selection criteria may be of equal importance and hence weighting were introduced from AHP (Analytical Hierarchy Process) technique to quantify the relative importance of the different selection criteria. Theweighting decision matrix is simply constructed by multiply each element of each column of the normalized decision matrix by the random weights.

$$V = V_{ij} = W_j \times R_{ij} \text{ -------------------(3)}$$

Step 4: Identify the Positive and Negative Ideal Solution

The positive ideal (A+) and the negative ideal (A-) solutions are defined according to theweighted decision matrix via equations (4) and (5) below.

$PIS = A^+ = \{V_1^+, V_2^+, \ldots\ldots, V_n^+\}$,where: V_j^+ ={(maxi(V_{ij}) if j $\in$ J);(mini V_{ij} if j $\in$ J')} -------(4)

$NIS = A^- = \{V_1^-, V_2^-, \ldots\ldots V_n^-\}$, where V_j^- ={(mini(V_{ij}) if j $\in$ J);(maxi V_{ij} ifj $\in$ J')} -------(5)

Where, J is associated with the beneficial attributes and J' is associated with the non-beneficial attributes.

Step 5: Calculate the separation distance of each competitive alternative from the ideal and non-idealsolution.

$$S^{+} = \sqrt{\sum_{j=1}^{n}(V_j^{+} - V_{ij})^2} \qquad \text{i = 1,...., m --------- (6)}$$

$$S^{-} = \sqrt{\sum_{j=1}^{n}(V_j^{-} - V_{ij})^2} \qquad \text{i = 1,...., m --------- (7)}$$

Where, i = criterion index, j = alternative index.

Step 6: Measure the relative closeness of each location to the ideal solution.

For each competitivealternative the relative closeness of the potential location with respect to the ideal solution is computed.

$$C_i = S_i^{-}/(S_i^{+} + S_i^{-}), 0 \leq C_i \leq 1 \text{ ---------------(8)}$$

Step 7: Rank the preference order

According to the value of the C_i higher the value of the relative closeness, the higher the ranking orderand hence the better the performance of the alternative. Ranking of the preference in descending order thus allows relatively better performances to be compared.

5.Conclusion:

There is no doubt that many real life problems can be dealt with as MCDM problems. Although the mathematical procedures for processing the pertinent data are rather simple, the real challenge is in quantifying these data. This is a non trivial problem. In matter of fact, it is not even a well defined problem. For these reasons, the literature has an abundance of competing methods. The main problem is that often nobody can know what is the optimal alternative. Operations research provides a systematic framework for dealing with such problems.

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