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Review

STATE OF ART SURVEYS OF OVERVIEWS ON MCDM/MADM METHODS

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Abstract. Decision-making is primarily a process that involves different actors: people, groups of people, institutions and the state. As a discipline, multi-criteria decision-making has a relatively short history. Since 1950s and 1960s, when foundations of modern multi-criteria decision-making methods have been laid, many researches devoted their time to development of new multi-criteria decision-making models and techniques. In the past decades, researches and development in the field have accelerated and seem to continue growing exponentially. Despite the intensive development worldwide, few attempts have been made to systematically present the theoretical bases and developments of multi-criteria decision-making methods. However, the methodological choices and framework for assessment of decisions are still under discussion. The article describes the situation with reviews of MCDM/MADM methods. Furthermore, there is a need for research to study the strengths and weaknesses of different decision-making methods.

Keywords: Multi-Criteria Decision Making (MCDM), Multiple Objective Decision Making (MODM), overview, ISI Web of Science databases.

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Introduction

Humans make decisions all the time. Decision-making is a very complex and difficult task. During the past decades, operations research (OR) has come a long way as a field that supports scientific management. OR mainly deals with model building and algorithmic optimization procedures that facilitate the analysis of complex real-world problems (Zopounidis,

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Pardalos 2010). Since von Neumann and Morgenstern (1947) and Savage (1954), this has become the dominant paradigm in decision analysis and decision support in the presence of multiple evaluation dimensions. Traditional OR techniques fit the same purpose: they maximise or minimize a utility function in the presence of constraints. Multi-Criteria Decision Making (MCDM) can be said to be both old and new part of OR, depending on one's frame of reference (Köksalan *et al.* 2011). MCDM has been one of the fastest growing problem areas in many disciplines. The central problem is how to evaluate a set of alternatives in terms of a number of criteria (Triantaphyllou 2010). Many modern researchers have considered MCDM problems. MCDM refers to making decisions in the presence of multiple, usually conflicting, criteria. The past decades have seen a dramatic increase on all main areas of MCDM:

- Formal models (algorithms, procedures and selection paradigms);
- Evaluation theories (assumptions about values or preferences and structured representations of values or preferences);
- Assessment methodologies (elicitation, estimation and scaling of individuals' preferences, utilities and subjective probabilities in MCDM situations) (Fishburn 1978).

There is no unique and well-defined methodology that one could follow step-by-step from the beginning to the end of a decision aiding process. When dealing with objects that can only be described and compared using several characteristics, aggregation is a major issue: it aims at operating a synthesis of the, usually contradictory, features of the objects, in view of achieving a goal such as choosing among the objects, rank ordering them, sorting them into categories and so on (Bouyssou *et al.* 2006).

MCDM methods cover a wide range of quite distinct approaches. MCDM methods can be broadly classified into two categories: discrete MCDM or discrete MADM (Multi-attribute Decision Making) and continuous MODM (Multi-Objective Decision Making) methods (Fig. 1). A dictionary definition of a "criterion" is "a means or standard of judging" by which one particular choice or course of action could be judged to be more desirable than another (h). Each problem has multiple, usually conflicting objectives/criteria. Each objective/criterion has a different unit of measurement. MCDM can be perceived as a process of evaluating real-world situations based on various qualitative/quantitative criteria in certain/uncertain/risky environments in order to find a suitable course of action/choice/strategy/policy among several available options (Raju, Kumar 2013).

