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A combined compromise solution (CoCoSo) method for multi-criteria decision-making problems

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Abstract

Purpose – The purpose of this paper is to discuss the advantage of a combinatory methodology presented in this study. The paper suggests that the comparison with results of previously developed methods is in high agreement.
Design/methodology/approach – This paper introduces a combined compromise decision-making algorithm with the aid of some aggregation strategies. The authors have considered a distance measure, which originates from grey relational coefficient and targets to enhance the flexibility of the results. Hence, the weight of the alternatives is placed in the decision-making process with three equations. In the final stage, an aggregated multiplication rule is employed to release the ranking of the alternatives and end the decision process.
Findings – The authors described a real case of choosing logistics and transportation companies in France from a supply chain project. Some comparisons such as sensitivity analysis approach and comparing to other studies and methods provided to validate the performance of the proposed algorithm.
Originality/value – The algorithm has a unique structure among MCDM methods which is presented for the first time in this paper.

Keywords Multi-criteria decision-making (MCDM), Combined compromise solution (CoCoSo) method

Paper type Research paper

1. Introduction

Project environments are particularly vulnerable to generating conflict (Zavadskas *et al.*, 2009). When stakes are very high, it is essential to define a problem, multiple conflicting criteria accurately; therefore, modern decision-makers (both scientists and experienced users) are required to explicitly evaluate numerous criteria, instead of making decisions based on only intuition and own experience. Well-structuring of complex issues and explicitly considering various rules lead to more informed and better decisions. The notion of sustainable development, which is increasingly omnipresent in all activity fields, is a part of the knowledge researchers in construction have to acquire as well (Zagorskas *et al.*, 2014). Different groups of decision-makers become involved in the practical problems solution process, each group bringing along different criteria and points of view, which need resolving within a framework of understanding and mutual compromise (concessions). The problems are often characterised by several non-commensurable and conflicting (competing) criteria, and there may be no solution satisfying all requirements simultaneously. Stakeholders need a compromise solution. Complicated issues solved in the last decades assume that the decision-maker looks for a compromise between objectives of a different character: financial, ethical or others. Robust options are those solutions that represent a process result or the one which appears after some algorithmic application (Šaparauskas *et al.*, 2011). Thus, the set of non-inferior options is a compromise solution according to the decision-makers' preferences. A solution acquiring thus as a compromise was accepted by the two main integral conflicting components: the economy (the anthropic dimension) and the environment. Building with better energy performance entails a conflict between users' economic objective and society's environmental objective (Olmeda and Aguilar, 2015). Around 30–50 per cent of new or refurbished buildings lead to building-related illness. Therefore, facilities management problems need compromise solution methods of a problem for the optimal allocation of such housing in a building development considering the energy rating (Liyanage and Hadjri, 2015).

Both process and algorithm have to lead and to help the decision-maker in the difficult task of choosing the best compromise solution of the decision problem he/she faces. However, out of the many available options, the decision-maker eventually has to accept only one answer by taking into account the priorities and objectives of different stakeholders' groups (Zavadskas *et al.*, 2017).

In general, all potential conflicts in projects fit one of the four categories (sometimes based on two or more of the types) (Verma, 1998):

1. Goal-oriented conflicts associate with performance specifications and criteria, priorities, and objectives.
2. Administrative conflicts refer to the management structure and philosophy and mainly based on a definition of roles and responsibilities, functions and decisions, complex project organisational structures, and interpersonal conflicts among participants result from differences in work ethics and styles.
3. The breakdown in communication: a lack of trust, respect, active listening skills, and perceptual differences.
4. Not proper interpretation of a design drawing. A misunderstood change orders delays in the delivery of critical components, and failure to execute instructions are all results of communication breakdown.

Over the years, three distinct views of conflict have evolved in projects:

1. The dominant (traditional) light from the late nineteenth century assumes that conflict is severe and always has a negative impact. The response to conflict is to reduce, suppress, or eliminate it.
2. The behavioural or contemporary view, also known as the human relations view, emerged in the late 1940s. It argues that conflict is natural and inevitable in all projects. Because of the potential benefits from conflict, project managers should focus on managing it effectively rather than suppressing or eliminating it.
3. The interaction view, emerged in the 1970s, assumes that conflict is necessary to increase performance. This approach encourages managers to maintain an appropriate compromise enough to keep projects self-critical, viable, creative, and innovative.

Recent years have seen significant new explorations along the boundaries between economics and psychology. For the economist, the immediate question about these developments is whether they include new advances in psychology that can be applied fruitfully to decision-making in economics (Simon, 1959). Katona (1953) presented and contrasted the most common forms of methodologies of the economic principle of rationality in both psychology and economics, and a general discussion of the role of empirical research among psychologists in the studies of economic behaviour initiated. Decision-making serves as the foundation on which utility theory rests (Keeney and Raiffa, 1976; Roy and Vincke, 1984). Although utility theory has well-recognised roots that extend into eighteenth and nineteenth centuries (Fishburn, 1970), much of its exponential applications growth has occurred in the last 15 years

(Zavadskas *et al.*, 2014). A significant number of works applying different MCDM techniques for engineering problems have been published recently (Zavadskas, Antucheviciene, Turskis and Adeli, 2016).

The multi-criteria optimisation is a process of determining the best feasible solution according to the established criteria (representing different effects). Algorithmic thinking and model building in MCDM provide a contemporary approach for explaining certain kinds of human behaviour and decision-making (Kochen *et al.*, 1967; Roy and Słowiński, 2013). MCDM is one of the most attractive fields of interdisciplinary research in management science and operations research (Ho *et al.*, 2010). The first references to multiple-criteria methods were already mentioned in 1772, 1785, 1881, 1896 by Franklin (1772), De Condorcet (1785), Edgeworth (1881), and Pareto (1986, 1906), respectively. The first decision-making axioms were formed by Ramsey (1931). Later, von Neumann and Morgenstern (1944) introduced theory of games and economic behaviour.

