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International Journal of Operations Research

International Journal of Operations Research Vol. 10, No. 2, 56−66 (2013)

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Received January 2013; Revised April 2013; Accepted May 2013

Abstract **—** Multi-Criteria Decision Making (MCDM) methods have evolved to accommodate various types of applications. Dozens of methods have been developed, with even small variations to existing methods causing the creation of new branches of research. This paper performs a literature review of common Multi-Criteria Decision Making methods, examines the advantages and disadvantages of the identified methods, and explains how their common applications relate to their relative strengths and weaknesses. The analysis of MCDM methods performed in this paper provides a clear guide for how MCDM methods should be used in particular situations.

Keywords **—** Multi-criteria analysis; multi-criteria decision making; multi-criteria decision analysis, MCDA, MCDM

1. INTRODUCTION

Multi-Criteria Decision Analysis has seen an incredible amount of use over the last several decades. Its role in different application areas has increased significantly, especially as new methods develop and as old methods improve. This paper analyzes several common multi-criteria decision making (MCDM) methods and determines their applicability to different situations by evaluating their relative advantages and disadvantages. A comprehensive literature review is first performed to allow for a summary of common multi-criteria decision making methods. A review of the use of these methods and an examination of the evolution of their use over time is then performed. In addition to applying single MCDM methods to real world decisions, the progression of technology over the past couple of decades has allowed for more complex decision analysis methods to be developed. This experimentation with combined multi-criteria decision-making methods has provided a whole new approach to decision analysis. The advantages and disadvantages of twelve separate methods identified in the literature review will be discussed. Their common applications will also be examined to see if correlations can be drawn between the use of a given method and its advantages and disadvantages. The conclusion of the paper will reveal that certain MCDM methods are better suited for specific situations, while other applications should avoid certain methods altogether.

2. LITERATURE REVIEW AND ANALYSIS OF METHODS

The literature review examined scholarly literature pertaining to decision analysis. In order to identify those articles that provided the most valuable information, a search was conducted for common MCDM methods in title, abstract, and keywords utilizing the following databases: Elsevier, Springer, ScienceDirect, and IEEExplore. These included journal articles and conference proceedings concentrating mainly on the areas of operations research and management science. These were narrowed down to articles that focused on application of popular MCDM approaches. Each paper was grouped by its MCDM technique and reviewed thoroughly. The following eleven MCDM methods were identified throughout the review: 1) Multi-Attribute Utility Theory, 2) Analytic Hierarchy Process, 3) Fuzzy Set Theory, 4) Case-based Reasoning, 5) Data Envelopment Analysis, 6) Simple Multi-Attribute Rating Technique, 7) Goal Programming, 8) ELECTRE, 9) PROMETHEE, 10) Simple Additive Weighting, and 11) Technique for Order of Preference by Similarity to Ideal Solution. The following sections address each particular method first with a summary and discussion of the reviewed studies, and then follow with a brief discussion of the general approach and an examination of the advantages and disadvantages of each method.

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2.1 Multi-Attribute Utility Theory (MAUT)

2.1.1 Literature Review

Multi-Attribute Utility Theory (see Fishburn, 1967; Keeney, 1974, 1977) was the most commonly utilized MCDM method identified in this study. MAUT is essentially an extension of Multi-Attribute Value Theory (MAVT) (see Keeney, 1974) and is "a more rigorous methodology for how to incorporate risk preferences and uncertainty into multi criteria decision support methods" (Loken, 2007, p. 1587). Earlier research in MAUT compared it to then-current MCDM methods. Siskos, Wascher, and Winkels (1983), for example, summarized outranking methods in decision making as well as Multiple Attribute Utility Theory. They presented the ELECTRE I method and provided a brief comparison to MAUT.

