



Ranking Models for Decisions that Allow Attribute Trade-offs – MAUT and AHP

An Online Continuing Education Course for Engineers

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Ranking Models for Decision that Allow Attribute Trade-offs – MAUT and AHP

Deandra T. Cassone, PhD, PMP

1.0 Introduction

In corporate or government decision making, there typically are a number of attributes or characteristics associated with the alternatives that are presented for a decision. In many circumstances, these alternatives need to be screened or ranked. There are a number of different approaches and methods that can be used to capture the decision environment and provide structure to the decision-making process.

This course addresses decision making circumstances where the decision-maker is permitted to trade-off attribute values. In these models, changes in one attribute or the weighting associated with that attribute can be offset with changes in any other attribute. With models such as these, a single number is usually assigned to each multidimensional characterization representing an alternative.

This course will address two methods, the Analytic Hierarchy Process (AHP) method and the Multiple Attribute Utility Theory (MAUT) method. Both of these methods are used in industry, the government, and the military. We will discuss the theory and application of these methods in this course.

Topics discussed in this course include the following:

- Multiple Criteria Decision Making (MCDM) problems
- Compensatory decision models
- Construction of the decision matrix
- The theory behind the Analytic Hierarchy Process (AHP)
- Application of the Analytic Hierarchy Process (AHP)
- The theory behind Multiple Attribute Utility Theory (MAUT)
- Application of Multiple Attribute Utility Theory (MAUT)
- A comparison of these methods is also presented in this course

Courses that discuss other methods have been developed for PDHEngineer.com. The author of this course encourages students to explore a variety of methods to assist them in their decision-making processes.

1.1 Multiple Criteria Decision Making

Decisions that rank alternatives based on several criteria measured with subjective and objective data are best modeled by multiple criteria decision-making methodologies. There is a large number of methods and variations of the methods that can be used to rank alternatives. Each method and its variation processes the data that is typically structured in a decision matrix in a different manner. Each of these methods has strengths and may be applied in different decision environments. Due to the nature of how these methods handle the data, they may position certain alternatives being higher ranking alternatives, based on how the processing occurs. As part of understanding the various

methods, it is also important to understand the nature of the computations and how certain alternatives may be more favorable, based on the method chosen.

Additionally, the data used in the decision is very important in the overall decision process. Subjective data is typically forward-looking when compared to objective data, which is historical or looking back. If some objective or historical data are readily available, this can be analyzed with statistics and used, along with the subjective data that is generated with expert opinion and used as input to the model.

Examples of multiple criteria decision-making models may include the following:

- Selection of executives for promotion or retirement based on performance, evaluation criteria, and the needs of the organization.
- Ranking critical items for the military based on their contributions to operation plans, readiness, sustainability, and availability.
- Selecting products to keep or delete in a product line based on sales volume, future potential sales, strategic importance, and their impact on operations.

If the time frame for the decision to be made is longer, you can use more sophisticated models to solve the problem. Based on the business conditions, the availability of data, the condition of data, the number of objectives of key decision-makers, and the organization's goals, you can combine methods to develop the model.

2.0 Multiple Attribute Decision-Making Problems

Decision-makers often deal with problems that involve multiple, usually conflicting criteria. These problems may involve personal decisions such as what or home to buy or may involve large scale decisions such as what products to produce in a company, which research and development projects to fund, and so on. Within industry, government, and the military, individuals are making these types of decisions on a daily basis. Multiple Attribute Decision Making refers to making preference decisions over the available alternatives that are characterized by multiple, usually conflicting attributes. Multiple Attribute Decision Making is part of a larger category of problems, Multiple Criteria Decision Making (MCDM) which includes the category of Multiple Objective Decision Making (MODM). The nature of MODM problems differs somewhat from MADM problems in their form and structure. In that MODM problems involve designing the best alternative given a set of conflicting objectives. An MODM problem involves developing a model that has conflicting objectives subject to resource constraints and will allow for an infinite number of design possibilities. This course addresses MADM problems and presents some useful methods to solve those problems.

