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RESEARCH ARTICLE

A multi-hierarchical framework for ranking maintenance sustainability strategies using PROMETHEE and fuzzy entropy methods

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Abstract Today, maintenance plays a significant responsibility in all stages of equipment life due to strong government interests in environmentally conscious manufacturing. The need of the hour is to ignore the sparse attention to sustainable maintenance research and pursue valuable links between maintenance strategy and sustainable maintenance. In maintenance strategy choice, available reports have not sufficiently addressed the imbalance caused by uncertainties in maintenance practices. In addition, current reports on maintenance strategy sustainability focus on technical and economic aspects of maintenance and scantily treat environmental, social and safety criteria. This affects the quality of decisions in maintenance systems. To remedy this situation, this study applies fuzzy entropy weight and PROMETHEE (Preference Ranking Organisation Method for Enrichment Evaluation) in ranking maintenance sustainability strategies. The proposed approach is tested in a cement plant. Based on the choice criteria, the PROMETHEE methods results identified the best maintenance strategy as maintenance optimisation strategy. Workforce training strategy was identified as the worst maintenance sustainability strategy. These obtained results were compared with fuzzy TOPSIS (Technique of Preference Order by Similarity to Ideal Solution) approach and the practical application of the approach was verified. The results serve as a basis and a platform for further application of the approach in other manufacturing companies.

Keywords PROMETHEE methods · Maintenance sustainability strategies · Fuzzy entropy weighting · Manufacturing system · Fuzzy TOPSIS

1 Introduction

Nowadays, besides the drive for enhanced equipment reliability, availability and maintainability, sustainability is perceived as central to the responsibility of the manufacturing concerns. Government regulations together with the short- and long-term economic advantages of executing environmentally-conscious manufacturing enhancements are compelling organisations to make sustainable maintenance their defaults. Consequently, the necessity of implementing the correct maintenance strategy is a non-negotiable focus of organisations. This has made the use of scientific (multi-criteria) tools with proven ability attractive instruments for value-driven maintenance strategy implementation. However, cement plants are yet to have not fully enjoyed the benefits of multi-criteria tools in its maintenance practices. Despite the facts that cement manufacturing maintenance activities need to be sustainable.

For short range, cement manufacturers may escape the treatment of its factory effluents, by avoiding extra costs, inconveniences and process slow-down as a result of slow responses for funds release by the responsible offices for effluent control pursuits. Likewise, the training of the workers (maintenance) on effluent control will certainly affect their normal day to day activities, including planned preventive maintenance (PM) schedules that may be disrupted. This result in increased costs, also, as overtime may

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be arranged to cover the lost maintenance time as the same workforce to carry out scheduled PM are responsible for the job training programme on effluents. Thus, the due period for the release of money for the treatment of effluents by the finance division of the organisation and the length of job training period on effluent control are important. Others include the lost hours of PM planning and so on. The sum of these periods is fuzzy, showing uncertainty in their completion times. Furthermore, effluent is only one of the several tenths of activities that come under sustainable maintenance. And so the computation of the performance of this system is complex. How important is one activity to the other? This is not known as it is complicated.

To ease the burden of monitoring these issues mentioned above, multi-criteria tool is needed for both fuzzy treatment as well as the priority of one activity relative to the other. Now, going back to the cost issue, we declare that there may be several other costs that may be incurred in the short-range, including recurring or preventive repairs at pre-defined cycles, slight modifications, lubrication, oil changes and so forth. In the long range, avoiding these costs brings a larger and more burdensome cost into play. Due to the accumulation of effluents in the community, it is usual to observe the affected community embarking on litigations with the company. The company may be charged for corporate irresponsibility, to have given birth to environmental degradation. Litigation arises as a result of irresponsiveness to protect the community from environmental harassments. This litigation cost alone runs into several millions of hard-earned currency, and may even threaten the existence of the organisation. By positing the above argument, we make notable contributions to maintenance and sustainability research. First, this work provides an account of the treatment of uncertainties arising from maintenance sustainability efforts by taking a look at the problem and proposing fuzzy entropy approach for evaluating the importance of maintenance sustainability sub-criteria. Second, PROMETHEE (Preference Ranking Organisation Method for Enrichment Evaluation) as ranking in maintenance sustainability strategies is proposed. Third, this work contributes to research on maintenance sustainability by revealing the scope of sustainability, including environmental, social and safety, technical and economy criteria.

The goal of this work is to determine the best maintenance sustainability strategy for a manufacturing organisation using PROMETHEE methods. The weights which are used for PROMETHEE are generated using fuzzy entropy weighted approach. Weights are generated from multi-hierarchy (hierarchy I) and multi-criteria (hierarchy II) perspectives when the ranking maintenance sustainability strategies. The performance of PROMETHEE method was compared with TOPSIS (Technique of Preference Order by Similarity to Ideal Solution). This article has the following structure. The opening section has provided enough motivation for the work. This is followed by a review of relevant literature through a survey. In Sect. 3, the presentation of the structure of the framework is made. The case study discussion follows in the reset section. The concluding section is the final part of the work.

2 Literature review

2.1 General overview

In the adoption of the theory guiding sustainable practices [7, 28] to maintenance engineering, the difficulty often encountered is the basis on which sustainability should be defined given. This is because no consensus of definition concerning this term exist [28]. This influences our decision on the formulation of maintenance sustainability problem and the development of an appropriate solution methodology suited for the needs of manufacturing concerns. In evolving an acceptable methodology, conscious efforts were made to adopt the CEN/TC 350 framework [8–11, 28]. This adopted framework has been successfully applied in the building sector [28]. Its potentially would greatly enhance sustainability practices in maintenance. The framework has five basic tenets of environment, economy, socials and safety as well as and technical matters.

A launch into the maintenance literature, for example, maintenance optimisation, reveals the basic pre-occupation of researchers on maintenance. From this prospective a number of articles were found focusing largely on technical matters, which include inventory optimisation [47], workforce sizing [25], failure investigation [42], maintenance policy [50], modelling [32], warranty modelling [44]. Other studies have incorporated economy in the conventions of their models [26, 51].

In the past few years, sustainability issues are being recognised as critical for maintenance survivability. Wang and Levrat [48] advocated for an association of ecological issues with manufacturing and in particular, maintenance. This viewpoint has been shared by other authors, including Hennequin and Restropo [22]. They insisted that an integrated maintenance a well as production model should incorporate sustainability issues. Still on the sustainability controversy in maintenance the contribution of the Henderson et al. [23] also stands tall in this regard. Till date, the attention of most maintenance research and more specifically maintenance optimisation discussions had been on the technical issues. Classical discourse prevails, calling for novel integrations of concepts. One of these is the association of maintenance as well as production functions in the course of optimisation as advanced by Hennequin and Restropo [22]. Another call has been in favour of multi-criteria issues in maintenance, which implies holistic approach to maintenance issue treatments. While we support the integrated maintenance and production modelling, the innovation in adopting multi-criteria viewpoints in modelling maintenance is equally important. The current study is based on the perspective of multi-criteria modelling in developing a framework that accounts for all the tenets of sustainability in maintenance.

