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## MCDM/A in practice: methodological developments and real-world applications

Experts have long acknowledged that structuring complex decision problems well and considering multiple criteria explicitly in decision making lead to better, more informed decisions (Belton and Stewart, 2002). This field of research has seen important advances since the dawn of contemporary multiple-criteria decision aid studies in the early 1960s. MCDM and MCDA are now well-known acronyms for multiple-criteria decision making and multiple-criteria decision analysis, respectively. Although epistemological differences exist between these two branches of operational research/management science (cf. Roy, 1985; Roy and Vanderpooten, 1997; Ormerod, 2013; Carayannis *et al.*, 2018), both approaches share a focus on decision aid.

At the organizational and individual levels, decision problems have been complicated by an ever-greater degree of complexity, forcing decision makers to seek out for new approaches and methodologies that facilitate the processes that support decision making. In response to the increased intricacy and multiplicity of problems and challenges faced by companies and individuals, recent decision-support systems have included performance analyses and the identification of critical success factors via multiple criteria. MCDM/A techniques constitute valuable tools for structuring and evaluating complex decision situations as these tools are able to build on the knowledge of experts in a given field, producing assessment systems based on their values and experience (Keeney, 1992).

This special issue brings together recent developments and methodological contributions within the MCDM/A arena and presents real-world decision situations to which MCDM/A techniques have been applied. The 13 applications included in this special issue are diverse, wide-reaching and reflective of MCDM/A's vast potential. The contributions are related to five large fields – corporate strategy, finance, logistics, human resources management and education – which are just some examples of these techniques' potential areas of application.

The papers selected for this special issue have not been grouped based on their use of MCDM or MCDA or on the mathematical techniques that support these tools' implementation but instead by the field in which they were applied. Traditionally, MCDM/A techniques have been extremely popular in the financial sector, which is demonstrated by the first three papers. The first contribution is "The robustness of portfolio efficient frontiers: a comparative analysis of bi-objective and multi-objective approaches" by Pavlou, Doumpos and Zopounidis. This study analyzed the future performance of an entire set of efficient portfolios rather than minimum risk portfolios or other arbitrarily chosen efficient portfolios. Using data from Standard and Poor's 500 index of US stocks from 2005 to 2016, the authors conducted a thorough comparative assessment of different bi-objective models and one multi-objective model in terms of the performance and robustness of the entire set of Pareto optimal investment portfolios. Pavlou *et al.* also used analytical techniques to assess stability and robustness over time through a rolling-window scheme – the results of which contrast favorably with the static results of prior research. The comparison of the obtained frontiers is based on indicators that measure the discrepancies between estimated (i.e. historical) frontiers, the actual (i.e. future) performance of the portfolios and an optimal (i.e. ideal) benchmark. The traditional mean-variance model proved to be the most robust bi-objective model compared to other well-known approaches (i.e. mean absolute deviation and conditional value at risk). The multi-objective model was shown to be quite attractive as it provided good results that were found to be closer to the



true bi-objective frontiers than the bi-objective models' results. This work facilitates further development of MCDM/A techniques for portfolio optimization models focusing on a multi-objective setting. In addition, similar concepts and ideas could be applicable to non-financial portfolios such as project portfolios.

The second paper is entitled "A new EDAS-based in-sample-out-of-sample classifier for risk-class prediction" by Ouenniche, Uvalle-Perez and Ettouhami. This study further contributed to the application of MCDM/A techniques in the financial field by focusing on predictive analytics and proposing a new non-parametric classifier that performs both in-sample and out-of-sample forecasts. The in-sample predictions were developed using a new evaluation based on a distance from average solution (EDAS-based) classifier, and out-of-sample predictions were obtained with a case-based reasoning classifier trained on the class predictions provided by the proposed EDAS-based classifier. Using data from UK firms, the non-parametric classifier was tested, and it delivered an outstanding performance regarding bankruptcy predictions – robust enough to guide implementation decisions. In addition to the proposed non-parametric classifier's usefulness in areas such as finance and investment, its exceptional performance makes it a real contender for applications in internet security, fraud and medical diagnosis. In these areas, the accuracy of risk-category predictions has serious consequences for the relevant stakeholders.