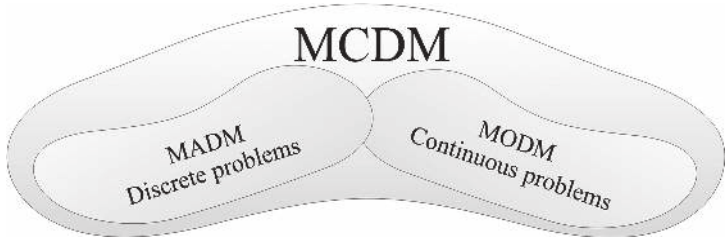

Fig. 1. Broad classification of MCDM methods

MODM methods are associated with problems where alternatives are non-predetermined and the aim of the problem under consideration is to design the best/optimal alternative by considering a set of well-defined design constraints, a set of quantifiable objectives. Thus, MODM methods deal with the design process and the number of alternatives is infinite (continuous). It is a constant challenge for designers to select the best materials and constructions to satisfy complex design problems (Jahan, Edwards 2013).

MADM art is interrelated with art of the Rational Choice Theory. It assumes that people are motivated by money and by the possibility of making a profit, and this has allowed constructing formal and often predictive models of human behaviour. They act rationally within specific given constraints and based on the information that they have about the conditions under which they are acting. Human actions involve both rational and non-rational elements (Scott 2000). Rational choice theories maintain that individuals must anticipate the outcomes of alternative courses of action and calculate that which will be best for them. As it is not possible for individuals to achieve everything they want, they must also make choices in relation to both their goals and means for attaining these goals. Rational individuals choose the alternative that is likely to give them the greatest satisfaction. Although the expected utility model has many possible founders, Von Neumann and Morgenstern (1947) are usually credited for the first axiomatic foundation of expected utility measurement. Today, the expected utility model is widely used as the normative cornerstone of decision analysis (Keeney, Raiffa 1976).

1. Main ideas of overview

Zavadskas and Turskis (2011) published a review of MCDM methods. This study looks at long known and relatively recently published methods. Liou and Tzeng (2012) published an article, which was intended to review the multi-criteria techniques that Zavadskas and Turskis (2011) did not mention in their article. Lately, Liou (2013) summarized the Tzeng's research work. Therefore, this gave rise to an idea to investigate the existing situation with reviews on MCDM/MADM methods.

Discrete MCDM/MADM methods deal with discrete and predetermined alternatives, which are described by a determined discrete criteria set. The main task is:

- Rational selection among limited number of alternatives;
- Assessment and ranking of limited number of alternatives.

Recently, hundreds of publications have been published to provide information about MCDM methods, their development and application in different fields. This article provides an overview of the publication, which provides an overview of MCDM methods. The research is based on Web of Science database, which is a part of Thomson Reuters Web of Knowledge. The 1970s was an important decade for many seminal works. Foundations of modern MCDM were developed in 1950s and 1960s. Development of MCDM researches accelerated during the 80s and early 90s, and seems to have continued its exponential growth (Köksalan *et al.* 2011). Fig. 2 provides information about this from databases of reference for review of MCDM methods and their application.

The overview provides systematically classified information on MCDM reviews. They are grouped as shown in Fig. 3:

- Books on MCDM methods (Table 2);
- Articles on multi-criteria methods in scientific journals (Table 3);
- Articles on different MCDM approaches (Table 4);
- Comparative analysis of several MCDM methods (Table 5);
- MCDM review related with individual activity topics (Table 6).

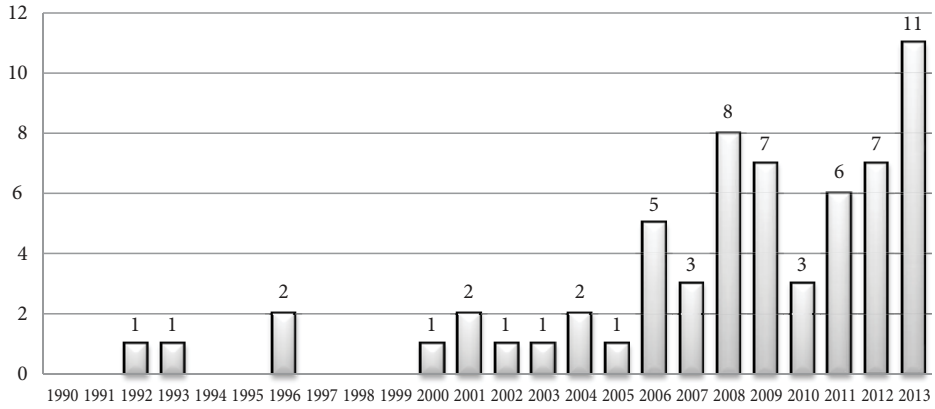

Fig. 2. Number of publications on topic: review papers on MCDM methods (based on ISI Web of Science database)