The present optimisation frameworks in maintenance are nice in the enhancement of manufacturing systems maintenance. The major shortcoming is that such optimisation frameworks hardly allow an evaluation of available technical issues and their interactions with the social aspects of maintenance. Hence, influences that such existing models may have in the sustainability of such maintenance concerns are not understandable. Although, economy issues have been incorporated in maintenance optimisation models, a great deal have been down played when considering the synergic possibility it has with other factors such as social issues. In addition, there appears to be absence of a tool of commercial nature that could aid practitioners in evaluating sustainability of maintenance in manufacturing systems along these important sustainability dimensions. This is a gap in maintenance literature, which when addressed will help researchers in detailing out the procedure for analysing and understanding the direction of solution in solving maintenance sustainability problems. This will change the perception been given to maintenance from a negative viewpoint to a positive one. For instance, maintenance has been viewed as a bottom less part of expenses [37]. This viewpoint is charging with the sustainability perspective of maintenance. In fact, Henderson et al. [23] showed the real picture of the negative outlook maintenance has to be public by stating that maintenance is known to provoke costs and trigger downtime. Henderson et al. [23] maintained that sustainability remains unique avenue to counter maintenance costs and change the perspective that maintenance is viewed from. Thus, this paper contribution to the current discussion on sustainability issues in maintenance. It results will enlighten stakeholders in maintenance on how to select the most suitable maintenance sustainability strategy for their system.

2.2 Maintenance and sustainability issues

Sustainable maintenance (SM) deals with a branch of learning and practice that reflects a systems' continued existence coupled with the role to reduce total operational cost, enhance quantity, lessen unreliability of equipment and promote excellence in the overall performance of plant. The SM field has substantial capability to affect significant areas of the technical activities, environment and social settings. Literature in this field has not fully demonstrated this capability. Many studies on maintenance directs attention to technical issues such as scheduling [4, 6, 30]. Internal degradation and external shock damage [18], prioritisation [27], decision making (Tang et al. [45]), reliability centred maintenance [38] are other areas of maintenance focus. Piasson et al. [38] presented a multi-objective reliability-centred maintenance framework aimed at reducing the cost of preventive maintenance in power distribution system. The conclusion of the report was the attainment of a robust, quality feedback from the practical case test from a three-feeder, 733-component organisation.

Bozorgi et al. [6] in an effort to enhance profit of generation companies explored the unit maintenance scheduling as a maintenance method. They considered a situation in which there may be unavailability of future data from the angle of fuzzy cost. A robust framework that proved to be effective was presented for the concurrent consideration of short and medium-term programmes. Zhou et al. [51] presented a framework that permits leased equipment that exhibits persistent internal decay using equipment's hazard rate. Their framework reduces the additive maintenance cost of leased equipment. It was concluded the model effectively declares the reliability of the equipment and separates the effects of external decay from internal decay. Li and Pan [30] developed a procedure that solves job-shop problem with maintenance activities at the centre of the procedure. Their work accounted for fuzziness through the incorporation of a measure that introduces uncertainty into the processing time.

Duran [17] considered the issues of ambiguity and uncertainty of factors in the choice of a specific computerised maintenance management using a multi-criteria analysis. The validity of the work was confirmed with a software program. Madhikermi et al. [34] carried out a review on the quality evaluation of maintenance data reporting steps.

From the understanding of the mentioned literature, the above-mentioned technical and conceptual literature on maintenance rarely extends this paper argument on sustainable maintenance. Contemporary maintenance practice has developed beyond the traditional conservative view and must be transformed to incorporate into the new perspective of sustainable maintenance. In order to make a strong case for sustainable maintenance, Hennequin and Restrepo [22] criticised the literature on sustainability. They observed that scholars seem to disdain the social aspects of sustainability with respect to having cause or being a solution to environmental issue. Furthermore, Hennequin and Restrepo [22] stated that safety and health of workers in a manufacturing plant is an aspect of social sustainability perspective.

Sustainable maintenance involves safety and human elements but very little literature has identified this. The contributions of Chiu and Hsieh [13] and Azadeh et al. [3] are parts of the few reports that drive maintenance towards sustainability perspective. Their studies considered the soft aspects of maintenance, and one that will influence the well-being of the employee. Chiu and Hsieh [13] developed an analytical process to evaluate human error with application in maintenance activities of aviation systems. Using HFACS, RCA and fuzzy TOPSIS, the work was founded on a approach for assessing human error. It was confirmed to be an effective approach. Azadeh et al. [3] contributed a unified method for optimising factors that aid in the implementation of activities of health, safety and environments in the actualisation of maintenance activities. The main pillars of their model are the fuzzy-oriented data envelopment analysis and Deming's constant enhancement cycle. Hennequin and Restrepo [22] raised the issue of uncertainty and fuzziness brought about by humans in system. This impression has long been recognised by scholars, who without even treating the subject of sustainability have incorporated it into their maintenance models [27, 33].

Jamshidi et al. [27] proposed a three stage approach for the choice of the most appropriate strategy for the maintenance of medical equipment. The approach consists of a failure-modes-and-effects-analysis-fuzzy based tool, a miscellaneous seven-dimensioned method and a strategy selection tool based on inputs from the previous two stages. Maatouk et al. [33] hybridised fuzzy logic-directed genetic algorithm as well as local search in the solution of a maintenance problem. They developed an optimisation framework that consists of many state series–parallel units in order to minimise overall cost. Balaji et al. [4] developed a mixed-integer optimisation problem for generator maintenance scheduling and tested the assisted differential evolution approach with two test problems. The conclusion of the work was that the results showed ability to provide optimal maintenance schedule.

Kumar and Maiti [29] dealt with the selection of maintenance policy using an industry as focus units. Their work used fuzzy analytic network process. The model was verified in a chemical industry and it was concluded that condition-based maintenance has preference in situations of great risks. They reported that corrective maintenance is the choice for low risk occurrences. Al-Najjar and Alsyouf [1] evaluated maintenance methods using a fuzzy multi-criteria decision making framework. Their model has the capacity to reduce cost due to failure. Bashiri et al. [5] used a fuzzy interactive linear assignments method to determine optional selection strategy for maintenance system. The method was claimed to be easily adaptable by managers. Hennequin and Restrepo [22] treated the problem of economic operations when simultaneous control of production and maintenance activities are involved.

3 Research methodology

This study methodology is based on the selection of maintenance sustainability strategy among maintenance policy (S_1), maintenance consumables optimisation (S_2), workforce training (S_3) and waste reduction and disposal (S_4). Environmental, social and safety, technical and economy are considered as four main criteria for maintenance sustainability strategy selection [24]. These elements have sub-criteria that are used for PROMETHEE method implementation (Fig. 1). In Fig. 1, the result from hierarchy I generates four options for decision-making. This is achieved using all the sub-criteria of the main criteria (Fig. 1). Hierarchy II generates one option for selecting the appropriate maintenance sustainability strategy for a manufacturing system.

PROMETHEE method is adopted in the current paper for ranking purposes due to the substantial advantages that it showcases over other ranking methods. In the first instance, PROMETHEE method exhibits the exclusive benefits in situation where vital building blocks of the choices exist. A second important benefit of a PROMETHEE is the fact of its straight-forwardness in applying its tactics when judged in reference to alternative outranking methods [39]. Goncalives and Belderrain [20] in consensus with Silva et al. [41] noted that the way in which each criterion is evaluated using the preference functions is a benefit. The other benefit is that it is possible to interpret geometrically the outcomes by the GAIA approach [20, 36].