Multiple Attribute Decision-Making models rank alternatives based on several criteria measured with subjective and objective data. These decisions are made with attributes (criteria) and alternatives (choices) that represent the key considerations that are made. One important aspect of these decision-making problems is that both objective and subjective data can be used in solving the problem. Subjective data is typically forward-looking and represents the expert's opinion on the descriptive features of the attribute. Objective data, which is typically historical in nature, is usually the type of data

you may find in a corporate database, analytical sources, and raw data information that describes the status of the attribute in relation to the alternative being evaluated.

Other features of the multiple attribute decision-making problem include an attribute hierarchy, conflict among criteria, a hybrid nature, uncertainty, a large-scale problem, an ideal-solution, a non-dominated solution, a satisfying solution, and preferred solution. For more information with regards to the background and definition of MADM problems, please refer to the PDHengineer course Characteristics of Ranking Problems with Multiple attributes.

2.1 Non-Compensatory and Compensatory Decision-Making Methods

Multiple attribute decision-making problems, or problems that rank alternatives, fall into two broad categories of methods. The first category is non-compensatory, which means that trade-offs between attributes are not allowed in selecting an alternative. Non-compensatory decision-making models are discussed in more detail in another PDHengineer course developed by this author. The second category is compensatory, where the value of one attribute can compensate for a lower value in another attribute in the alternative selection process. These methods are discussed in more detail in the following sections.

2.2 Compensatory Methods

Compensatory methods permit tradeoffs between attributes. A slight decline in one attribute is acceptable if it is compensated by some enhancement in one or more other attributes. These methods are very useful in real-world decision making. These methods fall into three general categories, with many variations in differentiation between the methods.

- Scoring Methods
- Compromising Methods
- Concordance Methods

Below is a brief definition of these three different types of compensatory methods. In this course, we will be addressing the computations associated with scoring methods Analytical Hierarchy Process (AHP) and Multiple Attribute Utility Theory (MAUT). The usefulness of these two methods makes them valuable in private and public-sector decision-making problems.

2.2.1 Scoring Methods

The scoring method selects or evaluates an alternative according to its score (or utility). Utility or score is used to express the decision maker's preference. It transforms attribute values into a common preference scale such as [0,1] or [1,5] so that comparisons between different attributes becomes possible. A very popular method in this category is the Simple Additive Weighting method (SAW). This method calculates the overall score of an alternative as the weighted sum of the attribute scores or utilities. The Analytical Hierarchy Process (AHP) is another popular method in this category. This method calculates the scores for each alternative based on pairwise comparisons. Additionally, Multiple Attribute Utility Theory (MAUT) is also a method that would be considered a scoring method.

2.2.2 Compromising Methods

The compromising method selects an alternative that is closest to the ideal solution. The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method belongs to this category. This method first normalizes the decision matrix of an MCDM problem. Then based on the normalized decision matrix, it calculates the weighted distances of each alternative from an ideal solution and a negative ideal solution. A solution relatively close to the ideal solution and far from the negative ideal solution is evaluated to be the best.

2.2.3 Concordance Methods

The concordance method generates a preference ranking, which best satisfies a given concordance measure. The Linear Assignment Method is one of the examples in this family. In this method, it is believed that an alternative having many highly ranked attributes should be ranked high. ELECTRE is also in this classification of methods.

3.0 The Decision Matrix

This section describes the decision matrix, which is used to structure and solve multiple attribute decision-making problems. The decision matrix provides a structure to capture the key aspects of the decision being considered. It also provides a standard form that can be used to apply different methods to solve the decision problem at hand. The decision matrix can be used to apply both compensatory and non-compensatory MADM methods to arrive at a solution.

3.1 Definition of the Decision Matrix

In general, there exist two distinctive types of MCDM problems. One type of problem has a finite number of alternative solutions and would be considered a multiple attribute decision-making problem and the other an infinite number of solutions, which would be considered a multiple objective decision-making problem. Normally in problems associated with selection and assessment, the number of alternative solutions is limited. In problems related to design, an attribute may take any value in a range. This means that the potential alternative solutions could be infinite. Our focus will be on the problems with a finite number of alternatives.

An MCDM problem may be described using a decision matrix. Suppose there are m alternatives to be assessed based on n attributes. A decision matrix is an $m \times n$ matrix with each element a_{ij} being the j -th attribute value of the i -th alternative. Decision criteria or attributes are represented as C_j . Importance weighting associated with the decision criteria is represented at w_j , and the alternatives under consideration are represented by A_i . Below is a representation of the decision matrix and a brief definition of the elements of the matrix.