MCDM and MCDA (multi-criteria decision analysis) are well-known acronyms for multiple-criteria decision-making and multiple-criteria decision analysis (Turskis and Zavadskas, 2010; Turskis *et al.*, 2012). Zionts (1979) focused on the applications of MCDM and started popularising the acronym "MCDM". MCDM methods include two classes of methods, namely, continuous and discrete methods, based on the nature of the considered alternatives. Continuous methods, or multi-objective decision-making methods, aim to identify an optimal quantity, which can vary infinitely in a decision problem. Discrete MCDM methods, or multi-attribute decision-making (MADM) methods, can be defined as decision support techniques that have a finite number of alternatives, a set of objectives, criteria by which the options judged, and a method of ranking choices, based on how well they satisfy the goals and measures. Discrete methods can be further subdivided into weighting methods and ranking methods (Nijkamp *et al.*, 1990, Ananda and Herath, 2009). Empirical MCDM techniques continue to be fine-tuning and their application to different problems expanded. As applications number grows, new insights gained about how to improve MADM approaches (Ananda and Herath, 2009).

Usually, four assumptions are made in management decision-making problem (Raiffa, 1968):

1. Before one gets to the stage of evaluating alternatives in a given problem domain, one must first recognise that a problem exists and one should seek creative options for review.
2. There is a need to select the best alternative from a fixed set of available options. A decision-maker knows or could determine the other options; he/she studies the problem, where each choice is described by a series of criteria, which are interdependent in various ways.
3. Most decision-makers in such situations would like a method that would help them process the criterion value information for each alternative. The alternative selected is in some sense optimal or best.
4. An explicit statement of constraints for a problem, even when the restrictions do not necessarily simplify the analysis, may still be useful.

Problem solving is interpreted in different ways:

1. finding the best or the most preferable of a decision-maker alternative from a set of available options;
2. choosing a small set of reasonable options, or grouping alternatives into different preference sets; and
3. finding all efficient or non-dominated options.

MacCrimmon (1968) presented his seminal work. The memorandum examined several methods and techniques, which advanced in the literature for making a quantitative and qualitative evaluation of multi-criteria alternatives. The memorandum provides basic assumptions for modern MCDM. Various methods are discussed and include dominance, satisficing, maximin, maximax, lexicography, additive weighting, effectiveness index, utility theory, trade-offs, and non-metric scaling. MacCrimmon (1968) concluded that a combination of methods to select the best option is more reasonable and valid approach than the choice of in any single way.

MCDM considered as a complex and dynamic process includes one managerial level and one engineering level (Duckstein and Opricovic, 1980). Stakeholders found compromise solutions based on opinion consensus (Razavi Hajiagha *et al.*, 2015).

In many cases, a system analyst can aid the decision-making process by making a comprehensive analysis and by listing the essential properties of non-inferior or compromise solutions (Yu, 1973).

The main steps of MCDM are the following (Opricovic and Tzeng, 2004):

(1) establishing system evaluation criteria that relate system capabilities to goals;

(2) developing alternative systems for attaining the goals (generating alternatives);

(3) evaluating options concerning rules (the values of the criterion functions);

(4) applying a normative multi-criteria analysis method;

(5) accepting one choice as “optimal” (preferred); and

(6) if the final solution is not approved, gather new information and go into the next iteration of multi-criteria optimisation.

Dozens of MCDM models are developed to solve problems with different and non-commensurable (different units) criteria. There are situations when the evaluation of feasible alternatives must handle the compromise of established standards values, and the development of a compromise MCDM model is necessary. Mathematical research on multi-criteria optimisation problems predominantly revolves around the set of Pareto optimal solutions (Kanellopoulos *et al.*, 2015). Reference point methods are a successful example of widely used in a real-world multi-criteria optimisation approach.

However, the compromise ranking method called “VIsekriterijumska optimizacija i KOmpromisno Resenje” (VIKOR) (in Serbian), which means multi-criteria optimisation and compromise solution, does not belong to this class of techniques, but instead determines the weight stability intervals, using the methodology presented in Opricovic (1998). VIKOR is based on old ideas of compromise programming (Yu, 1973; Duckstein and Opricovic, 1980). Opricovic developed the VIKOR method to solve discrete multi-criteria problems. VIKOR focusses on ranking and selecting from a set of alternatives in the presence of conflicting criteria, and on proposing a compromise solution (one or more). The compromise solution is a feasible solution, which is the closest to the ideal (Opricovic and Tzeng, 2004) and means an agreement established by mutual concessions. A compromise solution to a problem with different criteria can help the decision-makers to reach a final decision. The foundation for the compromise solution was established by Yu (1973) and Zeleny (1973). The VIKOR method is introduced as one suitable technique to implement within MCDM (Opricovic, 1998; Gul *et al.*, 2016). The technique for order preference by similarity to ideal solution (TOPSIS) method determines a solution with the shortest distance from the ideal solution and the farthest distance from the negative ideal solution, but it does not consider the relative importance of these distances (Hwang and Yoon, 1981).

Development of the new technologies and tools in each area of the science delivers a kind of perspective that allows users and experts to compare and choose based on relevant requirements. As a significant cluster in operation research, various areas of decision-making theories are discussed effectively to reach more optimal solutions. Adopted algorithms, integrated formulas along with mathematical and logical approaches lead to the invention of newer decision-making methods. MCDM family as a significant part of decision theory has widely been improved and applied in the relevant decision-making problems from human resources, energy sector, production and manufacturing to air transport management and education (Mardani *et al.*, 2015; Zavadskas, Govindan, Antucheviciene and Turskis, 2016). It is an ideal topic if one concentrates on the core idea of MCDM and brings up an improved algorithm that treats differently from others. An effort to restructure and remodel a previous model with the aid of new strategies is still being made, even if the results are too far.

