MULTI CRTERIA DECISION MAKING AND ITS APPLICATIONS: A LITERATURE REVIEW

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Abstract : This paper presents current techniques used in Multi Criteria Decision Making (MCDM) and their applications. Two basic approaches for MCDM, namely Artificial Intelligence MCDM (AIMCDM) and Classical MCDM (CMCDM) are discussed and investigated. Recent articles from international journals related to MCDM are collected and analyzed to find which approach is more common than the other in MCDM. Also, which area these techniques are applied to. Those articles are appearing in journals for the year 2008 only. This paper provides evidence that currently, both AIMCDM and CMCDM are equally common in MCDM.

Keywords: Multiple criteria decision making, Artificial intelligence.

1. INTRODUCTION

"Multi-Criteria Decision Making (MCDM) is the study of methods and procedures by which concerns about multiple conflicting criteria can be formally incorporated into the management planning process", as defined by the **International Society on Multiple Criteria Decision Making**[132]. These multiple criteria are typically measured in different units.

In this paper, we define AIMCDM as any approach combining with artificial intelligence used in MCDM and CMCDM as any approach using classical operational research technique which does not related to artificial intelligence. In both approaches there include stand alone and combination of either standard approach or new approach. Articles in this paper are

searched through online database via Emarald, Engvillage, Gale, Sciencedirect, and Springerlink.

To guide our review, MCDM is also referred to as:

- Multiple Criteria Analysis (MCA) or Multi-Criteria Decision Analysis (MCDA)
- Multi-Dimensions Decision-Making (MDDM)
- Multi-Attributes Decision Making (MADM)

MCDM has been used as a decision analysis or decision making since 1960's following the rapid growth of operational research in WW II [137]. Today, MCDM is already an establish methodology with dozen of books, thousands of applications, dedicated scientific journals, software packages and university courses (Figueira et al. 2005) in [137].

The present study is different from Steuer and Na [135], Vaidya and Kumar [134] and Ho [133], in which AHP and its applications are reviewed. The present study also different from Diaz-Balteiro and Romero [17], in which they review and analyzed MCDM approaches on forestry, Hajkowicz and Collins [136], made a review on 113 published water management MCA studies from 34 countries. They also present a comprehensive study on review papers that has been published by 4 other researchers between year 1987 and 2004, on the use of MCDM in various fields. Whereas, in this study, 133 published MCDM articles are reviewed and gives a current used of MCDM in different applications. It can be seen as a bigger picture of MCDM usage and can be useful to both AI and non-AI researchers, students and practitioners. The study covers a wide range of MCDM currently published. The study is not an exhaustive study and many more MCDM approaches and applications are indeed exists, many would be published somewhere else. The aim of this study is to prove that now, neither AI approaches nor non AI approaches is more common. Comparative and evaluation of MCDM techniques has been made by many researchers (see for example Hajkowitcz and Collins [136] page 1554). The general finding was that there is no single MCDM technique is inherently better.

Next section presents and analyses applications of AI techniques in MCDM highlighting the most common AI techniques used in MCDM. The result from this chapter is presented in Table 1. The section also presents Classical MCDM and its applications and the result is shown in Table 2. Third section presents observation on this study. Last section is the conclusion for this study.

