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M-generalised q-neutrosophic extension of CoCoSo method

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Abstract

Nowadays fuzzy approaches gain popularity to model multi-criteria decision making (MCDM) problems emerging in real-life applications. Modern modelling trends in this field include evaluation of the criteria information uncertainty and vagueness. Traditional neutrosophic sets are considered as the effective tool to express uncertainty of the information. However, in some cases, it cannot cover all recently proposed cases of the fuzzy sets. The m-generalized q-neutrosophic sets (mGqNNs) can effectively deal with this situation. The novel MCDM methodology CoCoSomGqNN is presented in this paper. An illustrative example presents the analysis of the effectiveness of different retrofit strategy selection decisions for the application in the civil engineering industry.

Keywords: Multi-criteria decision making, CoCoSo, Neutrosophic sets, retrofit strategy.

1 Introduction

Multi-criteria decision making (MCDM) approaches introduce efficient tools to solve conflict situations for the managers. The MCDM process can be distinguished into the following steps:

a) Defining management system governing criteria which are associated with the compulsory decision-making goals;

b) Establishing the discrete alternative systems to reach the prescribed necessary goals;

c) Performing multicriteria analysis by any MCDM method;

d) Acknowledging one alternative as the best by the ranking results. Therefore, the application of the MCDM techniques facilitates the decision-makers to choose the best alternative, which provides a suitable compromise between all possibly conflicting criteria.

Therefore, the application of the MCDM techniques facilitates the decision-makers to embrace the alternative of the highest quality, which provides a suitable compromise between all possibly conflicting criteria. During the last decade, MCDM methods have actively been applied for the solution of the various real-life problems. In [5], the authors point out the following the most popular MCDM methods, such as SAW, WASPAS, VIKOR, TOPSIS, ELECTRE PROMETHEE methods. Recently, in [28] was proposed a new MCDM technique, which composes a combined compromise solution (CoCoSo). This method constructs the compromise solution applying various aggregation approaches. This method was under intensive research during the last years. In [39], the authors solved the problem of the ideal sustainable supplier choice by combining two methods: CoCoSo and the BWM method. In [14] was proposed a hybrid MCDM approach which is constructed by combining the CoCoSo and CRITIC approaches and applied to evaluate the 5G industries. In [25], the authors combined SWARA and CoCoSo methods to solve the drug cold chain logistics supplier evaluation and the location selection for a logistics center problems. This relatively new (CoCoSo) technique was applied to study the sustainability aspects in the OPEC countries [3]. The extension of the CoCoSo approach was proposed in [4]. The essence of this extension is the modelling environment in the form of normalized weighted geometric Bonferroni mean functions. This approach was employed to solve the supply chain problem. In [11], stochastic multi-criteria acceptability analysis was performed within the multi-criteria decision-making framework, namely the CoCoSo approach, to handle the problem of the renewable energy investments with stochastic information. This hybrid approach is based on the DIBR method, which defines interrelationships between the ranked criteria, and the D'CoCoSo approach, which is modelled under fuzzy Dombi environment. This technique was applied to solve prioritizing aspects of the circular economy concepts for urban mobility [12]. The two-stage decision-making technique, which was realized by the data envelopment analysis (DEA) and the RCoCoSo method, which was modelled under rough full consistency (R-FUCOM) environment, was discussed in [30]. The tourism attraction selection problem was utilised by applying the probabilistic linguistic term set. For the solution, IDOCRIW and CoCoSo approaches are implemented [9]. Different versions of the hybrid MCDM proposals based on the CoCoSo technique have been presented in [23], [10], [24], [6].

Modern research in the area of multi-criteria decision-making tries to model the indeterminacy and inconsistency of the initial decision making information, which prevails in most cases of real-life applications. Therefore, different fuzzy set variations have been proposed starting width the pioneering work in [33]. Existing challenges and future development trends of the fuzzy modelling importance in the decision-making field have been discussed in [27]. During the last years have been proposed the different extensions of the CoCoSo method applying the environments of the different fuzzy sets.