A research plan conducted in this field of knowledge contains elimination, separation, differentiation or aggregation of reasonable formulas. Academicians conveyed several exciting projects associated with the creation or extension and integration of MCDM tools. Zavadskas *et al.* (1994) formed a sound structure called “COmplex PRoportional Assessment” (COPRAS) that originates from the correlation of complex relationships between elements of a decision matrix. Multi-objective optimisation ratio analysis (MOORA) was directly launched. This method conquers with TOPSIS and COPRAS in ranking strategies. The TOPSIS and COPRAS methods suffer from two significant shortcomings (Aouadni *et al.*, 2017):

1. the non-meaningfulness of the resulting rankings in mixed data contexts (i.e. the rankings of alternatives may change under possible transformations of the initial attribute values, in the measurement-theoretic sense of the term); and
2. rank reversals or ranking irregularities (i.e. the rankings of alternatives may change if a new option added to the given offered set of options or an old one is deleted from it or replaced it).

Same research group extracted Weighted Aggregated Sum Product ASsessment (WASPAS) which insists on the combination of two popular instruments – weighted product method (WPM) and weighted sum method (WSM) – to get advantages of both tools. A pack of research in this content regulated and solved sophisticated problems as well. Sort of techniques such as “evaluation based on distance from average solution” (EDAS) and “COmbinative Distance-based Assessment” (CODAS) have brought a more unobstructed view of the essential form of the MCDM in total. There are potentials to work and create a combined or integrated approach, which at the same time logically receives positive feedback and in other side is within a domain of as MCDM format.

Fundamentally, the intrinsic properties of MCDM make it appealing and practically useful for real class applications and projects. In the decision-making literature, distance-based methods like TOPSIS (Hwang and Yoon, 1981; Behzadian *et al.*, 2012; Zavadskas, Mardani, Turskis, Jusoh and Nor, 2016) and VIKOR (Opricovic, 1998; Mardani *et al.*, 2016; Gul *et al.*, 2016) and demonstration of outranking and preference-based methods like “ELimination Et Choix Traduisant la REalité” (Roy, 1968; Govindan and Jepsen, 2016; Figueira *et al.*, 2013), which means “ELimination and Choice Expressing Reality”, and preference ranking organisation method for enrichment evaluations (PROMETHEE) (Brans and Vincke, 1985; Roubens, 1982) have been argued and discussed widely. Although their importance is never deniable, a considerable shift is clear in restructuring decision-making tools pushes research lines to a different dialogue. Therefore, many studies are dealing with designing a new algorithm in practice.

Zavadskas and Turskis (2011) believed that developing economies, changing environment, and the sustainability of decisions are the reasons to create new operation research techniques and specifically decision-making tools. Beside this, a systematic and sustainability-focussed evaluation system for reasonable alternatives selection is needed from an organisational supply chain perspective (Luthra *et al.*, 2017). Carlsson and Fullér (1996) classified four distinct families of MCDM methods as the outranking; the value and utility theory-based; the multiple objective programming; and group decision and negotiation theory-based methods. Many of MCDM methods were developed to meet the increasing requirements of human society and the environment. A significant criticism of MCDM methods is that they yield different results when they are applied in solving the same problem. The MCDM methods – VIKOR and TOPSIS – are based on an aggregating function representing "closeness to the ideal", which originated in the compromise programming method. Linear normalisation in VIKOR and vector normalisation in TOPSIS are used to eliminate the different units of criterion functions. For example, both VIKOR and TOPSIS are distance-based tools and at the same time recognised as a compromise-based method (Opricovic and Tzeng, 2004).

Sort of decision-making tools were invented and extended through different applications and case studies. The COPRAS method was developed and formulated by Zavadskas *et al.* (1994) to build a new frame in MCDM family (Stefano *et al.*, 2015). The motivation of investigators to invent and adopt new algorithm has highly increased. The other introduced technique is MOORA (Brauers and Zavadskas, 2006; Baležentis and Baležentis, 2013). Its anatomy is not complicated and so permits one to arrive at a final solution faster like COPRAS. It is a superior technique especially concerning reference point technique and chooses the optimal solution for among a bunch of alternatives. The utilisation of the MOORA is extensive and covers various disciplines and industries. Sometimes, the logical integration of two methods can formally unify a valuable structure. For example, WPM and WSM jointly could establish a tool called WASPAS (Mardani *et al.*, 2017; Pavlovskis *et al.*, 2016). Several projects have interpreted the advantage of this method. This method validates a final performance score for alternatives through a linear relation and power and multiplication aggregation (Chakraborty *et al.*, 2015). More recently, the other techniques are practically available in the context of multi-criteria analysis. EDAS and CODAS methods originated as basic rules in the multi-criteria structure (Keshavarz Ghorabaee *et al.*, 2015). The CODAS uses the Euclidean distance as the primary measure of assessment. If the Euclidean distances of two alternatives are very close to each other, the Taxicab distance is used to compare them. A threshold parameter determines the degree of closeness of Euclidean distances. Keshavarz Ghorabaee *et al.* (2016) argued the advantages of the CODAS method. In this method, the desirability of alternatives is determined by using two measures. The principal and primary measure is related to the Euclidean distance of other options from the negative ideal. This short communication makes an effort to investigate the new strategy to achieve the solution of an MCDM problem. The contribution of the proposed algorithm is to yield weight aggregation process to the grey relational generation approach. First of all, the distance of each performance rating from the ideal one is measured. This approach is similar to the VIKOR method but with a slightly different formula. A different aggregation than VIKOR originates from the power of weights. This subject practically leads to a stronger distance measurement attitude seeming useful modelling. The proposed approach uses a comparability sequence and then the weights are aggregated through two manners. One of them follows the usual multiplication rule and the second one narrates the weighted power of the distance from comparability sequence. To validate the ranking index, we have defined three different measures (aggregation strategy) for a given alternative. At ultimate, a cumulative equation reports a ranking. There is not any algorithm among MCDM tools supporting this kind of aggregation. Each strategy would offer a ranking score, which would be further improved by a complete ranking index. If the presented procedure is based on a combination of compromise attitudes, it is entitled combined compromise solution (CoCoSo). Through this paper, we are trying to release a new approach to find the optimal solution for an MCDM problem. The organisation of the paper is as follows: Section 3 proposes the new-born CoCoSo algorithm, and then in Section 4, we organise some examples and comparisons. A real case of selecting a logistics provider chosen and the related discussion is considered. By the last part, a conclusion and discussion appear.