2. MCDM APPROACHES AND ITS APPLICATIONS

AI is a field in computer science that lend its advantages to improve MCDM performance. Researches to integrate AI and MCDM have long been done. A significant study towards the connectives of MCDM with artificial intelligence and soft computing techniques has been done, (see Zopunidis [138]). AI approaches found in this study are Fuzzy Logic(FL), Genetic Algorithm(GA), Neural Network(NN), Heuristic or meta-heuristics, Knowledge-Based(KB), Expert Systems(ES), tabu-search(meta-heuristic), Simulated-Annealing(SA), Dampster-Shafer(DS), and Self-Organizing-Map(SOM) (Table 1). Whereas, for CMCDM the commonly used MCDM tool including Analytic Hierarchy Process(AHP), Data Envelopment Analysis(DEA), ELimination Et Choix Traduisant la Realité(ELECTRE ([I,II,III]), Preference Ranking Organization MeTHod for Enrichment Evaluations(PROMETHEE([I,II,III]), Technique for Order-Preference by Similarity to Ideal Solution(TOPSIS), Multiobjective Optimization(MOP), Ordered Weighted Averaging(OWA), Mixed Integer Programming(MIP), Analytic Network Process(ANP), Decision Making Trial and Evaluation Laboratory(DAMATEL), Goal Programming(GP), Linear Programming(LP), compromise programming, weighted sum, and some other new techniques that are proposed to solve specific problem or improving existing techniques (Table 2).

Table 1 The AIMCDM approaches and their applications

Reference	Approaches	Authors	Applications	Specific area
[1]	Fuzzy logic	Tellaeche, A., et al.	Agriculture	Precision agriculture
[5]	Fuzzy AHP-CA	Bottani, E., Rizzi, A.	Manufacturing	Supplier selection
[8]	Fuzzy AHP, TOPSIS	Buyukozkan, G.,et al.	Logistic	Strategic alliance partner Selection
[9]	Fuzzy MCDM, VIKOR method	Buyukozkan, G., Ruan, D.	Management	Evaluation of ERP software products
[11]	GMCDM – Fuzzy measure and fuzzy Integral	Chen, C-T., Cheng, H-L	Management	Information system project selection
[12]	Fuzzy FMEA	Chin, K-S., et al.	Manufacturing	EPDS-1
[14]	Adaptive AHP – GA	Lin, C.-C. et al.	Management	Best value bid selection
[18]	Nature-inspired metaheuritics	Doerner, K.F., et al.	Management	Project selection
[19]	ANN and Fuzzy AHP	Efendigil, T., et. al	Management	Third-party logistics providers selection
[28]	Fuzzy mathematical programming	Gupta, P. et.al.	Management	Asset portfolio optimization
[30]	Fuzzy MCDM	Hsia, T-C. et al.	Management	Measuring RP aircraft maintenance technical orders
[31]	Fuzzy MCDM	Hung, K.-C. et al.	Manufacturing	Ranking selection
[40]	Knowledge-based, JGEA and MCDM	Ma, H. M., et al.	Control	Real-time power voltage control
[42]	Fuzzy AHP	Cascales, M. S. G., Lamata, M. T.,	Management	Maintenance decision
[49]	Fuzzy MCDM	Onut, S., et.al	Management	Supplier selection
[50]	Fuzzy MCDM	Onut, S., et.al	Management	Machine tool selection

Table 1 The AIMCDM approaches and their applications (cont.')