In the last decade, it has become commonplace for research to utilize MAUT to assist decision analysis in real-world problems. Canbolat, Chelst, and Garg (2007) applied a MAUT model to assist in selecting the location of a global manufacturing facility. Ananda and Herath (2005) also used MAUT in a real-world application to analyze risk preferences with regards to forest land-use in Australia. MAUT was utilized due to its common use in natural resource management problems. Their approach centered around societal risk preferences and they utilized a survey to obtain and examine desirable attributes. Gomez-Limon, Arriaza, and Riesgo (2003) utilized multi-criteria decision making analysis in regards to risk aversion. They utilized MAUT to address risk aversion coefficients, and their results in comparison to how risk was originally handled appeared to vary widely. The use of multi-criteria decision analysis allowed for proper analysis of all risks, an examination of where previous effort had been applied, and a focus on large gaps in the industry's risk assessment. Kailiponi (2010) used MAUT to assist with evacuation decisions that emergency managers are put in place to deal with. The Evacuation Responsiveness by Government Organizations (ERGO) project was put together by the European Commission sought to put together a model for evacuations. The model specifically addressed storm surge scenarios and, by utilizing Multi-Attribute Utility Theory, identified levels where evacuation actions were to be taken by emergency managers. Data was collected from input from emergency managers across eight different countries in Europe. The use of MAUT allowed emergency managers to understand and weigh values properly when preparing to make decision in emergency situations. Their model allowed for the analysis of evacuation policies and possible construction of training scenarios.

Technology has also evolved to allow complex problems to be addressed with relative ease. The use of decision support systems (DSS) utilizing a MAUT method, as well as other MCDM methods, has seen increasing use with relative success. Loetscher and Keller (2002) developed a model using MAUT incorporating technical, socio-cultural and institutional criteria for decisions about implementability and sustainability. They streamlined this model using a decision support system called SANEX, and applied it within a developing country in Malakasari, a suburb in Jakarta. Wang, Wee, and Ofori (2002) utilized MAUT in developing a DSS for the selection of a dewatering system. Their paper identified seven parameters for proper selection and displayed the model in an example focused on the construction of a temple in Singapore.

The newest trend with respect to MCDM method use is to combine two or more methods to make up for shortcomings in any single particular method. Although not exclusive to use of MAUT with other methods, MAUT features prominently in several combined methods. Konidari and Mavrakis (2007) utilized several methods to evaluate climate change mitigation policy instruments. In addition to utilizing Analytic Hierarchy Process (AHP), which will be discussed in the next section, to define coefficients for criteria, they used a combination of MAUT and a Simple Multi-Attribute Ranking Technique (SMART) process to assign grades to the instruments. Zabeo *et al.* (2011) assessed the risk and vulnerability of soil contamination in Europe by selecting a vulnerability assessment framework. They did this by combining multi-criteria decision analysis techniques (MAUT/MAVT) and spatial analysis.

2.1.2 Literature Review

MAUT is an expected utility theory that can decide the best course of action in a given problem by assigning a utility to every possible consequence and calculating the best possible utility (Konidari and Mavrakis, 2007). The major advantage of MAUT is that it takes uncertainty into account. It can have a utility assigned to it, which is not a quality that is accounted for in many MCDM methods. It is comprehensive and can account for and incorporate the preferences of each consequence at every step of the method. This amount of accuracy is convenient, however it can lead to many possible disadvantages. An incredible amount of input is necessary at every step of the procedure in order to accurately record the decision maker's preferences, making this method extremely data intensive. This level of input and amount of data may not be available for every decision-making problem. The preferences of the decision makers also need to be precise, giving specific weights to each of the consequences, which requires stronger assumptions at each level. This can be difficult to precisely apply and can be relatively subjective. Common applications of MAUT lean heavily on its major strength, which is its ability to take uncertainty into account. MAUT has seen heavy application in economic, financial, actuarial, water management, energy management, and agricultural problems. All of these types of problems have significant amounts of uncertainty and enough available data to make MAUT a proper method of decision-making.