The third contribution to this special issue is "Integrating corporate social responsibility and financial performance" by Bilbao-Terol, Arenas-Parra, Alvarez-Otero and Cañal-Fernández. This paper presents a multiple-criteria methodology for integrating corporate social responsibility (CSR) valuations by external rating agencies with companies' financial performance in a single measure of global sustainability performance. The research model was the result of a hybrid technique applying the order of preference by similarity to ideal solution (TOPSIS) methodology to transformed scores of both CSR valuations and financial ratios. In addition, two other methods were incorporated into classical TOPSIS. First, prospect theory was applied to the raw evaluations to determine when an outcome is either a gain or a loss. Second, design of experiments was used to eliminate the need to assign weights to the criteria by providing general ratings not associated with particular preferences. The proposed methodology was applied to 118 companies evaluated by the CSR agencies, Vigeo and Covalence, which revealed discrepancies between their ratings. Moreover, five financial ratios – Tobin's  $Q$ , market-to-book ratio, return on equity, return on assets and growth – were summarized into a measure of the firms' financial health. Finally, Bilbao-Terol *et al.* created a single ranking for CSR and financial performances and thus a ranking of the combined CSR–financial performance of the 118 firms. Consistent aggregation was achieved for firms scored on various issues by different CSR agencies. The proposed approach solves problems frequently present in social multiple-criteria evaluation contexts.

The fourth study in this special issue is closely related to the first three papers on the field of finance, providing a general perspective on firm competitiveness. This paper is entitled "A multiple criteria group decision-making approach for the assessment of small and medium-sized enterprise competitiveness" by Gonçalves, Ferreira, Ferreira and Farinha. The authors present an MCDA approach that integrates cognitive mapping and the measuring attractiveness by a categorical-based evaluation technique (MACBETH) to assess the most relevant competitive factors for small and medium-sized enterprises (SMEs). In operational terms, cognitive maps reveal the structure of decision problems, thereby helping to identify and understand the cause-and-effect relationships between assessment criteria, while MACBETH facilitates the determination of the selected criteria's weights. The most important factors drawn from the specialized know-how of a panel of decision makers (i.e. entrepreneurs and senior managers closely connected to SMEs) are innovation and the human dimension.

The fifth contribution is “A multiple attribute decision-making approach in evaluating employee care strategies of corporate social responsibility” by Liu, Shiue, Chen and Huang. This study’s findings reinforce the previous paper’s results by focusing on human resources, although Liu *et al.* address the topic from a CSR perspective. In contrast to the research reported in the third paper, the cited authors concentrated on an internal organizational perspective. They investigated companies’ employee care from the employees’ point of view and adopted a hybrid multiple-attribute decision-making model to plan and implement CSR-related employee care more effectively. Based on a questionnaire used to conduct 159 interviews, this study applied a decision-making trial and evaluation laboratory (DEMATEL) approach to construct an influential network relationship map with four dimensions and 13 criteria of employee care. In addition, the researchers used a DEMATEL-based analytic network process to determine each dimension and criterion’s weight. The *viskriterijumska optimizacija i kompromisno resenje* (VIKOR) method was also applied to calculate employees’ level of satisfaction and the gap between this and the “aspired level”.

The next contribution is by Mohammed, Harris and Dukyl, with the title “A transient decision-making tool for vendor selection: a hybrid-MCDM algorithm”. This paper deals with potential applications of MCDM techniques to activity outsourcing, which can drive competitiveness by reducing costs and improving performance. More specifically, these techniques were used to select vendors in such a way that various conflicting criteria could be considered and assessed. Based on seven tenders to become suppliers, the algorithm accommodated traditional and resilience criteria and sub-criteria. The analysis passed through different phases. First, the main transient sub-criteria were identified in a unified hierarchical framework taking into consideration the opinions of four employees who were nominated as a panel to select the best vendor experts in their organization. Second, a DEMATEL algorithm determined the relative importance of each criterion, and the weights thus obtained were integrated into the elimination et choix traduisant la réalité (ELECTRE) algorithm. Third, the TOPSIS algorithm was used to evaluate the vendors’ performance and select the one that best matched the weights of the criteria and sub-criteria obtained via DEMATEL. Last, Spearman’s rank correlation coefficient was utilized to obtain the statistical difference between the rankings generated by the two algorithms, revealing a strong absolute association between TOPSIS and ELECTRE.

Rezaei, van Wulfften Palthe, Tavasszy, Wiegman and van der Laan contributed the seventh paper, which is entitled “Port performance measurement in the context of port choice: an MCDA approach”. The authors present an integrated perspective on port performance and choice, demonstrating the application of a port performance measurement methodology that was extended to include port choice. The decision problem is inherently an MCDA issue due to the presence of sets of alternatives (i.e. routes including ports) and evaluation criteria. The research included assessing hinterland performance and weighting attributes from a port-choice perspective based on the ports’ comparative attractiveness. The proposed methodology consisted of four phases: identifying the decision-analysis context; quantifying the 17 criteria found; creating a weighted approach using the best-worst method; and calculating the alternatives’ performance. Finally, an empirical model was developed based on an extensive port stakeholder survey distributed in seven contestable hinterland regions in Europe, which thus far had not been subjected to quantitative analysis.