Reference	Approaches	Authors	Applications	Specific area
[52]	Fuzzy AHP	Pan, N.-F.	Management	Bridge construction method selection
[53]	Expert system MCDM (ELECTREE III)	Patlitzianas, K. D., et al.	Management	Formulation of Energy companies environment
[55]	MCDM expert system	Qin, X.S., et al.	Planning	Climate-change planning
[58]	Choquet-sugeno-GA	Saad, E., et al.	Management	Job-shop scheduling
[59]	Tabu search (TS) meta-heuristic	Kulturel-Konak et al.	Management	System redundancy allocation problem
[61]	Fuzzy-AHP, fuzzy-MCDM, TOPSIS	Sheu, J.-B.	Logistic	Global logistic operational mode
[63]	Fuzzy MCDM	Simonovic, S. P., Verma, R.,	Management	Waste water treatment planning
[65]	Fuzzy charquet integral	Sridhar, P. et al.	Management	Robot sensor networks
[66]	Fuzzy MCDM	Tai, W.-S., Chen, C.-T.,	Management	Intellectual capital performance
[67a][67b]	Fuzzy inference	Tay, K. M., Lim, C. P.	Management	Assessment model
[70]	Fuzzy AHP	Tsai, M. T., et. al.	Management	Service quality
[73]	Fuzzy MCDM	Wadhwa, S., et. al.	Logistic	Alternative selection
[74]	Heuristic	Gutjahr, W. J., et al.	Planning	Portfolio selection, scheduling and staff assignment
[78]	Fuzzy ANP	Wu, C. R. et al.	Construction	Selection of location
[79]	Fuzzy AHP	Wu, C. R., et al.	Management	Organizational performance
[81]	NN+GA and DOE+RSM	Wu, M. C., Chang, W. J.	Management	Trading capacity
[82]	FLMOEA	Shen, X., et al.	Control	Parameter optimization
[84]	Fuzzy MCDM	Yang, J. L., et al.	Management	Vendor selection
[85]	Fuzzy PERT+TOPSIS	Zammori, F, A., et al.	Management	Critical path identification
[86]	Fuzzy stochastic OWA	Zarghami, M., et al.	Management	Water resource management
[87]	Stochastic-fuzzy	Zarghami, M., Szidarovszky, F.	Management	Water resource management
[89]	PMSMO	Zinflou, A., et al.	Manufacturing	Industrial scheduling problem
[94]	Case-based	Chena, Y., et al.	Planning	Water supply planning
[98]	Fuzzy AHP	Huang, C. C., et al.	Management	R&D project selection
[101]	Fuzzy aggregation	Lee, D., et al.	Transportation	Driver satisfaction evaluation
[107]	PSA heuristic	Drexl, A., Nikulin, Y.	Management	Airport gate scheduling
[109]	QFD and fuzzy linear regression	Karsak, E. E.	Management	Robot selection
[110]	Fuzzy AHP	Genevois, M. E., Albayrak, Y. E.	Management	Human resource evaluation
[113]	FLP and LINMAP	Albayrak, Y. E.	Management	Knowledge management
[114]	Multiphase Fuzzy logic	Pochampally, K. K., Gupta, S. M.	Planning	Reverse supply chain network
[115]	Fuzzy AHP and BSC	Lee, A. H. I., et al.	Manufacturing	IT department performance evaluation
[116]	Fuzzy AHP	Cheng, A. C., et al.	Management	Comparison of technology forecasting method
[117]	Fuzzy AHP	Chang, C. W., et al	Management	Unstable slicing machine selection
[118]	Adaptive AHP + GA	Lin, C. C., et al	Construction	Best value bid
[119]	DS-AHP	Hua, Z., et al.	Management	Car park supplier selection
[120]	Fuzzy set + AHP	Jaber, J.O., et al.	Management	Conventional and renewable energy sources evaluation
[121]	Spatial Principal Component Analysis (SPCA) and cosine amplitude-AHP methods and a fuzzy logic technique	Maina, J., et al.	Management	Modelling susceptibility of coral reefs

Table 1 The AIMCDM approaches and their applications (cont.')

Reference	Approaches	Authors	Applications	Specific area
[122]	Fuzzy ranking method	Ma, L. C., et al.	Management	Renting an office
[123]	Fuzzy AHP + MDS	Chen, M. F., et al	Management	Finding right people
[124]	Fuzzy AHP	Dagdeviren, M., Yuksel, I.	Management	Behaviour-based safety management
[125]	Fuzzy CBR	Wu, M. C., et al.	Manufacturing	Product ideas generation
[126]	Fuzzy AHP	Nagahanumaiah, et al.	Manufacturing	Rapid tooling process selection
[127]	Fuzzy AHP	Duran, O., Aguilo, J.	Manufacturing	Machine-tool selection
[128]	EFNN	Li, S. G., Kuo, X.	Management	Automobile spare parts
[129]	Fuzzy MCDM	Chou, T. Y., et al	Management	Hotel location selection
[130]	SOM + AHP	Yan, W., et al.	Manufacturing	Bidding-oriented product conceptualization
[131]	AHP + BP NN	Bin, X., Bin, P.	Management	Supplier selection