2.2 Analytic Hierarchy Process (AHP)

2.2.1 Literature Review

A method similar in popularity to MAVT/MAUT is the Analytic Hierarchy Process (see Saaty, 1980). For MAUT and AHP, "the two methods rest on different assumptions on value measurements and AHP is developed independently of other decision theories…The major characteristic of the AHP method is the use of pair-wise comparisons, which are used both to compare the alternatives with respect to the various criteria and to estimate criteria weights" (Loken, 2007, p. 1587). AHP was quite common in the literature reviewed during this study. Like MAUT, most early research sought to compare it with other MCDM methods of the time. Lai (1995) examined AHP and its similarities to MAUT. He proved a theorem that the two multi-attribute decision making techniques resulted in a consistent preference structure. The focus of the paper was to provide a language that easily compared techniques and provided a scaling technique that was "designed to incorporate both MAUT and AHP into a common logic" (Lai, 1995, p. 459). Leung *et al.* (1998) address decision making within the Hawaii's pelagic fisheries using AHP. The AHP method, even with considerable variation among questionnaires used to create its input data, was able to successfully weight criteria important for sustaining fisheries and resulted in alternative rankings similar to successful rankings in the past. Bentes *et al.* (2012) examine a telecommunications company in Brazil and assess its organizational performance using AHP to prioritize performance perspectives and indicators. AHP is used in combination with the Balanced Scorecard (BSC), a framework for performance assessment, to properly rank alternatives. BSC specifically assesses organizational performance from multiple distinct perspectives. This framework revealed the associated necessary criteria and alternatives and AHP was used for comparisons, weighting, and rankings. With four criteria and three alternatives, AHP was able to handle the multiple measures and perspectives. Although limitations, like self-assessment bias affecting internal validity, were certainly present in this application, the paper concluded that the combination of methods led to a ranking of organizational performance that was far superior to previous methods. Lee *et al.* (2012) evaluated factors and alternatives of Technology Transfer Adoption to approve profitability using AHP to properly weight seven factors and rank three alternatives.

The development of AHP and its role in MCDM analysis followed a similar path to MAUT as it saw increased use in examples from real-world applications. Okeola & Sule (2012) used AHP to study urban water supply systems in Nigeria. This was also seen when Ambrasaite, Barfod, and Salling (2011) presented a way to utilize a combination of multi-criteria decision analysis and cost-benefit analysis for risk analysis in transport infrastructure appraisals. AHP was utilized in order to assess the various non-monetary criteria. Risk analysis was used to address shortcomings in the multi-criteria decision analysis in weighting the criteria. This was then applied to a railway line in the Baltic countries and Poland. This used a combination method, but in this instance sought to use the cost-benefit analysis to address deficiencies in multi-criteria decision analysis, an evolution similar to that of MAUT.

Like the relationship between MAUT and MAVT, the analytic network process (see Saaty, 2006) is an extension of AHP. ANP is essentially the general form of AHP and is nonlinear, as opposed to AHP, which "is hierarchical and linear with the goal at the top and the alternatives at the lower levels" (Wang, 2012, p. 931). ANP has become a popular MCDM method in the last couple of years and has seen heavy utilization in combination with other methods. Wang (2012) proposed a hybrid multi-criteria decision-making model combining Analytic Network Process (ANP) and decision making trial and evaluation laboratory technique (DEMATEL). Utilizing this hybrid method, Wang applied a framework of decision making to international trade practices in Taiwan. Tsai *et al.* (2010) take this one step further, although not directly building upon Wang's research, in which they combine ANP, DEMATEL, and zero-one goal programming (ZOGP). They use this method to apply to a sourcing decision about keeping IT functions in-house or contracting to a third party provider. Due to certain shortcomings in AHP, which will be described in the next section, ANP has seen increased use, especially in combination with other MCDM methods.

2.2.2 Overview and Analysis

AHP is "a theory of measurement through pairwise comparisons and relies on the judgments of experts to derive priority scales" (Saaty, 2008, p. 83). It is one of the more popular methods of MCDM and has many advantages, as well as disadvantages. One of its advantages is its ease of use. Its use of pairwise comparisons can allow decision makers to weight coefficients and compare alternatives with relative ease. It is scalable, and can easily adjust in size to accommodate decision making problems due to its hierarchical structure. And although it requires enough data to properly perform pairwise comparisons, it is not nearly as data intensive as MAUT. The method has experienced problems of interdependence between criteria and alternatives. Due to the approach of pairwise comparisons, it can also be subject to inconsistencies in judgment and ranking criteria and it "does not allow [individuals] to grade one instrument in isolation, but in comparison with the rest, without identifying weaknesses and strengths" (Konidari and Mavrakis, 2007, p. 6238). One of its biggest criticisms is that the general form of AHP is susceptible to rank reversal. Due to the nature of comparisons for rankings, the addition of alternatives at the end of the process could cause the final rankings to flip or reverse. AHP has seen much use in performance-type problems, resource management, corporate policy and strategy, public policy, political strategy, and planning. Resource management problems take away the disadvantage of rank reversal by having a limited number of alternatives to begin with. AHP's ability to handle larger problems makes it ideal to handle problems that compare performance among alternatives. But problems where alternatives are commonly added would do well to avoid this method.