3.1 Fuzzy entropy weight approach

FEWA is adopted as a tool for evaluating the importance of the sub-criteria in Fig. 1. It simplified structure ease decision maker from complex analysis that are experienced using other weight method (e.g., analytical hierarchy process). FEWA implementation requires three steps (i.e., design of decision matrix, determination of entropy values and estimation of criterion weight). Decision matrix is designed using linguistic terms (Table 1). The eight-scale linguistic expressions are employed to evaluate the significance of the sub-criteria (Table 1).

The procedures for FEWA are explained as follows [14, 40]:

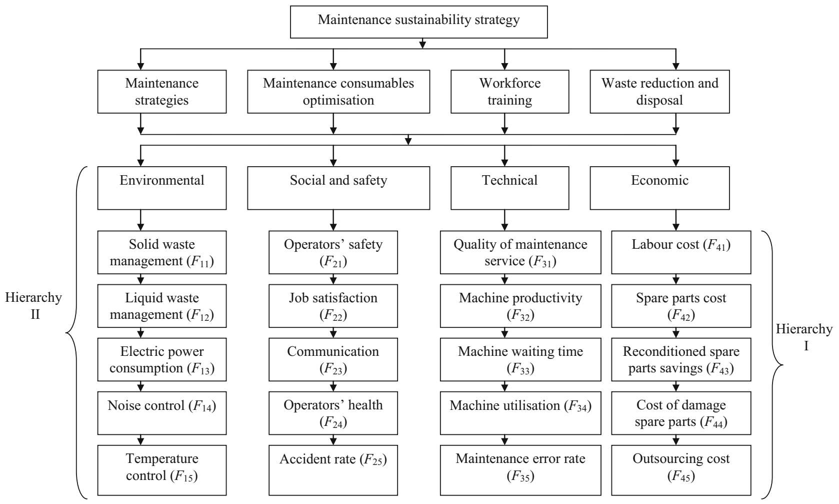

Fig. 1 A multi-criteria multi-hierarchy framework for maintenance sustainability strategies evaluation

Table 1 Trapezoidal fuzzy number for sub-criteria weights

Definition	Abbreviations	Importance
Highly unimportant	HU	(0.0, 0.1, 0.2, 0.3)
Slightly unimportant	SU	(0.1, 0.2, 0.3, 0.4)
Unimportant	U	(0.2, 0.3, 0.4, 0.5)
No comment	NC	(0.3, 0.4, 0.5, 0.6)
Important	I	(0.4, 0.5, 0.6, 0.7)
Slightly important	SI	(0.5, 0.6, 0.7, 0.8)
Highly important	HI	(0.6, 0.7, 0.8, 0.9)
Extremely important	EI	(0.7, 0.8, 0.9, 1.0)

Step 1: Design of decision matrix.

The trapezoidal fuzzy numbers in Table 1 are translated into crisp values using Eq. (1). Hesitant decision matrix is formed for each of the maintenance sustainability criterion based on the crisp values obtained from Eq. (1). The entropy values for the sub-criteria are determined by first normalising the information a hesitant decision (Eq. 2):

$$x_{ij} = \frac{\tau_{ij}\delta_{ij} + \frac{1}{3}(\tau_{ij} - \delta_{ij})^2 - \beta_{ij}\alpha_{ij} - \frac{1}{3}(\beta_{ij} - \alpha_{ij})^2}{\tau_{ij} + \delta_{ij} - \beta_{ij} - \alpha_{ij}} \qquad (1)$$

$$d_{ij} = \frac{x_{ij}}{\sum_{j}^{n} x_{ij}}. \qquad (2)$$

Step 2: Determination of entropy values.

The normalised values from different decision-makers are used to determine the entropy values for the various sub-criteria (Eq. 3):

$$E_j = -\frac{1}{\ln m}\sum_{i=1}^{m}\frac{d_{ij}}{D_j}\ln\frac{d_{ij}}{D_j} \qquad (3)$$

$$D_j = \sum_{i=1}^{m} d_{ij}. \qquad (4)$$

Step 3: Estimation of criterion weight.

Based on the entropy values for the sub-criteria, the weight for each sub-criterion is estimated using Eqs. (5) and (6):

$$w_{ij} = \frac{1 - E_{ij}}{n - E} \qquad (5)$$

$$E = \sum_{j=1}^{n} E_j. \qquad (6)$$

3.2 PROMETHEE methods

The PROMETHEE technique, being initiated by Brans as well as Vincke in the year 1985, is an outranking multi-criteria decision-making tool [16]. The application of PROMETHEE methods involves five steps [2, 16, 21, 31]. These steps are explained as follow:

Step 1: Data preparation.

This step involves the evaluation of the different maintenance sustainability strategy with respect to the sub-criteria. Since information in maintenance systems are often fuzzy in nature, triangular fuzzy numbers are used to express the different sub-criteria value with respect to the maintenance sustainability strategies (Table 2).

In order to limit the level of biasness of a decision-maker, more than one decision-maker is considered in this

Table 2 Linguistics variables and fuzzy number for the evaluation process

Linguistic variables	Abbreviations	Fuzzy number
Very low	VL	(1, 1, 3)
Low	L	(1, 3, 5)
Fairly good	FG	(3, 5, 7)
Good	G	(5, 7, 9)
Very good	VG	(7, 9, 9)

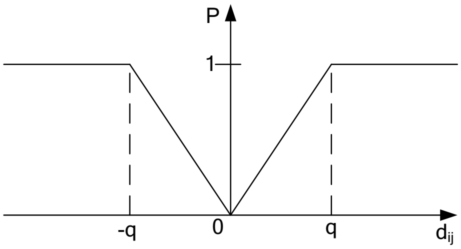

Fig. 2 V-shape criterion

study. The aggregated fuzzy and crisp values multi-response is given as Eqs. (7) and (8), respectively:

$$\left(a_{ij}, b_{ij}, c_{ij}\right) = \frac{1}{k}\left(\sum_{k=1}^{K} a_{ijk}, \sum_{k=1}^{K} b_{ijk}, \sum_{k=1}^{K} c_{ijk}\right) \tag{7}$$

$$\bar{d}_{ij} = \frac{a_{ij} + 4b_{ij} + c_{ij}}{6}. \tag{8}$$

The normalisation of crisp values for the sub-criteria is based on whether a sub-criterion is benefit or cost based. For benefit based sub-criteria, Eq. (9) is considered as a normalisation expression. Equation (10) is used to normalise cost base sub-criteria [2, 49]:

$$d_{ij} = \frac{\bar{d}_{ij} - \bar{d}_{i,\min}}{\bar{d}_{i,\max} - \bar{d}_{i,\min}} \tag{9}$$

$$d_{ij} = \frac{\bar{d}_{i\max} - \bar{d}_{ij}}{\bar{d}_{i,\max} - \bar{d}_{i,\min}}. \tag{10}$$

Step 2: Evaluation of preference degree.