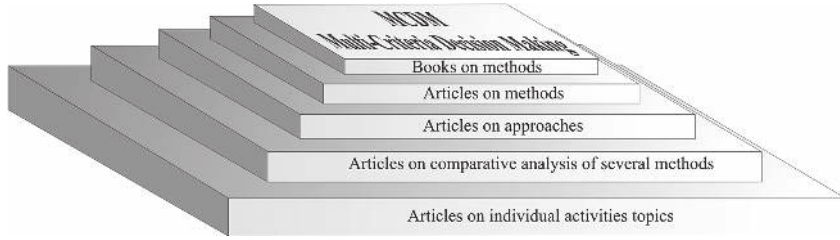

Fig. 3. Five-step pyramid of MCDM reviews

2. Main results

Table 1 provides information about the scope of the MCDM methods (Table 1). The total of 71 articles were found on the topic "MCDM review papers" in *ISI Web of Science* database (December 2013). However, there were only some articles that belonged to few different fields of the research area (Table 1).

Table. 1. Number of publications by research area MCDM review papers (from database *ISI Web of Science*)

MCDM review papers	Number of publications
Energy fuels	18
Operations research management science	17
Management	12
Environmental sciences, Ecology	10
Economics	5
Environmental sciences	5
Computer science artificial intelligence	3
Engineering Electrical Electronic	3
Biodiversity Conservation	2
Computer science information systems	2
Ecology	2
Environmental studies	2
Geography	2
Geography physical	2
Agronomy	1
Business	1
Chemistry Physical	1
Computer Science interdisciplinary application	1
Computer Science Software Engineering	1
Computer Science Theory Methods	1
Construction Building Technology	1
Engineering Civil	1
Engineering Industrial	1
Engineering Manufacturing	1
Forestry	1
Forestry	1
Health Care Sciences Service	1
Information Science Library Science	1
Mathematics Applied	1
Metallurgy Metallurgical Engineering	1
Mining Mineral Processing	1
Obstetrics Gynaecology	1
Planning Development	1
Public Environmental Occupational Health	1
Statistics Probability	1
Urban Studies	1
Water Resources	1

The book by Köksalan *et al.* (2011) provides a brief history of the development of MCDM methods. It briefly describes the development of the area from ancient to modern times. Keeney and Raiffa (1976) formulated the basics of Decision with Multiple Objectives. Hwang and Masud (1979) provided review on development of MODM methods and applications in a relatively short period of time. Later, Hwang and Yoon (1981) reviewed the MADM methods (SAW, TOPSIS, ELECTRE, LINMAP).

Saaty (1980) published a detailed study on the analytic hierarchy process (AHP). Later, Saaty (1996) published a study on the further development of the Analytic Network Process (ANP) method. Zeleny (1982) published a book, which deals with the problem of compromise theory. Hwang and Lin (1987) published a study for Group Decision Making under multi-criteria. Roy (1996) summarized the information on ELECTRE group methods. Seminal studies have been prepared by Belton and Stewart (2002), Gal *et al.* (2009), Miettinen (2009). Brauers (2004) published a study on the basis of which MOORA and MULTIMOORA methods were developed. A great job was done by Figueira *et al.* (2005), Ehrgott *et al.* (2010), editing wide studies in which well-known scientists in this area published individual studies on different classes of MCDM methods.