ANP can be considered the general form of AHP (Saaty, 2006) and is more concerned with network structure. In terms of advantages, it allows for dependence and includes independence. It has the ability to prioritize groups or clusters of elements. It can better handle interdependence than AHP and "can support a complex, networked decision-making with various intangible criteria" (Tsai *et al.*, 2010, p. 3884). Its major disadvantage, in addition to those associated with AHP, is that "it ignores the different effects among clusters" (Wang, 2012, p. 931). ANP is often utilized in project selection, product planning, green supply chain management, and optimal scheduling problems. Many of these problems have the interdependence among criteria that AHP normally does not handle well. It can also prioritize the groupings involved in project selection and scheduling problems.

2.3 Fuzzy Theory

2.3.1 Literature Review

Fuzzy Theory (see Zadeh, 1965) has existed now for several decades. Fuzzy logic itself has proven to be an effective MCDM method. Khadam and Kaluarachchi (2003) addressed the use of cost-benefit analysis as the primary method for decision analysis when addressing environmental projects. They indicated that cost-benefit analysis has its limitations and proposed several risk assessment techniques and even applied a ranking procedure methodology to a project consisting of addressing contaminated groundwater. They then explored "three potential methods for alternative ranking, a structured explicit decision analysis, a heuristic approach of importance of the order of criteria, and a fuzzy logic approach based on fuzzy dominance and similarity analysis" (Khadam and Kaluarachchi, 2003, p. 683). Balmat *et al.* (2011) provided a different approach to risk assessment in response to an increase in marine accidents according to the International Maritime Organization. They identified three common risk factors through a new marine risk assessment system that sought to address decision making through a fuzzy method. Using this method was simply a reaction to an increase in the number of marine accidents and the use of the fuzzy method has allowed for a refinement of their management of risk. This type of use exemplifies why a fuzzy method is still popular and effective in multi-criteria decision analysis. Esogbue, Theologidu, & Guo (1992) tackle decisions in water resource planning by applying fuzzy set methodologies. By incorporating measures that are both structural and non-structural, they are able to provide a model that assists on both local and national levels. Their model is then able to provide a method of ranking actions by their ability to reduce flood damage from recurrent floods.

After selecting and evaluating suppliers, allocating orders to those suppliers is the next step in supply chain management. Haleh and Hamidi (2011) apply a model using fuzzy techniques to assess and rank the allocation of orders to suppliers. Much of the information in this part of supply chain management remains vague, which plays to the strengths of a fuzzy method. They were able to rank the allocation of orders over the course of the year, as well as over portions of the year.

2.3.2 Overview and Analysis

Fuzzy set theory is an extension of classical set theory that "allows solving a lot of problems related to dealing the imprecise and uncertain data" (Balmat, 2011, p. 172). It has many advantages. Fuzzy logic "takes into account the insufficient information and the evolution of available knowledge" (Balmat, 2011, p. 172). It allows imprecise input. It allows for a few rules to encompass problems with great complexity. For disadvantages, fuzzy systems can sometimes be difficult to develop. In many cases, they can require numerous simulations before being able to be used in the real world. Fuzzy set theory is established and has been used in applications such as engineering, economic, environmental, social, medical, and management. Many of these types of problems take advantage of the availability of imprecise input. These types of applications favor a method that embraces vagueness and can be tested numerous times before real-world application.

2.4 Case-Based Reasoning (CBR)

2.4.1 Literature Review

There are two popular methods for distinguishing between companies in financial distress and those in healthy financial situations: human preference-oriented prediction and data-oriented prediction. Li and Sun (2008) provide a new method for predicting financial distress in companies one year prior to actual distress using case-based reasoning (CBR). The data came from the Shanghai and Shenzen Stock Exchanges in China. CBR compared three separate models using Manhuttan distance, Euclidian distance, and inductive method and compared these results to a ranking-order case-based reasoning model (ROCBR). ROCBR uses the ranking-order information to produce similarities between historical cases and the target case. ROCBR performed better than the other three separate models utilizing CBR.