In [29], the authors modelled the best supplier problem in construction management applying grey numbers and solving this problem with the DEMATEL, BWM, and CoCoSo methods. In [26] was considered the problem of the third party logistics service providers applying a hesitant linguistic fuzzy set environment to construct the extent of the CoCoSo method. In [13], the authors applied a q-rung orthopair fuzzy set to develop a hybrid MCDM extension including CoCoSo and CRITIC methods and tested this approach on the financial risk evaluation problem. In [1], the authors suggested a novel interval-valued intuitionistic set model for CoCoSo method extension and solved the problem of the sustainable evolution in the fabrication region by means of green growth indicators. In [17], was proposed a CoCoSo method extension applying a single-valued neutrosophic set. This technique was applied to deal with the problem of the equipment selection for the waste management field including sustainability aspects. Various fuzzy set environments have been implemented to model multi-criteria decision-making problems [15], [16], [31], [32], [37], [21], [7], [7]. [8], [35], [38].

In 1999, Smarandache [19] proposed the notion of the neutrosophic sets. Neutrosophic sets (NS) are based on the generalization of the fuzzy logic that takes into account the knowledge of neural thought. Therefore, the greater amount of uncertainty can be analyzed. Each parameter of the analyzed problem can be represented by the scope of the truth (T), the scope of the indeterminacy (I) and the scope of the falsity (F) using the NS logic. In 2019, a notion of neutrosophic sets, which can be considered as the generalization of the following fuzzy sets: intuitionistic fuzzy (IFS), q-rung orthopair fuzzy and Pythagorean fuzzy sets was proposed by Smarandache [20]. Based on this concept, the new extensions of the classical MCDM methods, like MULTIMOORA, WASPAS, PROMETHEE [34], [18], [2], were developed by applying the environment of the m-generalized q-neutrosophic sets (mGqNSs).

The structure of the paper is established as follows. The second chapter presents the basic foundations of the m-generalised q- neutrosophic sets. The third chapter provides the proposed extension of the CoCoSo method under the environment m-generalised q- neutrosophic set. The problem formulation together with the solution procedure of the case study are presented in the fourth chapter. The paper ends with conclusions.

2 Foundations of the m-generalised q-neutrosophic set

First, the m-generalised q-neutrosophic set (mGqNS) prevailing definitions and the algebraic operations are presented. The algebraic operation presentation is constructed by applying m-generalised q-neutrosophic numbers (mGqNNs). These neutrosophic numbers form the basis of the proposed CoCoSo method extension, namely CoCoSo-mGqNS.

2.1 Definitions

Definition 1. *The modelled objects form the set X, in which every single object is $x \in X$. In the present research, the objects are represented by a neutrosophic set. Given that X is a set of criteria modelled under the m-generalised q-neutrosophic environment, x is a single criterion value.*

Let $q \geq 1$, $m = 1 \parallel 3$. The three membership functions define m-generalised q-neutrosophic set A_{mq}:

$$T_{mq}, I_{mq}, F_{mq} : X \to [0, r], \text{ here } (0 \leq r \leq 1)$$

Given T_{mq} is the m-generalised function representing the scope of the truth, I_{mq} is the m-generalised indeterminacy membership function and F_{mq} is the m-generalised falsity membership function. In such a way, the m-generalised q-neutrosophic set is prescribed by the following expression:

$$A_{mq} = \{\langle T_{mq}(x), I_{mq}(x), F_{mq}(x)\rangle : x \in X\}$$

These three membership functions also must comply with the following requirements:

$$0 \leq T_{mq}(x), I_{mq}(x), F_{mq}(x) \leq 1, \ x \in X;$$
$$0 \leq (T_{mq}(x))^q + (I_{mq}(x))^q + (F_{mq}(x))^q \leq \frac{3}{m}, \ x \in X;$$

The different m and q values represent different fuzzy sets.

Definition 2. *The m-generalised q-neutrosophic number, mGqNN, is represented by the following expression:*

$$N_{mq} = \langle t, i, f\rangle$$

Definition 3. *The summation of the two mGqNNs, when* $N_{mq_1} = \langle t_1, i_1, f_1 \rangle$ *and* $N_{mq_2} = \langle t_2, i_2, f_2 \rangle$ *are the m-generalised q-neutrosophic numbers, we can designate as follows:*

$$N_{mq_1} \oplus N_{mq_2} = \langle (1-(1-t_1^q)(1-t_2^q)^{\frac{1}{q}}, i_1 i_2, f_1 f_2 \rangle \tag{1}$$

The multiplication between the two mGqNNs can be performed as follows:

$$N_{mq_1} \otimes N_{mq_2} = \langle t_1 t_2, (1-(1-i_1^q)(1-i_2^q))^{\frac{1}{q}}, (1-(1-f_1^q)(1-f_2^q))^{\frac{1}{q}} \rangle \tag{2}$$