2. Newly proposed algorithm: combined compromise solution (CoCoSo) method

The suggested approach is based on an integrated simple additive weighting and exponentially weighted product model. It can be a compendium of compromise solutions. To solve a CoCoSo decision problem, after determining the alternatives and the related criteria, the following steps are validated:

(1) The initial decision-making matrix is determined as shown below:

$$x_{ij} = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \dots & \dots & \dots & \dots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix}; \quad i = 1, 2, \dots, m; \quad j = 1, 2, \dots, n. \tag{1}$$

(2) The normalisation of criteria values is accomplished based on compromise normalisation equation (see Zeleny, 1973):

$$r_{ij} = \frac{x_{ij} - \min\limits_i x_{ij}}{\max\limits_i x_{ij} - \min\limits_i x_{ij}}; \quad \text{for benefit criterion,} \tag{2}$$

$$r_{ij} = \frac{\max\limits_i x_{ij} - x_{ij}}{\max\limits_i x_{ij} - \min\limits_i x_{ij}}, \quad \text{for cost criterion.} \tag{3}$$

(3) The total of the weighted comparability sequence and the whole of the power weight of comparability sequences for each alternative sum of the weighted comparability sequence and also an amount of the power weight of comparability sequences for each alternative as S_i and P_i, respectively:

$$S_i = \sum_{j=1}^{n} \left(w_j r_{ij}\right), \tag{4}$$

this S_i value is achieved based on grey relational generation approach:

$$P_i = \sum_{j=1}^{n} \left(r_{ij}\right)^{w_j}, \tag{5}$$

this P_i value is also achieved according to the WASPAS multiplicative attitude.

(4) Relative weights of the alternatives using the following aggregation strategies are computed. In this step, three appraisal score strategies are used to generate relative weights of other options, which are derived using Formulas (6)–(8):

$$k_{ia} = \frac{P_i + S_i}{\sum_{i=1}^{m} (P_i + S_i)}, \tag{6}$$

$$k_{ib} = \frac{S_i}{\min\limits_i S_i} + \frac{P_i}{\min\limits_i P_i}, \tag{7}$$

$$k_{ic} = \frac{\lambda(S_i) + (1-\lambda)(P_i)}{\left(\lambda \max_i S_i + (1-\lambda) \max_i P_i\right)}; \quad 0 \leqslant \lambda \leqslant 1. \tag{8}$$

It is interpreted that Equation (6) expresses the arithmetic mean of sums of WSM and WPM scores, while Equation (7) expresses a sum of relative scores of WSM and WPM compared to the best. Equation (8) releases the balanced compromise of WSM and WPM models scores. In Equation (8), λ (usually $\lambda = 0.5$) is chosen by decision-makers. However, the flexibility and stability of the proposed CoCoSo can rely on other values.

(5) The final ranking of the alternatives is determined based on k_i, values (as more significant as better):

$$k_i = (k_{ia} k_{ib} k_{ic})^{\frac{1}{3}} + \frac{1}{3}(k_{ia} + k_{ib} + k_{ic}). \tag{9}$$

3. Examples and comparisons

3.1 A logistic provider selection problem

The French Association of Supply Chain and Logistics (ASLOG) has been established and activated since 1972. It has encouraged companies to involve logistics and supply chain directions in the top level of the management decisions. Multi-activity with over 400 companies, nearly 1,500 people network, ASLOG is now the leading French network of professionals in the supply chain area. Its objectives are to provide forward-looking visions, generate standards and qualifications, measure and evaluate logistics performance, and ultimately to produce research dissemination in partnership with the academic sector and benchmark best practices (www.aslog.fr). For this research, seven logistics-based companies are selected (alternatives) to assess by the proposed fuzzy model: Mathez (A_1), Bansard (A_2), GEFCO (A_3), Schneider Transport (A_4), LDI Dimotrans (A_5), SAGA (A_6), and GETMA (A_7). Mathez group is a family-run company specialising in logistics coordination and international transportation (air, sea, and road freight). Main activities of this group need the extension from transport management by airfreight, sea freight, road haulage, storage, packing, supply and distribution management and optimisation, port agent, management of cargo and cruise ships. Bansard International offers a complete service for sea, air and road transportation through partnerships with major airlines to cover the needs of our customers. Thus, Bansard International serves the essential ports and airports. Besides, this company provides door-to-door service and assistance to facilitate customs operations. They offer a kind of service like air transport, sea transport, road transport, logistics, and industrial projects. A leading name in industrial and automotive logistics, GEFCO, provides complete, efficient logistics solutions for its industrial customers throughout the world. The group combines standards of quality and performance with the responsible management of its logistics activities. GEFCO incorporates and complies with all the elements of sustainable development. The group can respond all supply chain optimisation requirements, upstream or downstream from production sites: land transport, logistics, container management, vehicle distribution, and management of maritime and air flows. Schneider is a medium-sized international freight forwarding company providing specialised services in clearly defined markets. The Schneider Group combines high service quality with flexibility and commitment to delivery dates. The company plans and coordinates transportation of all kind of goods between Switzerland, Europe, the Far East and the USA. This group delivers from road transport, sea and air transport, and inventory and procurement management, reverse logistics, and food logistics. GETMA operates cargo handling in African ports, Central Africa, and coastal line. Through its network, GETMA offers a range of services tailored to business needs: port management, port handling, shipping agency, freight forwarding, and domestic logistics. LDI is a part of French Group DIMOTRANS which is presented in France with several hubs in Lyon, Paris, Lille, Marseille, and Toulouse and Eastern Europe with an own network of agencies such as Poland, Romania, Hungary, Bulgaria, Macedonia as well as other partners in Turkey, Greece, and Kazakhstan. The Saga Company is known for its sector-based service offers and its ability to tailor its services to fit the needs of different industries. Saga's primary objective is to master the entire logistics chain to offer its customers a full range of services including freight forwarding, handling (including stevedoring and overland), distribution (small package standard and express), and contractual logistics. Over the years, Saga has made significant investments in some African countries while simultaneously enlarging its network in France, in the French Overseas Departments and Territories, and in Asia. The decision problem contains five criteria and seven alternatives. The requirements considered as C_2 which is the offered price of logistics providers and is a non-benefit or cost-based factor and the four elements dedicated as benefit indicators (including C_1 – inventory capacity, C_3 – batch or delivery volume, C_4 – degree of flexibility, and C_5 – technology utilisation). Table I shows the data and details for a logistic provider selection problem including information about alternatives and weights of decision criteria. We form a decision-making matrix, run the algorithm and then explain the processes to the final step. It is evident to perform some comparison with other MCDM tools and sensitivity analysis to verify the applicability of the proposed algorithm. The information about logistic company performance and the weights of all criteria to evaluate the logistic providers are provided in Table I.