Table 2 The CMCDM and their applications

Reference	Approaches	Authors	Applications	Specific area
[2]	AHP-ZOGP	S.M. Ali Khatami Firouzabaldi, et al.	Manufacturing	Single vehicle selection
[3]	PVRM-AHP	Dhar, A., Ruprecht, H., Vacik, H.	Management	Conservation management
[4]	EVOLVE+	Ngo-The, A., Ruhe, G.	Planning	Software release planning
[6]	EDA	Noble, B.F., Christmas, L.M.	Agriculture	Environmental assessment
[7]	Additive Utility Model and AHP	Briceno-Elizondo, E., et al.	Forest	Stand treatment programmes assessment
[10]	Screening Technique	Chen, Y. et al.	Planning	Waterloo water supply planning problem (WWSP)
[13]	DEA	Chu, M.-T, et al.	Manufacturing	Firm performance evaluation
[15]	PASA - ELECTRE	Rocha, C., Dias, L. C.,	Management	Sorting algorithm
[16]	AHP and PROMETHEE	Dagdeviren, M.	Manufacturing	Decision making in equipment selection
[20]	MOP	Madetoja, E., Tarvainen	Manufacturing	Process line optimization
[21]	Linear/mixed multi-criteria optimization	ElMaraghy,H.A., Majety, R.	Management	Integrated supply chain design
[22]	TOPSIS	Thomaidis, F., et al.	Management	Ranking selection
[23]	FPTAS	Tsaggouris, G., Zaroliagis, C.	Management	Shortest path and non-linear applications
[24]	RO and AHP	Angelou, G.N., et.al.	Management	ICT business alternatives selection
[25]	AHP	Gomontean, B., et.al.	Management	Assessment of ecological criteria and indicators
[26]	UTAGMS	Greco, S. et. al	Manufacturing	Ranking alternatives
[27]	Regret theory and PROMETHEE II	Ozerol, G., Karasakal, E.	Management	Ranking alternatives
[29]	MCA-weighted summation	Hajkowicz, S.A., Wheeler, S. A.,	Management	Dairy effluent management evaluation
[32]	ABC-123	Al Kattan, I. Bin Adi, A.	Management	Inventory system
[33]	Branch-and-bound	Fulop, J.	Management	Pairwise comparison approximation
[34]	OWA	Renaud,J. et.al.	Manufacturing	Food production
[35]	Entended-RPM	Liesio, J., et al.	Management	Product release planning
[36]	DEA	Karsak, E.E.,	Manufacturing	FMS selection
[37]	AHP	Vadrevu, K. P. Et al.	Management	Agroecosystem health quantification
[38]	AHP and TOPSIS	Kuo, Y., et al.	Manufacture	Dispatching problems
[39]	AHP	Lamelas, M. T., et al.	Management	Definition of criteria weights
[41]	Elimination method	Ma, J., et al.	Management	Transboundary water policies

Table 2 The CMCDM and their applications (cont.')