Valuable studies were published by Triantaphyllou (2000, 2010). Hanne (2009) and Kaliszewski (2010) published a detailed study on soft computing intelligent strategies for Meta MCDM. Apparently, this is only a part of all existing noteworthy studies.

Table 2. Books on MCDM methods

Reference	Considered problem
Keeney, Raiffa 1976	Decision with MODM
Hwang, Masud 1979	MODM methods
Saaty 1980	The analytic hierarchy process
Hwang, Yoon 1981	MADM
Zeleny 1982	MCDM
Hwang, Lin 1987	Group MCDM
Zavadskas *et al.* 1994	Multi-criteria evaluation of projects in construction
Roy 1996	Multicriteria methodology for decision aiding
Saaty 1996	Decision making with dependence and feedback
Peldschus, Zavadskas 1997	Matrix games in building technology and management
Triantaphyllou 2000	MCDM methods
Belton, Stewart 2002	Multiple criteria decision analysis
Figueira *et al.* (Eds.) 2005	Multiple criteria decision analysis
Bouyssou *et al.* 2006	Evaluation and decision models with multiple criteria: stepping stones for the analyst
Chen, Li 2006	Environmental management in construction
Kahraman 2008	Fuzzy MCDM
Gal *et al.* 2009	Multi-criteria decision making advances in MCDM models, algorithms, theory and applications
Hanne 2009	Intelligent strategies for meta MCDM
Koo 2009	Development of sustainability assessment model
Miettinen 2009	Nonlinear multi objective optimization
Ballestero, Romero 2010	MCDM and its applications to economic problems
Ehrgott *et al.* 2010	Trends in multiple criteria decision analysis
Kaliszewski 2010	Soft computing for complex multiple criteria decision making
Pedrycz *et al.* 2010	Decision-making in system project, planning, operation, and control: motivation, objectives, and basic concepts of fuzzy MCDM

Continued Table 2

Reference	Considered problem
Triantaphyllou 2010	MCDM methods: a comparative study
Zopounidis, Pardalos 2010	Multi-criteria analysis
Köksalan *et al.* 2011	MCDM
Tzeng, Huang 2011	MADM
Doumpos, Grigoroudis 2013	Recent advances in intelligent decision making and presentation of hybrid models and algorithms for preference modelling and optimisation problems
Ishizaka, Nemery 2013	Multi-criteria decision analysis
Larichev, Olson 2001	Multiple criteria analysis in strategic siting problems

A number of books have been published, which contain detailed information about the MCDM approaches in separate specific areas of research. As an outcome of the development and growing application of MCDM methods, many specific subfields have emerged. Next, some of them are named: Ballestero and Romero (2009) analysed MCDM and its application to economic problems; Peldschus and Zavadskas (1997) analysed an application of discrete matrix games theory in construction and management; Chen and Li (2006) investigated applications of MCDM techniques in environmental management of construction; Zavadskas *et al.* (1994) applied MCDM in project construction; Venkata (2007) demonstrated how the graph theory and matrix approach as well as fuzzy MADM methods can be effectively used for decision-making in various situations of the manufacturing environment; Koo (2009) presented a study on the development of sustainability assessment model.

Table 3 provides information on reviews of general methods of MCDM. Only some have been listed. A seminal study by Bragge *et al.* (2012) has been recently published, which was carried out based on bibliometric study of MCDM methods prevalence. A large-scale survey was conducted by Toloie-Eshlaghy and Homayonfar (2011). It gives an overview of about 800 links. Zavadskas and Turskis (2011) provided an overview on MCDM methods based on the traditional classification (Hwang, Yoon 1981).