Daengdej, Lukose, and Murison (1999) propose a hybrid algorithm using case-based reasoning to produce acceptable solutions in vehicle insurance claims. Data in claims for vehicle insurance can be largely inconsistent, which can result in unpredictable and unacceptable answers. Case-based reasoning alone would provide these types of answers but its process is the most appropriate for problems with a large database like that in the insurance realm. A hybrid algorithm is proposed utilizing statistical methods to compensate for CBR's "sensitivity to inconsistency in data" (Daengdej, Lukose, & Murison, 1999, p. 239). This new system was successful in generating results close to the currently used system with less susceptibility to inconsistencies. Although successful, results still need to be evaluated by human-experts.

At the beginning stages of ship design, when proposals are still being conceived, designers often use older design and construction plans as part of the proposal to adequately convey the simple plan for the proposed design. Kowalski *et al.* (2005) utilize CBR to find existing designs to best match with early design requirements. This is applied specifically to engine room monitoring and automation systems design. This method was found to be successful not only at the early proposal stage, but also during the actual detailed design. Fuzzy logic is used to verify the results.

2.4.2 Overview and Analysis

CBR is a MCDM method that retrieves cases similar to a problem from an existing database of cases, and proposes a solution to a decision-making problem based on the most similar cases (Daengdej, Lukose, and Murison, 1999). This provides the first of its advantages, which is that it requires little effort in terms of acquiring additional data. It also requires little maintenance as the database will already be existing and requires little upkeep. One major advantage that it has over most MCDM methods is that it can improve over time, especially as more cases are added to the database. It can also adapt to changes in environment with its database of cases. Its major drawback is its sensitivity to inconsistency in data (Daengdej, Lukose, & Murison, 1999). Previous cases could be invalid or special cases may results in invalid answers. Sometimes similar cases may not always be the most accurate in terms of solving the problem at hand. CBR is used in industries where a substantial number of previous cases already exist. This includes comparisons of businesses, vehicle insurance, medicine, and engineering designs. Insurance bases its entire industry on previous cases which is similar to much of medicine. Engineering firms have plenty of previous projects to assist with certain problems, which favor the strengths of CBR. All of these instances have set stockpiles of "databases" which can be large enough in size to combat inconsistency in cases.

2.5 Data Envelopment Analysis (DEA)

2.5.1 Literature Review

Hermans, Brijs, Wets, and Vanhoof (2009) assess indicators in different countries for road safety performance. Data envelopment analysis (DEA) is used to provide policy makers of any country with a model to aid in prioritizing actions to improve the safety of their respective roadways in the most efficient ways possible. By obtaining data from 21 separate countries for a number of indicators, a model was able to successfully score each country's efficiencies. They found that the enormous amount of information that was used as input in the model made the process difficult. They decided that although more indicators would make the model more accurate in assessing efficiencies, it still proved to be valuable by including the best available indicators. Chauhan, Mohapatra, and Pandey (2006) examine the efficiencies of individual rice farmers in West Bengal, India using data envelopment analysis. They were able to identify wasteful methods of using energy by ranking farmers from most efficient to least efficient, and by assessing how the least efficient utilized their energy. They were then able to propose a method of using energy that could save most farmers energy in running their respective farms.

Chen, Larbani, and Chang (2009) presented a new linear programming problem for computing the efficiency of a decision-making unit (DMU). The model deviates from the objective function commonly seen in traditional Data Envelopment Analysis (DEA) and is based on "the difference between inputs and outputs instead of the outputs/input ratio" (Chen, Larbani, and Chang, 2009, p. 1556). They essentially provide a new approach for creating common weights in DEA "referring to the non-inferior solution set in MOLP, rather than from a single DMU perspective" (Chen, Larbani, and Chang, 2009, p. 1564). They conclude by presenting a real-world application of the revised approach to the research and development efficiencies of companies in the thin film transistor liquid-crystal display (TFT-LCD) industry in Taiwan. The application proved to have results similar to the rankings of other common weight models but did not require "the predetermination of weights for each DMU" (Chen, Larbani, and Chang, 2009, p. 1564) providing for a revised version of the traditional DEA approach.

Kuah and Wong (2011) used data envelopment analysis to assess the teaching and research efficiencies of 30 separate universities by examining 16 inputs and outputs. The study used a hypothetical model and the most essential inputs and outputs to successfully rank the overall efficiencies of the universities. Sowlati, Paradi, and Suld (2005) point out that bigger organizations have the ability to incorporate development information systems projects into their budgets. Deciding between the competing projects has been a continual concern in terms of choosing projects that will be successful and relatively cost efficient. They apply a model using a data envelopment analysis framework to rank the efficiency of projects at a large financial institution. They found the model to be quite successful in ranking the projects while allowing for new projects to be included at any time without altering the ranking order.