The multiplication operation of the m-generalised q-neutrosophic number and a real number $\lambda \geq 0$ *is performed as follows:*

$$\lambda \cdot N_{mq_1} = \langle (1-(1-t_1^q)^{\lambda})^{\frac{1}{q}}, i_1^{\lambda}, f_1^{\lambda} \rangle \tag{3}$$

When $\lambda \geq 0$*, the power function of mGqNN can be determined by:*

$$N_{mq_1}^{\lambda} = \langle t_1^{\lambda}, (1-(1-i_1^q)^{\lambda})^{\frac{1}{q}}, (1-(1-f_1^q)^{\lambda})^{\frac{1}{q}} \rangle \tag{4}$$

The complementary m-generalised q-neutrosophic numbers is calculated as:

$$N_{mq}^{c} = \langle f_1, 1-i_1, t_1 \rangle \tag{5}$$

Definition 4. *For the deneutrosophication step, the score value* $S(N_{mq})$ *can be calculated as follows:*

$$S(N_{mq}) = \frac{3+3t^q-2i^q-f^q}{6} \tag{6}$$

In this case, for $N_{mq_1} = \langle t_1, i_1, f_1 \rangle$ *and* $N_{mq_2} = \langle t_2, i_2, f_2 \rangle$ *the comparison operations will be completed by the following condition:*

$$\begin{array}{l} \textit{If } S(N_{mq}) \geq S(N_{mq}) \text{ , } \textit{then } N_{mq} \geq N_{mq} \\ \textit{If } S(N_{mq}) = S(N_{mq}) \text{ , } \textit{then } N_{mq} = N_{mq} \end{array} \tag{7}$$

3 Combined compromise solution (CoCoSo-mGqNN) method

A new extension of the CoCoSo method under m-generalised q-neutrosophic set environment, namelly CoCoSo-mGqNN, is designed. The main steps of this approach can be expressed as follows:

(1) Solution procedure of the CoCoSo method starts with the constructed initial decision-making matrix which can be defined as follows:

$$x_{ij} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1l} \\ x_{21} & x_{22} & \cdots & x_{2l} \\ \vdots & \vdots & \ddots & \vdots \\ x_{k1} & x_{k,2} & \cdots & x_{kl} \end{bmatrix} ; i=1,2,\ldots,k; j=1,2,\ldots,l. \tag{8}$$

(2) The compromise normalization approach is applied to normalize the decision-making matrix elements [36]:

$$r_{ij} = \frac{x_{ij} - \min_i x_{ij}}{\sqrt{k}(\max_i x_{ij} - \min_i x_{ij})} \text{ for maximised criteria,} \tag{9}$$

$$r_{ij} = \frac{\max_i x_{ij} - x_{ij}}{\sqrt{k}(\max_i x_{ij} - \min_i x_{ij})} \text{ for minimised criteria.} \tag{10}$$

The standard compromise normalization equation is slightly modified to make it be applicable for neutrosophic algebra.

(3) Next, the neutrosophication of the decision matrix should be accomplished. This means that crisp values r_{ij} of the decision matrix elements are replaced by the values $(N_{mq})_{ij}$ of m-generalised truth membership, m-generalised indeterminacy membership and m-generalised falsity membership functions. This action is performed applying the standard crisp-to-neutrosophic mapping. The novel m-generalised neutrosophic decision matrix is created at this step.

(4) At this step, the weighted comparability series and the power weighted comparability series for each alternative are constructed. These series are denoted by R_i and P_i, respectively:

$$R_i = \sum_{j=1}^{l}(w_j(N_{mq})_{ij}) \tag{11}$$

the R_i series reflect weighted sum model:

$$P_i = \sum_{j=1}^{l}((N_{mq})_{ij})^{w_j} \tag{12}$$

the P_i series correspond to the WASPAS multiplicative component.

(5) Three score assessment strategies are the basis for the calculations of the relative weights. These strategies are expressed by the following equations (13)-(15).

$$k_{ia} = \frac{S(P_i) + S(R_i)}{\sum_{i=1}^{k}(S(P_i) + S(R_i))}, \tag{13}$$

$$k_{ib} = \frac{S(R_i)}{\min\limits_i S(R_i)} + \frac{S(P_i)}{\min\limits_i S(P_i)}, \tag{14}$$

$$k_{ic} = \frac{\lambda S(R_i) + (1-\lambda)S(P_i)}{\lambda \max\limits_i S(R_i) + (1-\lambda)\max\limits_i S(P_i)}; 0 \leq \lambda \leq 1. \tag{15}$$

By equation (13), arithmetic mean values of the weighted sum model (WSM) and weighted product model (WPM) are calculated. By equation (14), relative scores of WSM and WPM are determined. These relatives scores are determined with respect to minimum values of $S(P_i)$ and $S(R_i)$. By equation (15), the balanced compromise scores of WSM and WPM models are calculated. In our case, value for $\lambda = 0.5$ is chosen.