Preference function is used to convert the value of the difference between two strategies (alternatives) to a value that is between 0 and 1. When a preference value of 0 is obtained, it implies that preference does not exist, a preference value of 1 show that an alternative is extremely preferred to another alternative [31]. The conversion process is achieved using linear, Gaussian, V-shape, U-shape, level and regular criteria. This study uses V-Shape criterion as its preference function for all the sub-criteria that are considered [31, 46]. Equation (11) is used to represents the expression for the preference between two criteria. The pictorial form of Eq. (11) is given as Fig. 2. The preference degree of a maintenance sustainability strategy is obtained by sum the product of each sub-criterion preference function value and their associated weights (Eq. 12):

$$P(d_{ij}) = \begin{cases} 0 & d_{ij} < 0 \\ \frac{d}{q} & 0 \le d_{ij} \le q \\ 1 & d_{ij} > q \end{cases} \tag{11}$$

$$\pi(a_1, a_2) = \sum_{j=1}^{n} w_{ij} P_{ij}. \tag{12}$$

Step 3: Positive and negative flows.

The positive flow value of the maintenance sustainability strategy is give as (Eq. 13). This flow measures degree which a maintenance sustainability strategy is preferred over other maintenance sustainability strategies. The negative flow value for a maintenance sustainability strategy evaluates the degree to which other maintenance sustainability strategies are preferred over a particular strategy (Eq. 14):

$$\phi_i^{+} = \frac{1}{n-1}\sum_{j=1}^{n} \pi(a_1, a_2) \tag{13}$$

Table 3 Sub-criteria importance using linguistic terms

	D_1	D_2	D_3	D_4
F_{11}	I	HI	HI	EI
F_{12}	HI	SI	EI	I
F_{13}	EI	I	EI	EI
F_{14}	HI	NC	HI	HI
F_{15}	HI	SU	HI	SI
F_{21}	EI	SI	EI	EI
F_{22}	EI	HI	EI	NC
F_{23}	HI	EI	EI	HI
F_{24}	EI	I	EI	EI
F_{25}	EI	SI	EI	NC
F_{31}	EI	EI	HI	EI
F_{32}	EI	HI	HI	EI
F_{33}	EI	HI	I	NC
F_{34}	EI	SI	EI	EI
F_{35}	EI	EI	EI	NC
F_{41}	EI	I	HI	I
F_{42}	EI	SI	HI	HI
F_{43}	SI	HI	I	HI
F_{44}	EI	U	I	HI
F_{45}	I	I	I	HI

Table 4 Importance of the sub-criteria using fuzzy number

	D_1	D_2	D_3	D_4
F_{11}	(0.4, 0.5, 0.6, 0.7)	(0.6, 0.7, 0.8, 0.9)	(0.6, 0.7, 0.8, 0.9)	(0.7, 0.8, 0.9, 1.0)
F_{12}	(0.6, 0.7, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.9, 1.0)	(0.4, 0.5, 0.6, 0.7)
F_{13}	(0.7, 0.8, 0.9, 1.0)	(0.4, 0.5, 0.6, 0.7)	(0.7, 0.8, 0.9, 1.0)	(0.7, 0.8, 0.9, 1.0)
F_{14}	(0.6, 0.7, 0.8, 0.9)	(0.3, 0.4, 0.5, 0.6)	(0.6, 0.7, 0.8, 0.9)	(0.6, 0.7, 0.8, 0.9)
F_{15}	(0.6, 0.7, 0.8, 0.9)	(0.1, 0.2, 0.3, 0.4)	(0.6, 0.7, 0.8, 0.9)	(0.5, 0.6, 0.7, 0.8)
F_{21}	(0.7, 0.8, 0.9, 1.0)	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.9, 1.0)	(0.7, 0.8, 0.9, 1.0)
F_{22}	(0.7, 0.8, 0.9, 1.0)	(0.6, 0.7, 0.8, 0.9)	(0.7, 0.8, 0.9, 1.0)	(0.3, 0.4, 0.5, 0.6)
F_{23}	(0.6, 0.7, 0.8, 0.9)	(0.7, 0.8, 0.9, 1.0)	(0.7, 0.8, 0.9, 1.0)	(0.6, 0.7, 0.8, 0.9)
F_{24}	(0.7, 0.8, 0.9, 1.0)	(0.4, 0.5, 0.6, 0.7)	(0.7, 0.8, 0.9, 1.0)	(0.7, 0.8, 0.9, 1.0)
F_{25}	(0.7, 0.8, 0.9, 1.0)	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.9, 1.0)	(0.3, 0.4, 0.5, 0.6)
F_{31}	(0.7, 0.8, 0.9, 1.0)	(0.7, 0.8, 0.9, 1.0)	(0.6, 0.7, 0.8, 0.9)	(0.7, 0.8, 0.9, 1.0)
F_{32}	(0.7, 0.8, 0.9, 1.0)	(0.6, 0.7, 0.8, 0.9)	(0.6, 0.7, 0.8, 0.9)	(0.7, 0.8, 0.9, 1.0)
F_{33}	(0.7, 0.8, 0.9, 1.0)	(0.6, 0.7, 0.8, 0.9)	(0.4, 0.5, 0.6, 0.7)	(0.3, 0.4, 0.5, 0.6)
F_{34}	(0.7, 0.8, 0.9, 1.0)	(0.5, 0.6, 0.7, 0.8)	(0.7, 0.8, 0.9, 1.0)	(0.7, 0.8, 0.9, 1.0)
F_{35}	(0.7, 0.8, 0.9, 1.0)	(0.7, 0.8, 0.9, 1.0)	(0.7, 0.8, 0.9, 1.0)	(0.3, 0.4, 0.5, 0.6)
F_{41}	(0.7, 0.8, 0.9, 1.0)	(0.4, 0.5, 0.6, 0.7)	(0.6, 0.7, 0.8, 0.9)	(0.4, 0.5, 0.6, 0.7)
F_{42}	(0.7, 0.8, 0.9, 1.0)	(0.5, 0.6, 0.7, 0.8)	(0.6, 0.7, 0.8, 0.9)	(0.6, 0.7, 0.8, 0.9)
F_{43}	(0.5, 0.6, 0.7, 0.8)	(0.6, 0.7, 0.8, 0.9)	(0.4, 0.5, 0.6, 0.7)	(0.6, 0.7, 0.8, 0.9)
F_{44}	(0.7, 0.8, 0.9, 1.0)	(0.2, 0.3, 0.4, 0.5)	(0.4, 0.5, 0.6, 0.7)	(0.6, 0.7, 0.8, 0.9)
F_{45}	(0.4, 0.5, 0.6, 0.7)	(0.4, 0.5, 0.6, 0.7)	(0.4, 0.5, 0.6, 0.7)	(0.6, 0.7, 0.8, 0.9)

Table 5 Crisp values of the sub-criteria importance

	D_1	D_2	D_3	D_4
F_{11}	0.55	0.75	0.75	0.85
F_{12}	0.75	0.65	0.85	0.55
F_{13}	0.85	0.55	0.85	0.85
F_{14}	0.75	0.45	0.75	0.75
F_{15}	0.75	0.25	0.75	0.65
F_{21}	0.85	0.65	0.85	0.85
F_{22}	0.85	0.75	0.85	0.45
F_{23}	0.75	0.85	0.85	0.75
F_{24}	0.85	0.55	0.85	0.85
F_{25}	0.85	0.65	0.85	0.45
F_{31}	0.85	0.85	0.75	0.85
F_{32}	0.85	0.75	0.75	0.85
F_{33}	0.85	0.75	0.55	0.45
F_{34}	0.85	0.65	0.85	0.85
F_{35}	0.85	0.85	0.85	0.45
F_{41}	0.85	0.55	0.75	0.55
F_{42}	0.85	0.65	0.75	0.75
F_{43}	0.65	0.75	0.55	0.75
F_{44}	0.85	0.35	0.55	0.75
F_{45}	0.55	0.55	0.55	0.75

$$\phi_i^- = \frac{1}{n-1}\sum_{j=1}^{n}\pi(a_2, a_1). \tag{14}$$

Step 4: Net flow.