2.5.2 Overview and Analysis

DEA uses a linear programming technique to measure the relative efficiencies of alternatives (Thanassoulis, Kortelainen, and Allen, 2012). It rates the efficiencies of alternatives against each other, with the most efficient alternative having a rating of 1.0, with all other alternatives being a fraction of 1.0. It has a number of advantages. It is capable of handling multiple inputs and outputs. Efficiency can be analyzed and quantified. It can uncover relationships that may be in hidden with other methods. An important disadvantage is that does "not deal with imprecise data and assumes that all input and output data are exactly known. In real world situations, however, this assumption may not always be true" (Wang, Greatbanks, and Yang, 2005, p. 348). The results can be sensitive depending on the inputs and outputs. DEA is used wherever efficiencies need to be compared. This is commonly used in economic, medical, utilities, road safety, agriculture, retail, and business problems. These categories are especially useful because they have precise data that could be utilized for input, which bypasses one of the method's major deficiencies.

2.6 Other Methods

2.6.1 Literature Review

Other MCDM methods were identified during this study but were not nearly as common as MAUT, AHP, ANP, fuzzy methods, CBR, and DEA. Mukherfee and Bera (1995) examine a similar case of selecting projects, but in this case in the Indian mining industry. They decided to apply goal programming techniques to a coal mining company, Indian Mines Limited. Being a large company, contributing "more than 90% of national coal production" (Mukherfee and Bera, 1995, p. 18) in the industry, ranking of large-scale projects is paramount in ensuring profitability in the company. They were able to effectively rank eight projects, providing the company, and the industry, with a solution for their investment decision problem. Outranking methods were observed in comparison with other MCDM methods, such as MAUT, by Siskos, Wascher, and Winkels (1983). They were also used by Qin *et al.* (2008), who in total used three techniques: Simple Additive Weighting (SAW), ELimination and Choice Translating REality (ELECTRE), and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) within a developed expert system they named MAEAC (MCDM-based expert system for adaptation analysis under changing climate). They utilized this system to address decisions in water resource management in the Georgia Basin in Canada and its relationship with climate change. TOPSIS proved to be useful when combined with a fuzzy approach, as demonstrated by Kim *et al.* (2013). They utilized a fuzzy TOPSIS approach to prioritize the best locations for treated wastewater (TWW) in South Korea using technical, social, economic, and environmental factors. The uncertainty of weighting values and input were considered through individual interviews. Incorporating a fuzzy approach was ideal for addressing the complexity of the ranking problem, which analyzed both water quantity and water quality for ten separate sites. The complexity of the problem created the need to account for any number of uncertainties or imprecise data that arose during the simulations and ranking procedures. A weighting sum method was also applied concurrently to the problem to compare and contrast the results and to give insight on whether incorporating a fuzzy approach had any significant impacts on the resulting rankings. The final rankings using the fuzzy TOPSIS approach were similar to the rankings produced using the weighting sum method. This result showed that the new framework could produce legitimate results and rankings close to identifying the ideal solution while still accounting for uncertainty and imprecise data.

2.6.2 SMART

SMART is one of the simplest forms of MAUT. It requires two assumptions, namely "utility independence and preferential independence" (Chen, Okudan, and Riley, 2010, p. 666). This method conveniently converts importance weights into actual numbers. Major advantages of SMART, in addition to those described in MAUT, are that it is simple to use and it actually allows for any type of weight assignment techniques (i.e., relative, absolute, etc.). It requires less effort by decision makers than MAUT. It also handles data well under each criterion. Like MAUT, a disadvantage is that the "procedure for determining work is not convenient considering the complicated framework" (Konidari and Mavrakis, 2007, p. 6238). SMART's common applications are in environmental, construction, transportation and logistics, military, manufacturing and assembly problems. Its ease of use helps in situations where a fair amount of information is available and access to decision-makers is easy to obtain. Its simplicity appears to be what keeps this method fairly popular.