(6) The final ranking function is constructed as follows:

$$k_i = (k_{ia}k_{ib}k_{ic})^{\frac{1}{3}} + \frac{1}{3}(k_{ia} + k_{ib} + k_{ic}). \tag{16}$$

4 Case study

A secondary school is the object of the research [22]. The school's frame is a three-story reinforced concrete frame (constructed in the eighth decade of the twentieth century). The 2478.60 m2 building has 240 mm thick aerated concrete slab exterior walls and the 200 mm thick reinforced concrete block plinth. Under part of the building was a local diesel boiler house. The building has plastered and painted external and external surfaces. The local municipality decided to renovate the structure according to the prepared project. They provide the following thermal insulation: 200 mm thick mineral wool boards for walls and 200 mm thick polystyrene boards for the plinth. The project envisages the roof insulated with 250 mm thick extruded polystyrene panels and an upper 20 mm thick mineral wool panels. Besides, old windows and doors need replacement as planned.

The most significant part of construction projects are multifaceted, and decision-makers must take into account tangible and intangible characteristics of plans, opinions, negotiations and dispute resolution and projects.

Decisions in the construction industry need compromise solutions [28], [29], [35]. Project managers should select among feasible discrete alternatives in a specific construction site and specific objects taking into account international and local perspectives. Designers presented nine possible project implementation scenarios. The building renovation process could involve several phases and be selected from other options with different employees (20, 40 or 60 for retrofitting at different speeds), see Table 1.

The project implementation contractor offered the following project implementation choices:

1. **One-phase retrofitting process**: The general contractor shall carry out all modernisation works in one phase:
    - Replacement of windows, exterior and interior doors; b) Insulation of basement and external walls and roof;
    - Installation of the roof;
    - Renovation of heating, ventilation, air conditioning and electrical systems;
    - Installation of a new lighting system.

      The modification process may affect the efficiency of the project due to the multi-tasking of the retrofitting methods.

2. **Two-phase retrofitting process**: The upgrading process takes place in two phases:
    - The first phase includes replacing windows and exterior doors, repairing the roof, and installing thermal insulation of exterior walls and the basement;
    - The second phase includes installing thermal insulation of ground-level floors, updating heating, ventilation, air conditioning and electric lighting systems.

      There is a nine months break between the first and the second phases. The employees work during the summer seasons (summer holidays).

      There is a risk (depending on the number of employees) that contractor not all works will finish in time, so construction work can adversely affect physical performance.

3. **Three-phase retrofitting** :
    - The first phase includes replacing windows and exterior doors;
    - The second phase includes repairing the roof and installing thermal insulation of exterior walls and the basement;
    - The third phase includes installing thermal insulation of ground-level floors, updating heating, ventilation, air conditioning and electric lighting systems.

      The contractor will make a one-year break between the first and the second phases. The employees work during the summer seasons (summer holidays).

      There is a risk (depending on the number of employees) that contractor not all works will finish in time, so construction work can adversely affect physical performance.

Many of the contradictory features reflect the solution to a complex problem. The authorities usually determine the winners based on a single indicator, the lowest price at the local level. This attitude of civil servants incorrectly describes the real economic benefits of renovating buildings and other features of modernised buildings. After three steps of the Delphi method, the decision-makers selected five key characteristics that assessed the renovation's economic benefits and the impact of the construction process on workers and visitors.