Weights	W_1	W_2	...	W_n
Alternatives/Criteria	C_1	C_2	...	C_n
A_1	a_{11}	a_{12}	...	a_{1n}
A_2	a_{21}	a_{22}	...	a_{2n}
...
A_m	a_{m1}	a_{m2}		a_{mn}

Criteria: A criterion or attribute is a measure of effectiveness. It is the basis for evaluation. Criteria emerge as attributes or objectives in the actual problem setting. In multiple attribute decision making, they can be viewed as performance parameters, components, factors, characteristics, and properties. An attribute should provide a means of evaluating the level of an objective. Each alternative can be characterized by a number of attributes, based on those elements that are important in the decision process.

Weights: Not all attributes are equally important when making a decision. Minimizing cost, for example, might be far more important than maximizing comfort. By assigning weights to the decision criteria or attributes, the decision-maker or team can represent their value of importance in the ultimate decision. As a note, not all decision methodologies support criteria weighting, therefore it is necessary to select a method that is representative of the types of considerations that the decision-maker or makers wish to consider.

Alternatives: Alternatives are those potential choices that a decision-maker can select based on his or her evaluation of the key aspects of the decision. You, for example, may decide to purchase a car and use a decision matrix for your evaluation process. Your alternatives are the different types of cars that you are considering, and the decision criteria or attributes are those elements that are important to you in your decision-making process.

Attribute Value for Alternatives: These values are the representation of the performance level for an alternative as it is associated with each attribute. For a given alternative, there is a scoring of each attribute to represent the value and consideration associated with the alternative. These evaluations are the data that are used in the evaluation process.

The decision matrix is the fundamental construct of the multiple attribute decision-making problem and is used as a basis for applying the numerous different types of decision-making methods that can be used to solve multiple attribute decision-making problems. The development of the attributes, alternatives, importance weighting, and data used in the decision matrix is important to developing a well-structured decision problem. Also, the development of the decision matrix is an important activity that can be used to gain consensus from the key decision-makers on the key considerations that are used in the decision process. Group decision-making techniques can be used to support this process. Group decision-making techniques are discussed in detail in another PDHengineer course developed by this author.

4.0 Analytic Hierarchy Process (AHP)

The analytic hierarchy process (AHP) is a method that helps decision-makers formalize their intuition of a complex problem using a hierarchical structure. This method forms an attribute and alternative hierarchy where comparisons of importance are developed and aggregated to arrive at a preferred alternative. The hierarchy has three levels where the top-level represents the goal. The second level represents the attributes that the goals are evaluated on, and the third level is the alternatives as they relate and compare to across the attributes. The fundamental process in this is a series of pairwise comparisons between attributes and alternatives, where an indication of the importance of one compared to another is captured and used to compute the overall preference of alternatives.

Below is a list of the general steps in the AHP process.

1. Define the problem and determine the objective of the analysis. This would include the key objective that you are trying to assess by utilizing this process. This step is extremely important to the process. You must clearly understand what you are trying to achieve in the decision process. If your goal is selected incorrectly, you will not be solving the right problem.
2. Structure the problem in a hierarchy. AHP problems use a hierarchy for the evaluation process. The top-level represents the goal or focus of the analysis. The second level represents the decision criteria or attributes that you are going to use to perform the evaluation. These attributes are important considerations that you would like to base your evaluation and selection on for your decision. The third level represents the actual alternatives that you are going to select from to achieve your objective. These alternatives should be well developed and representative of the key choices that you would like to consider in the decision-making process.
3. Construct a set of pairwise comparisons that addresses the relative importance of each element. The information gathered at the upper level is used to compare the elements at the lower level. Each alternative will be compared for its relative importance with regard to its importance. The information gathered at the upper level is used to compare the elements at the lower level. Each alternative will be compared with regard to its importance with regard to its importance.
4. Use the priorities to determine the overall priority. The weighted values are added until the final priority is obtained. To make comparisons between one alternative or attribute and another, a pairwise comparison is made between the two attributes or alternatives. The most important one of the two attributes or alternatives is identified. The description of the scale.

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