2.6.3 Goal Programming

Goal Programming is a pragmatic programming method that is able to choose from an infinite number of alternatives. One of its advantages is that it has the capacity to handle large-scale problems. Its ability to produce infinite alternatives provides a significant advantage over some methods, depending on the situation. A major disadvantage is its inability to weight coefficients. Many applications find it necessary to use other methods, such as AHP, to properly weight the coefficients. Goal programming has seen applications in production planning, scheduling, health care, portfolio selection, distribution system design, energy planning, water reservoir management, timber harvest scheduling, and wildlife management problems. Many of these applications have been used in combination with other methods to accommodate proper weighting. By doing so, it eliminates one of its weaknesses while still being able to choose from infinite alternatives. This follows a common theme where MCDM methods are most often utilized in applications that avoid most of their disadvantages.

2.6.4 ELECTRE

ELECTRE, along with its many iterations, is an outranking method based on concordance analysis. Its major advantage is that it takes into account uncertainty and vagueness. One disadvantage is that its process and outcomes can be hard to explain in layman's terms. Further, due to the way preferences are incorporated, the lowest performances under certain criteria are not displayed. The outranking method causes the strengths and weaknesses of the alternatives to not be directly identified, nor results and impacts to be verified (Konidari and Mavrakis, 2007, p. 6237). ELECTRE has been used in energy, economics, environmental, water management, and transportation problems. Like other methods, it also takes uncertainty and vagueness into account, which many of the mentioned applications appear to need.

2.6.5 PROMETHEE

PROMETHEE is similar to ELECTRE in that it also has several iterations and is also an outranking method.

> The PROMETHEE family of outranking methods, including the PROMETHEE I for partial ranking of the alternatives and the PROMETHEE II for complete ranking of the alternatives, were developed and presented for the first time in 1982. A few years later, several versions of the PROMETHEE methods such as the PROMETHEE III for ranking based on interval, the PROMETHEE IV for complete or partial ranking of the alternatives when the set of viable solutions is continuous, the PROMETHEE V for problems with segmentation constraints, the PROMETHEE VI for the human brain representation (Behzadian *et al.*, 2010, p. 199).

Its advantage is that it is easy to use. It does not require the assumption that the criteria are proportionate. The disadvantages are that it does not provide a clear method by which to assign weights and it requires the assignment of values but does not provide a clear method by which to assign those values. PROMETHEE has seen much use in environmental management, hydrology and water management, business and financial management, chemistry, logistics and transportation, manufacturing and assembly, energy management, and agriculture. PROMETHEE has been utilized for many decades and its ease of use has made it a common method as its iterations have improved.

2.6.6 SAW

SAW is "a value function is established based on a simple addition of scores that represent the goal achievement under each criterion, multiplied by the particular weights" (Qin *et al.*, 2008, p. 2166). It has the ability to compensate among criteria. It is also intuitive to decision makers. The calculation is simple and can be performed without the help of complex computer programs. It has specific disadvantages:

> 1) All the values of the criteria Ri (i=1,...,m) should be maximizing. Minimizing criteria should be transformed to maximizing ones, for example, by formula (2) before being used in the analysis. 2) All the values of the criteria Ri (i=1,...,m) should be positive. The evaluation results, i.e. the values of the criterion Sj, depend on the type of their transformation to positive values. 3) The estimates yielded by SAW do not always reflect the real situation. The result obtained may not be logical, with the values of one particular criterion largely differing from those of other criteria. (Podvezko, 2011, p. 137).

SAW has had applications in water management, business, and financial management. It is extremely simple to use and but users have applied it in limited applications.

2.6.7 TOPSIS

TOPSIS is "an approach to identify an alternative which is closest to the ideal solution and farthest to the negative ideal solution in a multi-dimensional computing space" (Qin *et al.*, 2008, p. 2166). It has numerous advantages. It has a simple process. It is easy to use and programmable. The number of steps remains the same regardless of the number of attributes (Ic, 2012). A disadvantage is that its use of Euclidean Distance does not consider the correlation of attributes. It is difficult to weight attributes and keep consistency of judgment, especially with additional attributes. TOPSIS has been used in supply chain management and logistics, design, engineering and manufacturing systems, business and marketing management, environmental management, human resources management, and water resources management. This is another method where its ease of use has kept its application popular. Many of the uses seen in the literature review had TOPSIS confirm the answers proposed by other MCDM methods. The advantage of its simplicity and its ability to maintain the same amount of steps regardless of problem size has allowed it to be utilized quickly to review other methods or to stand on its own as a decision-making tool.