The first step demonstrates forming of the normalised decision-making matrix (using compromise equation (max–min)), which is shown in Table II.

			Criteria		
Alternatives	C_1	C_2	C_3	C_4	C_5
Weights	0.036	0.192	0.326	0.326	0.12
Optimal value	max.	min.	max.	max.	max.
A_1	60	0.4	2,540	500	990
A_2	6.35	0.15	1,016	3,000	1,041
A_3	6.8	0.1	1,727.2	1,500	1,676
A_4	10	0.2	1,000	2,000	965
A_5	2.5	0.1	560	500	915
A_6	4.5	0.08	1,016	350	508
A_7	3	0.1	1,778	1,000	920

Table I. Example of a logistic provider selection problem

	C_1	C_2	C_3	C_4	C_5
A_1	0.6441	0.3540	0.2636	0.0565	0.1411
A_2	0.0682	0.1327	0.1054	0.3390	0.1484
A_3	0.0730	0.0885	0.1792	0.1695	0.2389
A_4	0.1074	0.1770	0.1038	0.2260	0.1376
A_5	0.0268	0.0885	0.0581	0.0565	0.1304
A_6	0.0483	0.0708	0.1054	0.0395	0.0724
A_7	0.0322	0.0885	0.1845	0.1130	0.1311

Table II. The normalised decision-making matrix

The further step is to generate the comparability sequence matrix. In this process, the weights of decision-making criteria are involved in the algorithm. By having Table III, the S_i and P_i vectors must be generated using formulas (4) and (5), respectively. The obtained values are shown in Tables IV and V.

Aggregation strategies are required to get results for the final ranking. At this moment, the values of K_a, K_b, and K_c are derived using Equations (7), (8) and (9). Checking of the alternatives ranks is based on these k values. Equation (10) produces the ranking score by k to find final ranks for the options. This vector is represented in Table VI. According to Table VI,

Table III.
Comparability sequence measures

	C_1	C_2	C_3	C_4	C_5
A_1	1	0	1	0.0566	0.4127
A_2	0.067	0.7813	0.2303	1	0.4563
A_3	0.0748	0.9375	0.5895	0.434	1
A_4	0.1304	0.625	0.2222	0.6226	0.3913
A_5	0	0.9375	0	0.0566	0.3485
A_6	0.0348	1	0.2303	0	0
A_7	0.0087	0.9375	0.6152	0.2453	0.3527

Table IV.
Weighted comparability sequence and S_j

	C_1	C_2	C_3	C_4	C_5	S_i
A_1	0.036	0	0.326	0.0185	0.0495	0.43
A_2	0.0024	0.15	0.0751	0.326	0.0548	0.6082
A_3	0.0027	0.18	0.1922	0.1415	0.12	0.6363
A_4	0.0047	0.12	0.0724	0.203	0.047	0.4471
A_5	0	0.18	0	0.0185	0.0418	0.2403
A_6	0.0013	0.192	0.0751	0	0	0.2683
A_7	0.0003	0.18	0.2005	0.08	0.0423	0.5031

Table V.
Exponentially weighted comparability sequence and P_i

	C_1	C_2	C_3	C_4	C_5	P_i
A_1	1	0	1	0.3921	0.8992	3.2914
A_2	0.9073	0.9537	0.6196	1	0.9102	4.3907
A_3	0.9109	0.9877	0.8417	0.7617	1	4.502
A_4	0.9293	0.9137	0.6124	0.8569	0.8935	4.2058
A_5	0	0.9877	0	0.3921	0.8812	2.261
A_6	0.8861	1	0.6196	0	0	2.5057
A_7	0.843	0.988	0.8535	0.6325	0.8825	4.1991

Table VI.
Final aggregation and CoCoSo ranking of the alternatives

	k_a	Ranks	k_b	Ranks	k_c	Ranks	k	Final ranks
A_1	0.131	5	3.245	5	0.724	5	2.041	5
A_2	0.175	2	4.473	2	0.973	2	2.788	2
A_3	0.18	1	4.64	1	1	1	2.882	1
A_4	0.163	4	3.721	4	0.906	4	2.416	4
A_5	0.088	7	2	7	0.487	7	1.3	7
A_6	0.097	6	2.225	6	0.54	6	1.443	6
A_7	0.165	3	3.951	3	0.915	3	2.52	3

A_3 is the best logistic provider, and provider A_5 is counted as the worst alternative. It is entirely a trustable approach when one checks the ranking produced by each piece of *k* and final *k* are in highest agreement. The observation expresses that final ranking and each particular ranking are the same. So, the evaluation decision for logistic provider selection problem is stated as below:

$$A_3 \succ A_2 \succ A_7 \succ A_4 \succ A_1 \succ A_6 \succ A_5.$$

3.2 Test and validation of the proposed method

Herein, we intend to compare the performance of the proposed algorithm (CoCoSo) employing two approaches.