The net flow of a maintenance sustainability strategy is the difference between the positive and negative flows (Eq. 15). This flow helps to determine the balance between the positive and negative flows a maintenance sustainability strategy [31]:

$$\phi_i = \phi_i^+ - \phi_i^-. \tag{15}$$

Step 5: Decision making.

PROMETHEE I: For positive flow value, the best maintenance sustainability strategy is the maintenance strategy with the largest positive flow value. The maintenance sustainability strategy with least negative flow value represents the best maintenance sustainability strategy. Information that is obtained using PROMETHEE I method creates partial pre-order of the maintenance sustainability strategies.

Table 6 Hierarchies I and II weights for the sub-criteria

Criterion	Sub-criterion	Hierarchy I			Hierarchy II		
		E_j	d_j	w_j	E_j	d_j	w_j
Environmental	F_{11}	0.5952	0.4048	0.1982	0.2011	0.7989	0.0499
	F_{12}	0.6216	0.3784	0.1852	0.1953	0.8047	0.0502
	F_{13}	0.6190	0.3810	0.1865	0.2085	0.7915	0.0494
	F_{14}	0.5851	0.4149	0.2031	0.1897	0.8103	0.0506
	F_{15}	0.5364	0.4636	0.2269	0.1713	0.8287	0.0517
Social and safety	F_{21}	0.5972	0.4028	0.2007	0.2138	0.7862	0.0491
	F_{22}	0.6079	0.3921	0.1953	0.1989	0.8011	0.0500
	F_{23}	0.6066	0.3934	0.1960	0.2148	0.7852	0.0490
	F_{24}	0.5837	0.4163	0.2074	0.2085	0.7915	0.0494
	F_{25}	0.5972	0.4028	0.2007	0.1940	0.8060	0.0503
Technical	F_{31}	0.6072	0.3928	0.1954	0.2192	0.7808	0.0487
	F_{32}	0.5980	0.4020	0.2000	0.2145	0.7855	0.0490
	F_{33}	0.5729	0.4271	0.2125	0.1851	0.8149	0.0508
	F_{34}	0.5956	0.4044	0.2012	0.2138	0.7862	0.0491
	F_{35}	0.6163	0.3837	0.1909	0.2035	0.7965	0.0497
Economic	F_{41}	0.5840	0.4160	0.1884	0.1899	0.8101	0.0506
	F_{42}	0.5978	0.4022	0.1821	0.2051	0.7949	0.0496
	F_{43}	0.5637	0.4363	0.1976	0.1919	0.8081	0.0504
	F_{44}	0.5215	0.4785	0.2167	0.1779	0.8221	0.0513
	F_{45}	0.5248	0.4752	0.2152	0.1768	0.8232	0.0514

PROMETHEE II: A complete pre-order of the maintenance sustainability strategies is obtained using PROMETHEE II method. The best maintenance sustainability strategy is the maintenance strategy with the largest net flow value.

3.3 Fuzzy TOPSIS

The application of TOPSIS approach as multi-criteria tool has received the attentions of different researchers in various research domains [12, 14, 15]. This is due to its attributes of using the best and worst outcomes for each criterion for decision making. Also, the ease of incorporating fuzzy logic into its TOPSIS framework is another attribute for its wide acceptance among researchers. Maintenance study has enjoyed the application of TOPSIS and fuzzy TOPSIS approaches [15, 19, 35, 43, 52]. The procedures involved in the application of fuzzy TOPSIS are: formulation of decision matrix, normalisation of decision matrix, generation of weighted decision matrix, computation of positive ideal and negative ideal solutions of each alternative and determination of closeness coefficient [14, 15].

The decision matrix which is used for fuzzy TOPSIS implementation is generated using alternative (i.e., strategies) and criteria (see Fig. 1). The normalisation of a fuzzy TOPSIS decision matrix is based on the concept of the maximum fuzzy number for a benefit-based criterion among alternatives (Eq. 16). The normalised values for cost-based criteria are based on the minimum fuzzy number among alternatives (Eq. 18):

$$\left(\hat{a}_{ij}, \hat{b}_{ij}, \hat{c}_{ij}\right) = \left(\frac{a_{ij}}{c_j}, \frac{b_{ij}}{c_j}, \frac{c_{ij}}{c_j}\right) \tag{16}$$

$$c_j = \max(c_{ij}) \tag{17}$$

$$\left(\hat{a}_{ij}, \hat{b}_{ij}, \hat{c}_{ij}\right) = \left(\frac{a_j}{c_{ij}}, \frac{a_j}{b_{ij}}, \frac{a_j}{a_{ij}}\right) \tag{18}$$

$$a_j = \min(a_{ij}). \tag{19}$$

In order to drop the emphasis on whether a criterion is benefit or cost based, the linguistic terms should be design to reflect a particular direction (i.e., benefit or cost) only (see Table 2). A weighted decision matrix is created by multiplying normalised decision matrix with criteria weights (Eqs. 20, 21). When the weights and normalised values membership functions are different, Eq. (20) is considered, otherwise Eq. (21) is considered:

$$\left(\bar{a}_{ij}, \bar{b}_{ij}, \bar{c}_{ij}\right) = \left(a^w_{ij}\hat{a}_{ij}, b^w_{ij}\hat{b}_{ij}, c^w_{ij}\hat{c}_{ij}\right) \tag{20}$$

$$\left(\bar{a}_{ij}, \bar{b}_{ij}, \bar{c}_{ij}\right) = \left(w_{ij}\hat{a}_{ij}, w_{ij}\hat{b}_{ij}, w_{ij}\hat{c}_{ij}\right). \tag{21}$$

To determine alternatives positive and negative ideal solutions, the positive ideal and negative ideal values for each criterion are considered (Eqs. 22, 23):