Reference	Approaches	Authors	Applications	Specific area
[43]	Weighted sum	Marangon, F., Troiano, S.	Management	Agroenvironmental policies
[44]	Multiobjective integer programming	Medaglia, A., L., et; al.	Management	Projects selection
[45]	Disjunctive and an additive weighting approach	Meyer, V., et al.	River	Flood risk mapping
[46]	Progressive methods	Meyer, P.	-	-
[47]	Smart and Efficient	Morcos, M. S.	Manufacturing	R&D project selection
[48]	MIP	Muata, K., Bryson, O.	Medical	Regression tree pruning
[51]	ANP	Onut, S., et al.	Manufacturing	Energy resources
[54]	Extended cards procedure	Pictet, J., Bollinger, D.	Management	Public procurement
[56]	PROMETHEE	Rousis, K., et al.	Management	WEEE management scenario
[57]	PROMETHEE II	Roux, O., et al.	Manufacturing	Scheduling strategies ranking
[60]	AHP	Mansar, S. L., et al.	Management	Business process redesign
[62]	Incremental analysis to Group TOPSIS	Shih, H. S.	Manufacturing	Robot selection
[64]	ELECTREE III	Labbouz, S. et al.	Transportation	Public transport line that facilitate conservation
[68]	SMAA	Tervonen, T. et al.	Management	Elevator planning
[69]	ANP	Tosun, O. K., et al.	Management	Evaluating Turkish mobile communication operators
[71]	Possibilistic linear programming	Vasant, P. M. et al.	Manufacturing	Construction industry
[72]	ELECTREE III	Ballester, V. A. C., et al.	Education	Environmental education
[75]	AIM/MAV	Wang , J., Zionts, S.	Management	Negotiation
[76]	ELECTREE and AHP	Wang, X., Triantaphyllou, E.	Management	Ranking irregularities
[77a][77b]	ANP and AHP	Wong, J., Li, H., Lai, J.,	Construction	Intelligent building systems
[80]	ANP and DAMATEL	Wu, W. W.	Management	Choosing management knowledge
[83]	RE	Xie, X., et al.	Management	Ship selection
[88]	COPRAS-G	Zavadskas, E. K., et al.	Management	Dwelling house walls selection
[90]	DEA	Adler, N., Raveh, A.	Manufacturing	Graphical presentation
[91]	MCDA	Barcus, A., Montibeller, G.	Management	Software development allocation
[92]	PROMETHEE	Beynon, M. J., Wells, P.	Manufacturing	Motor vehicle ranking
[93]	ELECTREE III	Bollinger, D., Pictet, J.	Management	Waste incineration residues
[95]	AHP	Chen, Y. W., et al.	Management	Route selection problem
[96]	ANP and MOMILP	Demirtas, E. A., Ustun, O.	Management	Supplier selection and order allocation
[97]	DEA	Eilat, H., Golany, A. S. B.	Management	R&D project evaluation
[99]	AHP	Kaka, A., et al.	Management	Pricing system selection
[100]	AHP	Katsumura, Y., et al.	Medical	Cancer screening option
[102]	AHP	Melon, M. G., et al.	Education	Educational project evaluation
[103]	DEA	Meng, W., et al.	Education	Basic research evaluation

Table 2 The CMCDM and their applications (cont.')

Reference	Approaches	Authors	Applications	Specific area
[104]	Non-numerical objective function, k-means algorithm,	Taboada, H. A., Coit, D. W.	Manufacturing	Bottleneck operation scheduling
[105]	AHP	Wang, J., et al.	Management	Data mining software comparison and scenario analysis
[106]	OWA+ reference point methodology	Ogryczak, W., et al.	Management	Bandwidth allocation
[108]	AHP	Dolan, J. G., Iadarola, S.	Medical	Patient preferences
[111]	Grey relational analysis	Chan, J. W. K.	Manufacturing	Product end-of-life options
[112]	Compromise programming	Pantouvakis, J. P., Manoliadis, O. G.	Management	Site selection

2.1 Types of MCDM techniques

Some of the major techniques encountered in this study are classified as follows:

- *Non-classical Approaches*; Fuzzy logic (45 articles), heuristics ([18], [59], [74], [89], [107], neural network ([19], [81], [131]), genetic algorithm ([13], [58], [81], [118]), experts systems ([53], [55]), knowledge-based [40], Dampster-Shafer [119], self organizing map [130] and case-based reasoning [94], [125]. Fuzzy logic has been the most popular technique in this class (Figure 2).
- *Outranking methods*; ELECTRE III ([53], [15], [72], [76], [93]), PROMETHEE (I, II, III) ([16], [27], [56], [57], [92]).
- *Multiattribute Utility and Value Theories*; AIM/MAV [35], additive utility model [7].
- *Multiobjective Mathematical Programming*; Multiobjective integer programming ([44], [48], [96], [20]),
- *Pairwise comparison*; AHP (36 articles). AHP has been the most popular method in this class.
- *Weighted summation*; Weighted sum ([29], [43], [45]).
- *Distance to ideal point*; TOPSIS ([8], [61], [85], [22], [38]), compromise programming [112], goal programming [2].
- *Tailored method.* Adaptations of existing methods or development of a new one; EVOLVE+ [4], EDA [6], screening technique [10], extended FTAS [23], UTAGMs [26], ABC123 [32], branch-and-bound [33], and etc.