3.2.1 Doing a sensitivity analysis. A sensitivity analysis is designed to validate the results and justify the accuracy and deviation of the decision outcomes. A sensitivity analysis test could help decision-makers to prove their method outcomes by some changes in the primary model. Here, we perform a weight replacement strategy for that purpose. Table VII contains the 48 different tests to exchange the weights of criteria and demonstrate the corresponding ranks of alternatives. We have arranged 48 possible sensitivity analyses to test our obtained results. Table VII indicates required tests for weights sensitivity analysis. In 38 tests, A_3 is determined as the first ranked alternative which is quite sufficient to conclude that A_3 as the best option. Even though the worst alternative varies between A_6 and A_7, the sensitivity analysis process recommends us to choose A_6 as the least importance item. Doing a full range of tests to credit our methodology and its structure is a very complicated process. We have measured the Spearman correlation coefficients (CCs) between original ranking and each sensitivity test, despite the small number of them, the rest have a high and acceptable range ($>$ 80 per cent). For instance, *T*1, *T*2, *T*7, *T*14, *T*18, *T*20, *T*25, *T*28, *T*30, *T*35, *T*38, *T*40, *T*43, and *T*47 show a very acceptable level of similarity among other tests. Conclusively, the strength of the proposed method is verified by a comparison of the sensitivity analysis, which is an instrument to check the ranking similarity. It has been tried to perform weight well-organised exchange by two, three or four criteria. Exclusive high CC enhances the credibility of the proposed algorithm and can be an alternative tool in MCDM applications and projects. Figure 1 points out the different ranking of alternatives according to the extracted tests. The figure indicates a coherent sort of ranking measures. More of that, the performance of the top alternative (A_3), based on results stability in all those tests, cannot be overlooked at all. In contrast, worse alternatives positions as A_5 and A_6 are identical to the initial ranking of the CoCoSo (Table VIII).

3.2.2 Comparing to the other methods. The Spearman's rank CC is acquired to compare the ranking results obtained from the different techniques. If this CC is more excellent than 0.8, the relationship between variables is considered high. The CC between those methods and the newly proposed algorithm can be listed here: the WASPAS and VIKOR rankings are equal and identical. The proposed technique is similar to WASPAS and VIKOR. This fact stands that the proposed method is stable enough and feasible using in MCDM applications. This value for TOPSIS and CODAS achieved as 0.93; for MOORA – 0.97; and for COPRAS – 0.86. The EDAS observes the unsuitable correlation as 0.58. Consequently, six applied methods are in a significant agreement with the proposed algorithm. The evidence is presented in Table IX.

3.2.3 A green supplier selection problem. The second approach to validate the performance of the proposed algorithm is to compare it with other already solved and approved studies. This study carried out by comparison of a green supplier selection problem adopted from Yazdani *et al.* (2017). The authors of that study proposed an integrated algorithm and announced final ranking with two methods as COPRAS and MOORA.

Table VII.
The 48 different scenarios for weight sensitivity analysis

	w_1	w_2	w_3	w_4	w_5
Test 1	0.036	0.192	0.120	0.326	0.326
Test 2	0.036	0.192	0.326	0.120	0.326
Test 3	0.036	0.120	0.192	0.326	0.326
Test 4	0.036	0.326	0.192	0.120	0.326
Test 5	0.036	0.326	0.12	0.192	0.326
Test 6	0.036	0.12	0.326	0.192	0.326
Test 7	0.036	0.326	0.192	0.326	0.12
Test 8	0.036	0.192	0.326	0.326	0.12
Test 9	0.036	0.12	0.326	0.326	0.192
Test 10	0.036	0.326	0.326	0.120	0.192
Test 11	0.036	0.326	0.326	0.192	0.12
Test 12	0.326	0.036	0.120	0.326	0.192
Test 13	0.326	0.036	0.12	0.192	0.326
Test 14	0.326	0.192	0.036	0.12	0.326
Test 15	0.326	0.326	0.192	0.036	0.12
Test 16	0.326	0.12	0.036	0.192	0.326
Test 17	0.326	0.326	0.12	0.036	0.192
Test 18	0.326	0.326	0.192	0.12	0.036
Test 19	0.326	0.192	0.12	0.036	0.326
Test 20	0.326	0.192	0.12	0.326	0.036
Test 21	0.326	0.192	0.036	0.326	0.12
Test 22	0.326	0.326	0.192	0.036	0.12
Test 23	0.326	0.12	0.192	0.326	0.036
Test 24	0.326	0.12	0.192	0.036	0.326
Test 25	0.326	0.12	0.036	0.326	0.192
Test 26	0.192	0.326	0.12	0.036	0.326
Test 27	0.192	0.326	0.326	0.12	0.036
Test 28	0.192	0.12	0.326	0.326	0.036
Test 29	0.192	0.036	0.12	0.326	0.326
Test 30	0.192	0.326	0.036	0.12	0.326
Test 31	0.192	0.326	0.326	0.036	0.12
Test 32	0.192	0.036	0.326	0.326	0.12
Test 33	0.192	0.036	0.326	0.12	0.326
Test 34	0.192	0.12	0.326	0.036	0.326
Test 35	0.192	0.326	0.12	0.326	0.036
Test 36	0.192	0.326	0.036	0.326	0.12
Test 37	0.192	0.12	0.036	0.326	0.326
Test 38	0.12	0.192	0.036	0.326	0.326
Test 39	0.12	0.192	0.326	0.036	0.326
Test 40	0.12	0.192	0.326	0.326	0.036
Test 41	0.12	0.036	0.192	0.326	0.326
Test 42	0.12	0.036	0.326	0.192	0.326
Test 43	0.12	0.036	0.326	0.326	0.192
Test 44	0.12	0.326	0.326	0.036	0.192
Test 45	0.12	0.326	0.036	0.326	0.192
Test 46	0.12	0.326	0.036	0.192	0.326
Test 47	0.12	0.326	0.192	0.326	0.036
Test 48	0.12	0.326	0.326	0.192	0.036