Table 7 Triangular number for maintenance strategies

	S_1				S_2				S_3				S_4			
	D_1	D_2	D_3	D_4	D_1	D_2	D_3	D_4	D_1	D_2	D_3	D_4	D_1	D_2	D_3	D_4
F_{11}	(5, 7, 9)	(1, 1, 3)	(7, 9, 9)	(7, 9, 9)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(3, 5, 7)	(5, 7, 9)	(1, 3, 5)	(5, 7, 9)	(7, 9, 9)	(3, 5, 7)	(3, 5, 7)	(3, 5, 7)
F_{12}	(5, 7, 9)	(1, 1, 3)	(7, 9, 9)	(5, 7, 9)	(7, 9, 9)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(3, 5, 7)	(5, 7, 9)	(1, 3, 5)	(5, 7, 9)	(7, 9, 9)	(1, 3, 5)	(3, 5, 7)	(3, 5, 7)
F_{13}	(7, 9, 9)	(1, 1, 3)	(7, 9, 9)	(7, 9, 9)	(7, 9, 9)	(1, 3, 5)	(5, 7, 9)	(5, 7, 9)	(1, 3, 5)	(1, 1, 3)	(3, 5, 7)	(5, 7, 9)	(3, 5, 7)	(1, 3, 5)	(3, 5, 7)	(5, 7, 9)
F_{14}	(5, 7, 9)	(1, 1, 3)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(1, 1, 3)	(5, 7, 9)	(5, 7, 9)	(1, 3, 5)	(1, 1, 3)	(3, 5, 7)	(5, 7, 9)	(1, 3, 5)	(1, 1, 3)	(3, 5, 7)	(5, 7, 9)
F_{15}	(5, 7, 9)	(1, 1, 3)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(1, 1, 3)	(5, 7, 9)	(5, 7, 9)	(1, 3, 5)	(1, 1, 3)	(3, 5, 7)	(3, 5, 7)	(3, 5, 7)	(1, 1, 3)	(3, 5, 7)	(5, 7, 9)
F_{21}	(7, 9, 9)	(1, 1, 3)	(7, 9, 9)	(5, 7, 9)	(7, 9, 9)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(1, 1, 3)	(5, 7, 9)	(5, 7, 9)	(7, 9, 9)	(5, 7, 9)	(3, 5, 7)	(5, 7, 9)
F_{22}	(7, 9, 9)	(1, 1, 3)	(7, 9, 9)	(5, 7, 9)	(7, 9, 9)	(7, 9, 9)	(5, 7, 9)	(5, 7, 9)	(3, 5, 7)	(1, 3, 5)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(3, 5, 7)	(5, 7, 9)	(5, 7, 9)
F_{23}	(5, 7, 9)	(1, 1, 3)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(7, 9, 9)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(1, 1, 3)	(5, 7, 9)	(5, 7, 9)	(3, 5, 7)	(1, 1, 3)	(5, 7, 9)	(5, 7, 9)
F_{24}	(7, 9, 9)	(1, 1, 3)	(7, 9, 9)	(5, 7, 9)	(7, 9, 9)	(1, 3, 5)	(5, 7, 9)	(7, 9, 9)	(5, 7, 9)	(1, 1, 3)	(5, 7, 9)	(5, 7, 9)	(7, 9, 9)	(3, 5, 7)	(5, 7, 9)	(7, 9, 9)
F_{25}	(7, 9, 9)	(1, 3, 5)	(7, 9, 9)	(1, 3, 5)	(7, 9, 9)	(1, 3, 5)	(5, 7, 9)	(3, 5, 7)	(7, 9, 9)	(1, 1, 3)	(3, 5, 7)	(5, 7, 9)	(7, 9, 9)	(3, 5, 7)	(3, 5, 7)	(7, 9, 9)
F_{31}	(5, 7, 9)	(5, 7, 9)	(7, 9, 9)	(7, 9, 9)	(7, 9, 9)	(7, 9, 9)	(5, 7, 9)	(7, 9, 9)	(3, 5, 7)	(3, 5, 7)	(5, 7, 9)	(5, 7, 9)	(7, 9, 9)	(3, 5, 7)	(5, 7, 9)	(7, 9, 9)
F_{32}	(7, 9, 9)	(7, 9, 9)	(5, 7, 9)	(7, 9, 9)	(7, 9, 9)	(5, 7, 9)	(5, 7, 9)	(7, 9, 9)	(3, 5, 7)	(1, 3, 5)	(5, 7, 9)	(5, 7, 9)	(7, 9, 9)	(5, 7, 9)	(5, 7, 9)	(7, 9, 9)
F_{33}	(7, 9, 9)	(3, 5, 7)	(3, 5, 7)	(1, 3, 5)	(7, 9, 9)	(1, 3, 5)	(3, 5, 7)	(7, 9, 9)	(3, 5, 7)	(1, 1, 3)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(3, 5, 7)	(3, 5, 7)	(3, 5, 7)
F_{34}	(7, 9, 9)	(5, 7, 9)	(7, 9, 9)	(7, 9, 9)	(7, 9, 9)	(1, 3, 5)	(5, 7, 9)	(7, 9, 9)	(5, 7, 9)	(1, 1, 3)	(5, 7, 9)	(5, 7, 9)	(7, 9, 9)	(1, 1, 3)	(5, 7, 9)	(5, 7, 9)
F_{35}	(7, 9, 9)	(1, 3, 5)	(5, 7, 9)	(1, 3, 5)	(7, 9, 9)	(3, 5, 7)	(5, 7, 9)	(1, 3, 5)	(3, 5, 7)	(1, 3, 5)	(3, 5, 7)	(7, 9, 9)	(3, 5, 7)	(1, 3, 5)	(3, 5, 7)	(3, 5, 7)
F_{41}	(5, 7, 9)	(3, 5, 7)	(5, 7, 9)	(5, 7, 9)	(3, 5, 7)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(7, 9, 9)	(3, 5, 7)	(3, 5, 7)	(5, 7, 9)	(3, 5, 7)	(3, 5, 7)	(3, 5, 7)	(5, 7, 9)
F_{42}	(3, 5, 7)	(5, 7, 9)	(5, 7, 9)	(7, 9, 9)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(7, 9, 9)	(3, 5, 7)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(7, 9, 9)	(1, 3, 5)	(5, 7, 9)	(7, 9, 9)
F_{43}	(3, 5, 7)	(5, 7, 9)	(7, 9, 9)	(5, 7, 9)	(5, 7, 9)	(7, 9, 9)	(5, 7, 9)	(5, 7, 9)	(3, 5, 7)	(7, 9, 9)	(3, 5, 7)	(5, 7, 9)	(5, 7, 9)	(1, 3, 5)	(5, 7, 9)	(5, 7, 9)
F_{44}	(7, 9, 9)	(3, 5, 7)	(5, 7, 9)	(5, 7, 9)	(7, 9, 9)	(3, 5, 7)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(7, 9, 9)	(1, 3, 5)	(3, 5, 7)	(5, 7, 9)
F_{45}	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(5, 7, 9)	(3, 5, 7)	(5, 7, 9)	(5, 7, 9)	(3, 5, 7)	(1, 3, 5)	(3, 5, 7)	(5, 7, 9)	(1, 3, 5)	(5, 7, 9)	(5, 7, 9)	(7, 9, 9)