Table 3. General reviews on MCDM in articles of scientific journals

Reference	Considered problem
Manouselis, Costopoulou 2007	Analysis and classification of multi-criteria recommender systems
El-Wahed 2008	Intelligent fuzzy MCDM
Chu, Lin 2009	An extension to fuzzy MCDM
Zavadskas, Turskis 2011	Multiple criteria decision making (MCDM) methods in economics
Bragge *et al.* 2012	Scholarly communities of research in multiple criteria decision making: a bibliometric research profiling study
Liou, Tzeng 2012	Multiple criteria decision making (MCDM) methods in economics
Liou 2013	New concepts and trends of MCDM
Aruldoss *et al.* 2013	A survey on multi criteria decision making methods and its applications

A number of publications can be found in regional journals, such as Alias *et al.* (2008), and several publications, which provide an overview on the theory of fuzzy MCDM applications, such as Chu, Lin (2009), El-Wahed (2008) and the analysis and classification of multi-criteria systems.

Significantly more review articles on separate MCDM methods (Table 4) have been published. Kaplinski and Tamošaitienė (2010) reviewed applications of discrete matrix game theory, Behzadian *et al.* (2010) – PROMETHEE method, and Behzadian *et al.* (2012) – TOPSIS method. Zopounidis and Doumpos (2002) conducted a review on a multi-criteria classification and sorting. Adler *et al.* (2002) reviewed the DEA method's applications. Shih (2008) conducted a review on TOPSIS group methods. Ishizaka, Labib (2011) and Ho (2008) publications were devoted to the analysis of AHP method. Jadhav and Rajendra Sonar (2009) overviewed MCDM software packages. Baležentis and Baležentis (2013) published a review article on MULTIMOORA method.

Table 4. Overview on application of different MCDM methods

Reference	Considered problem
Adler *et al.* 2002	Data Envelopment Analysis (DEA)
Zopounidis, Doumpos 2002	Multicriteria classification and sorting methods
Ho 2008	Integrated analytic hierarchy process
Shih 2008	MCDM with an application to group TOPSIS
Jadhav, Rajendra Sonar 2009	Software packages
Cook, Seiford 2009	Data envelopment analysis (DEA)
Kapliński, Tamosaitiene 2010	Game theory application
Behzadian *et al.* 2010	PROMETHEE
Ishizaka, Labib 2011	Analytic hierarchy process
Behzadian *et al.* 2012	A state-of the-art survey of TOPSIS applications
Balezentis, T., Balezentis, A. 2013	Applications of the multi criteria decision making method MULTIMOORA

A significantly greater number of publications have been devoted to comparative analysis of separate MCDM methods (Table 5). Opricovic and Tzeng (2004) conducted a benchmarking on TOPSIS and VIKOR methods. Simanavičienė and Ustinovičius (2012) provided a benchmarking on TOPSIS, SAW and COPRAS methods. Podvezko (2011) conducted a comparative study of SAW and COPRAS methods and Podviezko (2012) provided a comparative study on SAW, PROMETHEE, TOPSIS, and COPRAS methods. Albiñana and Vila (2012) conducted benchmarking on VIKOR, ELECTRE, COPRAS, and EVAMIX methods. A benchmarking MOORA, AHP, TOPSIS, VIKOR, ELECTRE and PROMETHEE methods has been provided by Chakraborty (2011). Interesting and valuable work in the field of MCDM benchmarking has been performed by Kou *et al.* (2012), Peng *et al.* (2011), Baležentis *et al.* (2012) and Stanujkic *et al.* (2012). Antuchevičienė *et al.* (2011, 2012) carried out investigation on fuzzy MCDM methods (TOPSIS, VIKOR and COPRAS) and provided a comparative analysis. A large number of valuable works has been conducted, which enables us to evaluate the positive and negative characteristics of different MCDM methods and their ability to help solving real practical problems in different areas.