Table X explains the information of supplies and the required criteria. Ten suppliers and seven green factors compose the decision table. List of assessment factors is introduced here: quality adaptation (QD), price (P), energy and natural resource consumption (ENRC), delivery speed (DS), green design (GD), re-use and recycle rate (RRR), and production planning (PP). Among decision-makers, price (P) and ENRC are generally considered as the cost criteria.

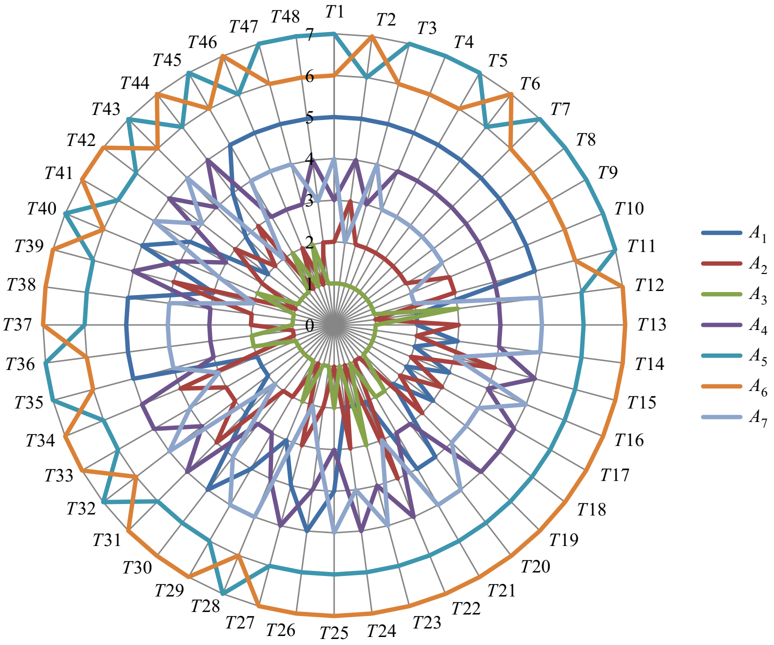

Figure 1.
The illustrative ranking of CoCoSo method divided by sensitivity tests

The matrix is normalised. So, by implementing the newly proposed algorithm, the optimal solutions reported are as presented in Table XI. Again, the three different k ranked scores are the same as the final k value. All the three decision-making methods agree that S_7 and S_2 are the best and second-ranked suppliers, respectively. Even if, the CC between COPRAS and CoCoSo is almost 0.7, which lies in the acceptable range, the similar ranking in the first and second alternatives seems quite interesting. This proves the contribution of the proposed algorithm cause its results are very similar to the other MCDM techniques. This value for MOORA is 0.91, which is a very high closeness to the proposed algorithm.

One may concentrate on ranking values of (k). The significant issue is that there is a minimal difference between each alternative score. Despite various levels of ranking values (Figure 2), it seems they follow the same route that insists on the consistency and accuracy of the results. More on that, rather than comparing top alternatives due to a minimal difference between k values, suggested giving attention to the middle stage alternatives. In this kind of situation, it is much more convenient to apply the proposed method when a significant number of other options is presented. The tendency and fluency of each k value reflect that the proposed algorithm lies in a unique rhythm.

4. Conclusion

The logical and meaningful integration of some rules and techniques in the area of decision-making methodologies will add values and advantages to the particular body of knowledge. In decision-making theory, MCDM family developed in many areas and applications. The necessity of implementing an approach to constantly improve this branch of operations research is always admired because organisations, industries, communities and research centres are feed with such kind of innovative approach to make a structured decision making.

Table VIII. Sensitivity analysis tests and ranking of alternatives

	$T1$	$T2$	$T3$	$T4$	$T5$	$T6$	$T7$	$T8$	$T9$	$T10$
A_1	5	5	5	5	5	5	5	5	5	5
A_2	2	3	2	2	2	2	2	2	2	3
A_3	1	1	1	1	1	1	1	1	1	1
A_4	3	4	3	4	4	4	4	4	4	4
A_5	7	6	7	7	7	6	7	7	7	7
A_6	6	7	6	6	6	7	6	6	6	6
A_7	4	2	4	3	3	3	3	3	3	2
	$T11$	$T12$	$T13$	$T14$	$T15$	$T16$	$T17$	$T18$	$T19$	$T20$
A_1	5	2	2	3	2	3	2	3	2	4
A_2	3	1	3	2	4	2	3	2	3	1
A_3	1	3	1	1	1	1	1	1	1	2
A_4	4	4	4	4	5	4	5	5	5	3
A_5	7	6	6	6	6	6	6	6	6	6
A_6	6	7	7	7	7	7	7	7	7	7
A_7	2	5	5	5	3	5	4	4	4	5
	$T21$	$T22$	$T23$	$T24$	$T25$	$T26$	$T27$	$T28$	$T29$	$T30$
A_1	4	2	2	2	4	5	4	3	4	5
A_2	1	4	1	3	1	2	3	1	2	2
A_3	2	1	3	1	2	1	1	2	1	1
A_4	3	5	4	5	3	4	5	4	3	3
A_5	6	6	6	6	6	6	6	7	6	6
A_6	7	7	7	7	7	7	7	6	7	7
A_7	5	3	5	4	5	3	2	5	5	4
	$T31$	$T32$	$T33$	$T34$	$T35$	$T36$	$T37$	$T38$	$T39$	$T40$
A_1	3	2	2	2	5	5	5	5	3	5
A_2	4	3	3	4	1	1	2	2	4	1
A_3	1	1	1	1	2	2	1	1	1	2
A_4	5	4	5	5	3	3	3	3	5	4
A_5	6	7	6	6	7	7	6	6	6	7
A_6	7	6	7	7	6	6	7	7	7	6
A_7	2	5	4	3	4	4	4	4	2	3
	$T41$	$T42$	$T43$	$T44$	$T45$	$T46$	$T47$	$T48$		
A_1	4	2	3	4	5	5	5	5		
A_2	2	3	2	3	1	2	1	2		
A_3	1	1	1	1	2	1	2	1		
A_4	3	5	4	5	3	3	3	4		
A_5	6	6	7	6	7	6	7	7		
A_6	7	7	6	7	6	7	6	6		
A_7	5	4	5	2	4	4	4	3		