Table 8 Aggregated triangular fuzzy number for maintenance strategies

Sub-criterion	S_1	S_2	S_3	S_4
F_{11}	(5.0, 6.5, 7.5)	(5.0, 7.0, 9.0)	(3.5, 4.0, 7.5)	(4.0, 4.5, 7.5)
F_{12}	(4.5, 6.0, 7.5)	(5.5, 7.5, 9.0)	(3.5, 4.0, 7.5)	(3.5, 3.5, 7.0)
F_{13}	(5.5, 7.0, 7.5)	(4.5, 6.5, 8.0)	(2.5, 3.0, 6.0)	(3.0, 3.5, 7.0)
F_{14}	(4.0, 5.5, 7.5)	(4.0, 5.5, 7.5)	(2.5, 4.0, 6.0)	(2.5, 3.0, 6.0)
F_{15}	(4.0, 5.5, 7.5)	(4.0, 5.5, 7.5)	(2.0, 3.5, 5.5)	(3.0, 3.5, 6.5)
F_{21}	(5.0, 5.5, 7.5)	(5.5, 7.5, 9.0)	(4.0, 5.5, 7.5)	(5.0, 7.0, 8.5)
F_{22}	(5.0, 6.5, 7.5)	(6.0, 8.0, 9.0)	(3.5, 5.5, 7.5)	(4.5, 6.5, 8.5)
F_{23}	(4.0, 4.5, 7. 0)	(5.5, 7.5, 9.0)	(4.0, 5.5, 7.5)	(3.5, 5.8, 7.0)
F_{24}	(5.0, 6.5, 7.5)	(4.0, 7.0, 8.0)	(4.0, 5.5, 7.5)	(5.5, 7.5, 8.5)
F_{25}	(4.0, 6.0, 7.0)	(4.0, 6.0, 7.5)	(4.0, 5.5, 7.0)	(5.0, 7.0, 8.0)
F_{31}	(6.0, 8.0, 9.0)	(6.5, 8.5, 9.0)	(4.0, 6.0, 8.0)	(5.5, 7.5, 8.5)
F_{32}	(6.5, 8.5, 9.0)	(6.0, 8.0, 9.0)	(3.5, 5.5, 7.5)	(6.0, 8.0, 9.0)
F_{33}	(6.5, 5.5, 7.0)	(4.5, 6.5, 7.5)	(3.5, 5.0, 7.0)	(3.5, 5.5, 7.5)
F_{34}	(6.5, 8.5, 9.0)	(5.0, 7.0, 8.0)	(4.0, 5.5, 7.5)	(4.5, 6.0, 7.5)
F_{35}	(3.5, 5.5, 7.0)	(4.0, 6.0, 7.5)	(3.5, 5.5, 7.0)	(2.5, 4.5, 6.5)
F_{41}	(4.5, 6.5, 8.5)	(4.5, 6.5, 8.5)	(4.5, 6.5, 8.0)	(3.5, 5.5, 7.5)
F_{42}	(5.0, 7.0, 8.5)	(5.5, 7.5, 9.0)	(4.5, 6.5, 8.5)	(5.0, 7.0, 8.0)
F_{43}	(5.0, 7.0, 8.5)	(5.5, 7.5, 9.0)	(4.5, 6.5, 8.0)	(4.0, 6.0, 8.0)
F_{44}	(5.0, 7.0, 8.5)	(5.0, 7.0, 8.5)	(5.0, 7.0, 9.0)	(4.0, 6.0, 7.5)
F_{45}	(5.0, 7.0, 9.0)	(4.5, 6.5, 8.5)	(3.0, 5.0, 7.0)	(4.5, 6.5, 8.0)

Table 9 Crisp values maintenance strategies

Sub-criterion	S_1	S_2	S_3	S_4
F_{11}	6.4167	7.0000	4.5000	4.9167
F_{12}	6.0000	7.4167	4.5000	4.0833
F_{13}	6.8333	6.4167	3.4167	4.0000
F_{14}	5.5833	5.5833	4.0833	3.4167
F_{15}	5.5833	5.5833	3.5833	3.9167
F_{21}	5.7500	7.4167	5.5833	6.9167
F_{22}	6.4167	7.8333	5.5000	6.5000
F_{23}	4.9167	7.4167	5.5833	5.5833
F_{24}	6.4167	6.6667	5.5833	7.3333
F_{25}	5.8333	5.9167	5.5000	6.8333
F_{31}	7.8333	8.2500	6.0000	7.3333
F_{32}	8.2500	7.8333	5.5000	7.8333
F_{33}	5.9167	6.3333	5.0833	5.5000
F_{34}	8.2500	6.8333	5.5833	6.0000
F_{35}	5.4167	5.9167	5.4167	4.5000
F_{41}	6.5000	6.5000	6.4167	5.5000
F_{42}	6.9167	7.4167	6.5000	6.8333
F_{43}	6.9167	7.4167	6.4167	6.0000
F_{44}	6.9167	6.9167	7.0000	5.9167
F_{45}	7.0000	6.5000	5.0000	6.4167

$$\left(a_j^{+}, b_j^{+}, c_j^{+}\right) = (1, 1, 1) \tag{22}$$

$$\left(a_j^{-}, b_j^{-}, c_j^{-}\right) = (0, 0, 0). \tag{23}$$

The alternatives positive ideal (Eq. 24) and negative ideal (Eq. 25) solutions are determined based on the concept of Euclidean distance:

$$d_i^{+} = \sqrt{\left(\bar{a}_{ij} - a_j^{+}\right)^2 + \left(\bar{b}_{ij} - b_j^{+}\right)^2 + \left(\bar{c}_{ij} - c_j^{+}\right)^2} \tag{24}$$

$$d_i^{-} = \sqrt{\left(\bar{a}_{ij} - a_j^{-}\right)^2 + \left(\bar{b}_{ij} - b_j^{-}\right)^2 + \left(\bar{c}_{ij} - c_j^{-}\right)^2} \tag{25}$$

where d_i^{+} represents the positive ideal solution of alternative i and negative ideal and d_i^{-} represents the negative ideal solution of alternative i.

The alternatives closeness coefficient is a function of the values of their alternative positive ideal and negative ideal solutions (Eq. 26). The best ranked alternative is the alternative with the highest closeness coefficient:

$$c_i = \frac{d_i^{-}}{d_i^{+} + d_i^{-}} \tag{26}$$

where c_i represents the closeness coefficient of alternative i.

Table 10 Normalised values for the PROMETHEE method

Criterion	F_{11}	F_{12}	F_{13}	F_{14}	F_{15}
Environmental					
S_1	0.7667	0.5750	1.0000	1.0000	1.0000
S_2	1.0000	1.0000	0.8781	1.0000	1.0000
S_3	0.0000	0.1250	0.0000	0.3077	0.0000
S_4	0.1667	0.0000	0.1707	0.0000	0.1667
	F_{21}	F_{22}	F_{23}	F_{24}	F_{25}
Social and safety					
S_1	0.0909	0.3929	0.0000	0.4762	0.2500
S_2	1.0000	1.0000	1.0000	0.6191	0.3125
S_3	0.0000	0.0000	0.2666	0.0000	0.0000
S_4	0.7273	0.4286	0.2666	1.0000	1.0000
	F_{31}	F_{32}	F_{33}	F_{34}	F_{35}
Technical					
S_1	0.8148	1.0000	0.6667	1.0000	0.6471
S_2	1.0000	0.8485	1.0000	0.4687	1.0000
S_3	0.0000	0.0000	0.0000	0.0000	0.6471
S_4	0.5926	0.8485	0.3334	0.1563	0.0000
	F_{41}	F_{42}	F_{43}	F_{44}	F_{45}
Economic					
S_1	1.0000	0.4546	0.6471	0.9231	1.0000
S_2	1.0000	1.0000	1.0000	0.9231	0.7500
S_3	0.9167	0.0000	0.2941	1.0000	0.0000
S_4	0.0000	0.3636	0.0000	0.0000	0.7084