The eighth paper was written by Vasilienė-Vasiliauskienė, Vasiliauskas, Golembovskij, Meidutė-Kavaliauskienė, Zavadskas, Banaitis and Govindan and given the title “Transportation systems’ impacts on the Vilnius housing market”. The authors sought to identify transportation system factors’ level of impact on housing markets and on residents’ quality of life. A sample of 317 Vilnius residents provided basic information, and the

significance of transportation system factors in different zones of Vilnius was estimated by using the analytic hierarchy process with 18 real estate experts.

El Itani, Ben Abdelaziz and Masri contributed the ninth paper, which is titled “A bi-objective covering location problem: case of ambulance location in the Beirut area, Lebanon”. The authors applied multiple-criteria techniques to the field of logistics to deal with a situation in which the probability of satisfying demand needed to be increased under cost constraints. El Itani *et al.* opted to treat the maximum expected covering location problem of ambulances as a bi-objective optimization problem (BCLP). In this way, the cost of responding to emergency calls could be minimized via an epsilon-constraint approach in order to build an equivalent linear program to deal with the BCLP. The proposed model was tested using data retrieved from the Lebanese Red Cross in Beirut, Lebanon.

The next contribution comes from Khalfalli, Ben Abdelaziz and Kamoun under the title “Multi-objective surgery scheduling integrating surgeon constraints”. This paper also presents a scheduling logistics application with the objective of generating a daily operating theatre schedule that minimized completion time and maximum permissible overtime. The schedule needed further to integrate real-life surgeon constraints, such as their role, specialty, qualifications and availability. Due to the difficulty of solving combinatorial problems with nonlinear constraints, Khalfalli *et al.* applied a weighted sum-based model and the tabu search heuristic method. The weighted sum and  $\epsilon$ -constraint methods produced efficient schedules that satisfied the decision makers of the department of surgery under study.

The paper entitled “Assessing teaching performance in higher education: a framework for continuous improvement” was contributed by Carlucci, Renna, Izzo and Schiuma. The authors developed an MCDM/A framework for analyses of students’ ratings of teaching quality in higher education and the identification of risk issues undermining the quality of teaching. The framework integrated two decision-based methods: a standardized u-control chart to highlight those courses requiring improvements in teaching quality according to students’ assessments; and ABC analysis using fuzzy weights to deal with any vagueness and uncertainty in students’ evaluations. The proposed framework facilitated the identification of teaching and course quality areas that needed corrective action according to students’ critiques, including assigning different levels of priority. The framework was applied in an action-based case study conducted in an Italian public university, which corroborated fuzzy set theory’s usefulness when dealing with natural language’s vagueness and uncertainty in student evaluations.

The paper “A VIKOR-based approach for the ranking of mathematical instructional videos” was written by Acuña-Soto, Liern and Pérez-Gladish, and it also addresses the use of multiple-criteria methods in education. The authors sought to assess and rank the educational quality of free online instructional videos from a multi-dimensional perspective by using an MCDM/A approach based on the compromise ranking method, VIKOR. This approach includes a normalization process especially suited for situations in which the nature of different decision-making criteria does not allow homogeneous aggregation. The quality assessment of the mathematical videos relied on both quantitative and qualitative criteria and incorporated continuous real variables, binary variables and linguistic variables and/or interval data. In this research, two methods, ideal solution (IS)-TOPSIS and IS-VIKOR, were compared. IS-VIKOR relies on the idea that the reference solutions, instead of being optimal solutions, can take any value between the minimum and maximum values of the range of criteria. Using VIKOR allowed the researchers to rank the videos based on their similarity with an ideal video that was considered a reference point by instructors. The IS-TOPSIS ranks decision alternatives based on a set of decision criteria by choosing the alternatives that simultaneously have the shortest distance from the positive IS and the farther distance from the negative IS. The selection of one ranking method over another depends on the instructors’ educational objectives.

The final contribution to this special issue is “The long-run sustainability of the European Union countries: assessing the Europe 2020 strategy through a fuzzy goal programming model” by Vié, Colapinto, La Torre and Liuzzi. This paper provides a wider perspective on MCDM/A models through their ability to analyze sustainable economic growth. Strong internal pressures have been put on policymakers to reconcile economic, social and environmental objectives to ensure sustainable development and improvements in citizens’ quality of life. The interdependence between these development variables and acting entities has frequently constrained research on optimal policy strategies and the design of efficient public measures capable of achieving a combination of objectives without restricting each goal’s completion. As these decision problems often deal with imprecise information, fuzzy goal programming appears to be a suitable method of modeling the uncertainty related to objectives without assuming a-priori any distribution of probability.

By highlighting MCDM/A methods’ potential and demonstrating these methods’ role as aids to decision making, we believe this special issue will alert management practitioners, policymakers and researchers to the theoretical developments and practical applications of these methodologies. This project’s completion would not have been possible without Patrick Murphy and Andy Adcroft’s editorial support. We are extremely grateful for their faith in this endeavor’s worth and the opportunity to bring it into fruition.

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