3. CONCLUSION

Numerous MCDM methods have been created and utilized over the last several decades. Based on the literature reviewed, the observed advantages and advantages, as well as areas of application for each method, are summarized in Table 1. Most have seen a common pattern of improvement and evolution, such as the transition from MAVT to MAUT and, to an extent, AHP to ANP. Outranking methods, like ELECTRE and PROMETHEE, which were prevalent early on in the development of the MCDA field, were overtaken by the use of value measurement approaches such as AHP, ANP, and MAUT. In recent years, because of ease of use due to advancing technologies, combining different methods has become commonplace in MCDA. The combination of multiple methods addresses deficiencies that may be seen in certain methods. These methods, along with the methods in their original forms, can be extremely successful in their applications, but only if their strengths and weaknesses are properly assessed. Certain problems could easily utilize a method that may not be best suited to solve it. This paper assessed the more common methods of MCDM in order to benefit practitioners to choose a method for solving a specific problem. Identification of common MCDM methods and identification of strengths and weaknesses is a major step in establishing the foundation of research in this area, but it is only the first step. This research could lead to a survey of users to assess which advantages and disadvantages are more prevalent for each method. The industry could then begin to research new methods which utilize and incorporate advantages, while accounting for or altogether eliminating disadvantages.

Table 1. Summary of MCDM Methods

Method	Advantages	Disadvantages	Areas of Application
Multi-Attribute Utility Theory (MAUT)	Takes uncertainty into account; can incorporate preferences.	Needs a lot of input; preferences need to be precise.	Economics, finance, actuarial, water management, energy management, agriculture
Analytic Hierarchy Process (AHP)	Easy to use; scalable; hierarchy structure can easily adjust to fit many sized problems; not data intensive.	Problems due to interdependence between criteria and alternatives; can lead to inconsistencies between judgment and ranking criteria; rank reversal.	Performance-type problems, resource management, corporate policy and strategy, public policy, political strategy, and planning.
Case-Based Reasoning (CBR)	Not data intensive; requires little maintenance; can improve over time; can adapt to changes in environment.	Sensitive to inconsistent data; requires many cases.	Businesses, vehicle insurance, medicine, and engineering design.
Data Envelopment Analysis (DEA)	Capable of handling multiple inputs and outputs; efficiency can be analyzed and quantified.	Does not deal with imprecise data; assumes that all input and output are exactly known.	Economics, medicine, utilities, road safety, agriculture, retail, and business problems.
Fuzzy Set Theory	Allows for imprecise input; takes into account insufficient information.	Difficult to develop; can require numerous simulations before use.	Engineering, economics, environmental, social, medical, and management.
Simple Multi-Attribute Rating Technique (SMART)	Simple; allows for any type of weight assignment technique; less effort by decision makers.	Procedure may not be convenient considering the framework.	Environmental, construction, transportation and logistics, military, manufacturing and assembly problems.
Goal Programming (GP)	Capable of handling large-scale problems; can produce infinite alternatives.	It's ability to weight coefficients; typically needs to be used in combination with other MCDM methods to weight coefficients.	Production planning, scheduling, health care, portfolio selection, distribution systems, energy planning, water reservoir management, scheduling, wildlife management.
ELECTRE	Takes uncertainty and vagueness into account.	Its process and outcome can be difficult to explain in layman's terms; outranking causes the strengths and weaknesses of the alternatives to not be directly identified.	Energy, economics, environmental, water management, and transportation problems.

PROMETHEE	Easy to use; does not require assumption that criteria are proportionate.	Does not provide a clear method by which to assign weights.	Environmental, hydrology, water management, business and finance, chemistry, logistics and transportation, manufacturing and assembly, energy, agriculture.
Simple Additive Weighting (SAW)	Ability to compensate among criteria; intuitive to decision makers; calculation is simple does not require complex computer programs.	Estimates revealed do not always reflect the real situation; result obtained may not be logical.	Water management, business, and financial management.
Technique for Order Preferences by Similarity to Ideal Solutions (TOPSIS)	Has a simple process; easy to use and program; the number of steps remains the same regardless of the number of attributes.	Its use of Euclidean Distance does not consider the correlation of attributes; difficult to weight and keep consistency of judgment.	Supply chain management and logistics, engineering, manufacturing systems, business and marketing, environmental, human resources, and water resources management.

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