Costs with VAT, [€]: The construction works costs interlinks with the amount of work required to complete the project, the current price level in the country (salary, prices of materials and equipment), the number of potentially competitive contractors and their competitive advantages, construction time and project implementation time. Longer project implementation time and an increasing number of

Table 1: Initial decision-making matrix

Alternatives	Price with VAT, €	Number of working days (8 working hours per day)	Renovation's payback time, [years]	Energy savings through ten years, [MWh]	People's satisfaction, [scores]
A_1	1309.50	800	21.86	3656.0	6.66
A_2	1309.50	510	21.86	3656.0	11.38
A_3	1309.50	320	21.86	3656.0	12.89
A_4	1379.0	920	21.86	3524.4	7.46
A_5	1379.0	640	22.60	3524.4	12.18
A_6	1415.0	440	22.60	3524.4	13.69
A_7	1415.0	980	23.18	3188.7	8.27
A_8	1415.0	700	23.18	3188.7	12.98
A_9	1415.0	500	23.18	3188.7	14.49
Optimality	min, ↓	min, ↓	min, ↓	max, ↑	max, ↑

stages of construction processes increase construction costs. Longer-term constructions are expensive because the project requires household and storage facilities to bring and take out bio-toilets, temporary construction site's fencing, lighting, and need to implement protection measures.

Duration of project implementation [working days]: depends on the number of outputs (person-hours) and the number of workers on the construction site. This study examines the project implementation options (twenty, forty or sixty employees employed on the construction site). The contractors comply with all the necessary construction technology and safety requirements. They cannot perform the work faster than the established technological requirements in terms of time. For instance, it cannot paint the facade until three weeks have elapsed since the end of the plastering. The mineral plaster is undergoing chemical processes at that time.

Renewal payback period, [years]: The customers calculate this time according to the investment required for the construction work and the energy savings. They consider the efficiency of the work performed (such as replacing exterior doors and windows). The fuel's calorific value, the boiler's efficiency, the level of fuel prices and laboratory tests of the research object are the basis for calculating the economic payback time. Laboratory research shows actual energy savings by implementing specific design modernisation solutions.

Energy savings over ten years, [MWh], determine the expected economic benefits and return on investment. Calculating the value of this indicator over a more extended period is very difficult or even impossible due to the significant change in inflation, the change in energy prices and the price of energy resources, the changing rate requirements that govern the environmental impact and many other reasons. The changing climate is also contributing to its contribution. Determining energy savings by calculating energy consumption [MWh] rather than monetary value [€] partially reduces this uncertainty.

People Satisfaction, [points]: Survey of members of interest groups (building staff and visitors) is the basis for calculating this characteristic. Twenty-five stakeholders gave nine points for the best available option and one for the worst. Decision-makers multiplied the final scores by 100 per cent at the end. Determining weights of attributes is one of the most important and critically acclaimed issues in multi-attribute decision-making problems. The decision-makers chose and applied a systematic procedure for the study: the SWARA (Step-wise Weight Assessment Ratio Analysis) method.

The formulated initial decision-making matrix is presented in Table 1, and the normalized values of the weights are w=(0.37, 0.12, 0.36, 0.1, 0.05). At the following step the proposed extension CoCoSo-mGqNN was applied to perform the final ranking of the alternatives. The normalization of the decision-making matrix was performed applying equations (9-10). The elements of the initial decision-making matrix after the normalization step are presented in Table 2. The results of the neutrosophication step are presented in Table 3. The intermediate results of the proposed extension CoCoSo-mGqNN together with final ranking results are presented in Table 4.

Table 2: Initial decision-making matrix

Alternatives	X_1	X_2	X_3	X_4	X_5
A_1	0.3333	0.0909	0.3333	0.3333	0
A_2	0.3333	0.2374	0.3333	0.3333	0.2009
A_3	0.3333	0.3333	0.3333	0.3333	0.2652
A_4	0.1137	0.0303	0.3333	0.2395	0.0341
A_5	0.1137	0.1717	0.1465	0.2395	0.2350
A_6	0	0.2727	0.1465	0.2395	0.2993
A_7	0	0	0	0	0.0685
A_8	0	0.1414	0	0	0.2691
A_9	0	0.2424	0	0	0.3333
Optimality	min, ↓	min, ↓	min, ↓	max, ↑	max, ↑