Table IX. A ranking comparison of other MCDM tools

	TOPSIS	VIKOR	COPRAS	WASPAS	MOORA	EDAS	CODAS	CoCoSo
A_1	5	5	3	5	5	4	4	5
A_2	1	2	1	2	1	1	1	2
A_3	2	1	2	1	2	3	2	1
A_4	3	4	5	4	4	2	5	4
A_5	7	7	7	7	7	5	7	7
A_6	6	6	6	6	6	7	6	6
A_7	4	3	4	3	3	6	3	3

The goal of this study is pertinent to a new approach in the MCDM domain. The paper proposes a new strategy to solve an MCDM problem through some specific modification to the main structure. To head to that goal, calculation of normalised criteria values, weighted comparability sequence, and the exponential weight of comparability sequences for

Weight	0.132 QD	0.135 *P*	0.138 ENRC	0.162 DS	0.09 GD	0.223 RRR	0.12 PP
S_1	0.068	0.066	0.15	0.098	0.156	0.114	0.098
S_2	0.078	0.076	0.108	0.136	0.082	0.171	0.105
S_3	0.157	0.114	0.128	0.083	0.108	0.113	0.131
S_4	0.106	0.139	0.058	0.074	0.132	0.084	0.12
S_5	0.103	0.187	0.125	0.176	0.074	0.064	0.057
S_6	0.105	0.083	0.15	0.051	0.134	0.094	0.113
S_7	0.137	0.127	0.056	0.133	0.122	0.119	0.114
S_8	0.1	0.082	0.086	0.06	0.062	0.109	0.093
S_9	0.053	0.052	0.043	0.1	0.05	0.078	0.063
S_{10}	0.094	0.074	0.097	0.087	0.08	0.054	0.106

Source: Yazdani *et al.* (2017)

Table X. Green supplier selection problem

	k_a	Ranking	k_b	Ranking	k_c	Ranking	k	CoCoSo	COPRAS	MOORA
S_1	0.0974	6	2.8816	6	0.8087	6	1.8727	6	5	4
S_2	0.1177	2	3.6851	2	0.9772	2	2.3446	2	2	2
S_3	0.1142	3	3.3882	3	0.9477	3	2.1991	3	4	3
S_4	0.1113	4	3.1467	4	0.9236	4	2.0803	4	6	5
S_5	0.0742	10	2	10	0.6158	10	1.3471	10	10	10
S_6	0.0832	8	2.4779	8	0.6906	8	1.6061	8	8	8
S_7	0.1205	1	3.8388	1	1	1	2.4265	1	1	1
S_8	0.1072	5	2.8991	5	0.89	5	1.9503	5	7	6
S_9	0.0778	9	2.3485	9	0.6457	9	1.5145	9	3	7
S_{10}	0.0964	7	2.595	7	0.8	7	1.7488	7	9	9

Table XI. Supplier ranking results of CoCoSo and comparison

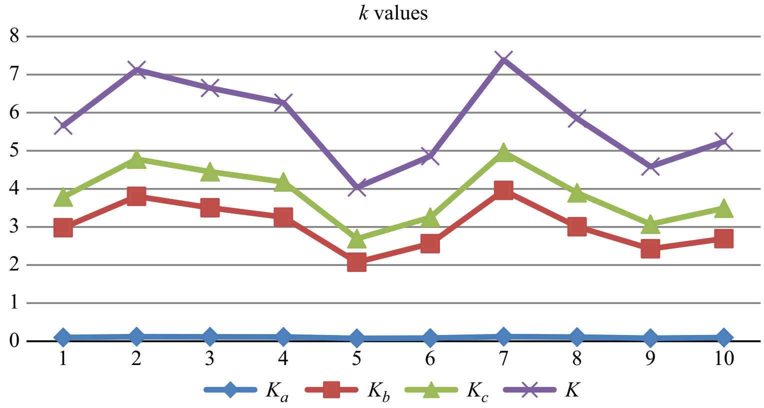

Figure 2. Comparison *k* values for the proposed algorithm

each alternative identified. Then, three aggregator strategies are established to form a complete measure. Generating of the relevant and adjusted aggregator to reach optimal rank index has been presented. An equation can correlate those three rank indexes ultimately, and alternative priorities are obtained. A real problem of logistic company's assessment in France is handled to examine the performance of the proposed algorithm. By some comparative analysis and through the evidence, the stability of the CoCoSo algorithm is also approved. The similarity of the results is very high with other MCDM approaches. The algorithm can compete with favourite tools like COPRAS, MOORA, and VIKOR as well. The authors suggest extending this algorithm by ordinary fuzzy sets, interval values, neutrosophic and intuitionistic fuzzy sets. Implementing and applying this new-born technique not only increases the accuracy of the decision making system, but also aids company policies, accredits the global objectives, and delivers the beneficial consequences to the management control.

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