Thorough and detail discussion on each of the above MCDM class is beyond the focus of this study.

2.2 Types of MCDM Applications

In this study, we found MCDM has been applied in management, manufacturing, planning, education, transportation, construction, logistic, medical, control, agriculture, river, and forest (Table 3).

Table 3 MCDM Applications

Application	Number of articles
Management	79
Manufacturing	26
Planning	6
Education	3
Not stated	1
Transportation	2
Construction	4
Logistic	3
Medical	3
Control	2
Agriculture	1
River	1
Forest	1
Total	133

The majority of MCDM applications are in management (79 articles) and manufacturing (26 articles). In management, most MCDM are used for selection, ranking and evaluation of alternatives. In manufacturing, most MCDM are used for selection and evaluation. There are 4 articles for construction. There are 3 articles for education, medical and logistic. There are 2 articles for control and 1 article each for agriculture, river, and forest. There is 1 paper that did not state the area of application since it is a summary of a PhD thesis [46].

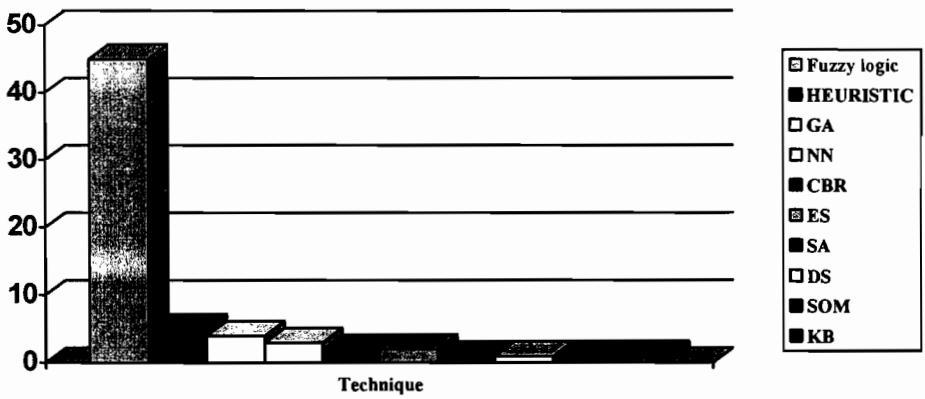
3. OBSERVATIONS

Figure 1 shows the number of articles published in 2008. There are 65 articles published for AIMCDM. On the other hand, there are 68 articles were found related to CMCDM.

Figure 1. Number of Articles in Journals

Figure 2 shows the number of articles published using specific AI technique or combination of AI technique with either new method or classical MCDM method.

Figure 2. Artificial Intelligence technique in MCDM



Among 65 articles for AIMCDM, we found 45 articles using fuzzy logic, 4 articles using genetic algorithm, 3 articles using neural network, 1 articles using self organizing map, 2 articles using case-based, 5 articles using heuristics or meta-heuristics, 1 article using simulated annealing, 1 article using dampster-shafer, 2 article using expert systems and 1article using knowledge-based. Fuzzy logic has been found the most popular AI technique used in MCDM based on the number of articles published recently.

4. CONCLUSION

The number of articles that we found in journals shows that in 2008, about the same number between AIMCDM and CMCDM were published. Based on this review, one may pursue research on either AIMCDM or CMCDM. In this study and in our previous review, M. Ashari et al. [137], we found that, fuzzy logic is the most popular AI technique used in MCDM.

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