Table 3: Neurosophic decision-making matrix

Alternatives	X_1	X_2	X_3	X_4	X_5
A_1	(0.3333, 0.7167, 0.6667)	(0.0909, 0.9091, 0.9091)	(0.3333, 0.7167, 0.6667)	(0.3333, 0.7167, 0.6667)	(0.0, 1.0, 1.0)
A_2	(0.3333, 0.7167, 0.6667)	(0.2374, 0.8126, 0.7626)	(0.3333, 0.7167, 0.6667)	(0.3333, 0.7167, 0.6667)	(0.2009, 0.8491, 0.7991)
A_3	(0.3333, 0.7167, 0.6667)	(0.3333, 0.7167, 0.6667)	(0.3333, 0.7167, 0.6667)	(0.3333, 0.7167, 0.6667)	(0.2652, 0.7848, 0.7348)
A_4	(0.1137, 0.8931, 0.8863)	(0.0303, 0.9697, 0.9697)	0.3333, 0.7167, 0.6667)	(0.2395, 0.8105, 0.7605)	(0.0341, 0.9659, 0.9659)
A_5	(0.1137, 0.8931, 0.8863)	(0.1717, 0.8641, 0.8283)	(0.1465, 0.8768, 0.8535)	(0.2395, 0.8105, 0.7605)	(0.2350, 0.8150, 0.7650)
A_6	(0.0, 1.0, 1.0)	(0.2727, 0.7773, 0.7273)	0.1465, 0.8768, 0.8535)	(0.2395, 0.8105, 0.7605)	(0.2993, 0.7507, 0.7007)
A_7	(0.0, 1.0, 1.0)	(0.0, 1.0, 1.0)	(0.0, 1.0, 1.0)	(0.0, 1.0, 1.0)	(0.0685, 0.9315, 0.9315)
A_8	(0.0, 1.0, 1.0)	(0.1414, 0.8793, 0.8586)	(0.0, 1.0, 1.0)	(0.0, 1.0, 1.0)	(0.2691, 0.7809, 0.7309)
A_9	(0.0, 1.0, 1.0)	(0.2424, 0.8076, 0.07576)	(0.0, 1.0, 1.0)	(0.0, 1.0, 1.0)	(0.3333, 0.7167, 0.6667)
Optimality	min, ↓	min, ↓	min, ↓	max, ↑	max, ↑

Table 4: Intermediate results of the CoCoSo-mGqNN and the final ranking of the alternatives

Alternatives	R	P	k_a	k_b	k_c	k	$Rank$
A_1	(0.3139, 0.7498, 0.7061)	(0.9728, 0.0548, 0.0425)	0.1241	60.8264	0.9529	22.5646	3
A_2	(0.3201, 0.7337, 0.6837)	(0.9960, 0.0163, 0.0106)	0.1288	63.7319	0.9895	23.6271	2
A_3	(0.3306 0.7199 0.6699)	(0.9973, 0.0123, 0.0080)	0.1302	66.0184	1.0000	24.4313	1
A_4	(0.2488, 0.8285, 0.7998)	(0.9786, 0.0485, 0.0404)	0.1168	45.1218	0.8715	17.0566	4
A_5	(0.1628, 0.8712, 0.8478)	(0.9914, 0.0342, 0.0255)	0.1135	35.2094	0.8715	13.5805	5
A_6	(0.1848, 0.8932, 0.8690)	(0.9937, 0.0364, 0.0270)	0.1115	30.6951	0.8561	11.9850	6
A_7	(0.0253, 0.9965, 0.9965)	(0.8746, 0.4295, 0.4295)	0.0778	2.0000	0.5973	1.3446	9
A_8	(0.1098, 0.9726, 0.9666)	(0.9689, 0.1596, 0.1405)	0.0969	9.3949	0.7439	4.2899	8
A_9	(0.1533, 0.9586, 0.9478)	(0.9793, 0.1249, 0.1048)	0.1006	13.7132	0.7727	5.8837	7

5 Conclusion

Modern modelling trends in this field include evaluation of the uncertainty and vagueness of the initial information. Traditional neutrosophic sets are considered as the effective tool to express uncertainty of the information. However, in some cases, it cannot cover all recently proposed cases of the fuzzy sets. The m-generalized q-neutrosophic sets were recently proposed to deal with this situation. The m-generalized q-neutrosophic sets can be considered as the generalisation of fuzzy set, Pythagorean fuzzy set, intuitionistic fuzzy set, q-rung orthopair fuzzy set, single-valued neutrosophic set, single-valued n-hyperspherical neutrosophic set and single-valued spherical neutrosophic set. In this paper, the CoCoSo method extension under the environment of the m-generalized q-neutrosophic numbers (mGqNN) is proposed. This novel extension has been tested for the selection of the best retrofit strategy. The numerical example also showed that the CoCoSo-mGqNN extension provides a robust approach that can be applied to deal with different fuzzy sets within the same MCDM framework.

Author contributions

The authors contributed equally to this work.

Conflict of interest

The authors declare no conflict of interest.

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