Table 5. Comparative analysis of MCDM methods

Reference	Considered problem
Kou *et al.* 2012	Evaluation of classification algorithms using MCDM and rank correlation
Peng *et al.* 2011	FAMCDM
Podvezko 2011	Comparative analysis SAW and COPRAS
Antuchevičienė *et al.* 2012	Comparative analysis of FTOPSIS, FVIKOR and COPRAS-F
Antuchevičienė *et al.* 2011	Measuring congruence of ranking results applying particular MCDM methods
Opricovic, Tzeng 2004	TOPSIS and VIKOR
Simanavičienė, Ustinovičius 2012	TOPSIS, SAW, COPRAS
Chakraborty 2011	MOORA, AHP, TOPSIS, VIKOR, ELECTRE, PROMETHEE
Baležentis *et al.* 2012	VIKOR, TOPSIS, ARAS
Albiñana, Vila 2012	VIKOR, ELECTRE, COPRAS, EVAMIX
Stanujkic *et al.* 2012	Comparative analysis of some prominent MCDM methods

Table 6. MCDM review on topics of individual activities

Reference	Considered problem
Greening, Bernow 2004	Design of coordinated energy and environmental policies
Melo *et al.* 2009	Facility location and supply chain management
Moffett, Sarkar 2006	Design of conservation area networks
Ananda, Herath 2009	Forest management and planning
Diaz-Balteiro, Romero 2008	Forestry decisions
Ehrgott *et al.* 2004	Portfolio optimization
Ho *et al.* 2010	Supplier evaluation and selection
Jahan *et al.* 2010	Material screening and choosing
Xidonas, Psarras 2009	Equity portfolio management
Kaplinski, Tupenaite 2011	Modern construction economics
Wang *et al.* 2009	Sustainable energy
Kapliński, Peldschus 2011	Social science
Huang *et al.* 2011	Environmental sciences
Zavadskas *et al.* 2008	Quality in bridges and road construction
Yazdani-Chamzini *et al.* 2013	Selecting the optimal renewable energy
Tamošaitienė, Kaplinski 2013	Application of MCDM methods in social sciences
Kabir *et al.* 2013	A review of multi-criteria decision-making methods for infrastructure management

Reviews on topics of individual activities can be identified into a separate group of reviews on MCDM methods. Ehrgott *et al.* (2004), Xidonas and Psarras (2009) applied the MCDM methods to portfolio optimization and management; Jahan *et al.* (2010) – material choosing and screening; Diaz-Balteiro and Romero (2008) – forestry-related decisions; Ananda and Herath (2009) – forest management and planning. Greening and Bernow (2004) applied the MCDM methods to design of Coordinated Energy and Environmental Policy; Moffett

and Sarkar (2006) – design of conservation area networks. Kaplinski and Tupėnaitė (2011) reviewed the latest MCDM applications in modern construction economics. Wang *et al.* (2009) and Yazdani-Chamzini *et al.* (2013) reviewed MCDM applications for energy systems assessment. Kaplinski and Peldschus (2011) and Tamošaitienė and Kaplinski (2013) reviewed the applications of MCDM methods in the social sciences; Zavadskas *et al.* (2008) reviewed the applications of MCDM methods in the area of bridge and road construction; and Huang *et al.* (2011) – MCDM methods in the social sciences.

Conclusions

The paper presents synopsis of numerous publications, which describe the use of traditional MCDM methods and some of the relatively recently developed methods. However, this review does not cover recent methods that have not yet been reviewed in articles or books. However, it is worth noting that publications reviewed in this article at least allow for a partial representation of the structure of those MCDM methods, which are gaining wider use.

Recently, development of hybrid and modular methods is becoming increasingly important. They are based on previously developed well-known methods, such as TOPSIS, SAW, DEA, AHP, ANP, VIKOR, DEMATEL, DEA, PROMETHEE, ELECTRE and their modification, by applying fuzzy and grey number theory. Relatively recently developed MCDM methods, such as COPRAS, ARAS, MOORA, MULTIMOORA, SWARA and WASPAS are rapidly developed and applied to solve real life problems. In order to help researchers and practitioners interested in hybrid MCDM techniques and applications of hybrid MCDM methods, it is necessary to publish reviews on these issues in future.

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