4 Case study

The proposed fuzzy entropy weight approach and PROMETHEE framework was tested by applying it in a cement production plant. This section gives an account of the cement manufacturers' problems as well as their diagnosis. The observation of the plant shows realness in the scientific execution of maintenance strategy using guided principles. This situation often results in unwarranted breakdowns, an embarrassing situation that puts strain on all the stakeholders of the company. The purpose of manufacturing cement is to improve on the strength of the concrete with which these fire-grained particles are mixed, for construction assignments. Cement is known for its esteemed quality as a construction material and also recognised world-wide for its cost-effectiveness. However, the inaccurate development of appropriate maintenance strategies has been a major problem in achieving optimised pre- and post-clinkerisation activities.

In real world, it is very rare to find effective substitutes of cement in the construction field, globally. The production of cement is however technologically-sophisticated, involving plant components of clinker grinder a well as slug grinder. Cement involves two principal processes, crushing as well as grinding, employing limestone, sand, alumina as well as iron ore as raw materials. These inputs are mixed in definite ratios and set to high temperature in a Kiln. The temperature is usually in the order of 1500 °C, depending on the technological sophistication on the plant, the crushing and grinding activities could be either in the dry or wet form. However, the dry form is preferred as it is more technologically advanced. The output of the crushing and grinding processes in referred to as clinkered materials. This output is further processed with the addition of gypsum to obtain cement particles. In dealing with the maintenance aspects of the cement manufacturing process, the milling, turbo-blowers, compressors, cooler fans are the principal equipment that must be manufactured in the cement plant while the turbine is the main equipment to focus attention on in the power plant. It is conventional to have more than a mill for high production purposes and the components of the mill that warrants maintenance are the charging of the balls, wearing and possible replacements of the diaphragm plates, repairs of separator varies (which could be of static or rotary type). Others are adjustments of vanes in the inlet vanes, filters, lip plates, hood arrangement, auxiliary equipment venting.

For the past few months, the sourcing of foreign exchange to meet the cement manufacturer's purchase of plants has been challenging. In addition, the conversion ratio from the local currency to the foreign equivalent has gone up in multiples, thus printing huge maintenance activities in general. Thus, there is no other tune than now closely revise the maintenance policy and select the best strategy for best operations of the plant. In fact, thin great need has motivated the current case examination. Since the problem is maintenance-based, the group of professionals that were chosen for the survey are engineers and many of them are experienced in cement manufacturing activities. The least certificate for this group is a university's first degree. However, very rare case(s) may occur in which a lower ranking officer, but with significant experience in engineering aspects of cement, may be assigned by the superior to fill the questionnaire. The cement manufacturer, like many other production system, emits particles or substances to the surrounding. In this instance, the manufacturer emits dust particles into the environment such that the surrounding habitants of the place physically feel drops of particles on their bodies and this is a serious environmental hazard that the organisation could work on. This is the responsibility of the

Table 11 Preference values for the sub-criteria

	F_{11}	F_{12}	F_{13}	F_{14}	F_{15}	F_{21}	F_{22}	F_{23}	F_{24}	F_{25}
S_1, S_2	0.0000	0.0000	0.1219	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
S_1, S_3	0.7667	0.4500	1.0000	0.6923	1.0000	0.0182	0.0767	0.0000	0.0988	0.0502
S_1, S_4	0.6000	0.5750	0.8293	1.0000	0.8333	0.0000	0.0000	0.0000	0.0000	0.0000
S_2, S_1	0.2333	0.4250	0.0000	0.0000	0.0000	0.1825	0.1186	0.1960	0.0296	0.0125
S_2, S_3	1.0000	0.8750	0.8781	0.6923	1.0000	0.2007	0.1953	0.1960	0.1284	0.0627
S_2, S_4	0.8333	1.0000	0.7074	1.0000	0.8333	0.0547	0.1116	0.1437	0.0000	0.0000
S_3, S_1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0523	0.0000	0.0000
S_3, S_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
S_3, S_4	0.0000	0.1250	0.0000	0.3077	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
S_4, S_1	0.0000	0.0000	0.0000	0.0000	0.0000	0.1277	0.0070	0.0523	0.1086	0.1505
S_4, S_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0790	0.1380
S_4, S_3	0.1667	0.0000	0.1707	0.0000	0.1667	0.1460	0.0837	0.0000	0.2074	0.2007
	F_{31}	F_{32}	F_{33}	F_{34}	F_{35}	F_{41}	F_{42}	F_{43}	F_{44}	F_{45}
S_1, S_2	0.0000	0.1515	0.0000	0.5313	0.0000	0.0000	0.0000	0.0000	0.0000	0.2500
S_1, S_3	0.8148	1.0000	0.6667	1.0000	0.0000	0.0833	0.4546	0.3530	0.0000	1.0000
S_1, S_4	0.2222	0.1515	0.3333	0.8437	0.6471	1.0000	0.0910	0.6471	0.9231	0.2916
S_2, S_1	0.1852	0.0000	0.3333	0.0000	0.3529	0.0000	0.5454	0.3529	0.0000	0.0000
S_2, S_3	1.0000	0.8485	1.0000	0.4687	0.3529	0.0833	1.0000	0.7059	0.0769	0.7500
S_2, S_4	0.4074	0.0000	0.6666	0.3124	1.0000	1.0000	0.6364	1.0000	0.9231	0.0416
S_3, S_1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0769	1.0000
S_3, S_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0769	0.0000
S_3, S_4	0.0000	0.0000	0.0000	0.0000	0.6471	0.9167	0.0000	0.2941	1.0000	0.0000
S_4, S_1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
S_4, S_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
S_4, S_3	0.5926	0.8485	0.3334	0.1563	0.0000	0.0000	0.3636	0.0000	1.0000	0.7084

maintenance function who could devise a means of reducing such impacts on the environments. Nevertheless, the efficiency of maintenance as well as the maintenance strategy to adopt in this instance had not been affected by this. Beyond affecting the environment, particles from the cement processing activities are dangerous health hazards in terms of safety of workers.

In addition, the noise from the plant is enormous and unwarranted. Measures incorporating these have not been made into the current assessment methods of the plants maintenance team. This needs a revisit as incorporating this into the assessment scheme is a first step in its control. Besides, in considering the technical aspects, there is no integration of the very key measures under the technical ratio to determine the best strategy to adopt in maintenance. Lastly, costs are incurred in enormous quantities in maintenance but little efforts are made to integrate these into developing maintenance policy that would yield the best results. In order to turn around this problem, the current paper aims to address this concern by harnessing the measures towards obtaining the best maintenance strategy to adopt in this cement plant.

A structured questionnaire was administered to four decision-makers in the cement plant. The linguistic responses (Table 3) from the decision-makers were first converted into fuzzy numbers (Table 4). By applying Eq. (1), the crisp values for the importance of the sub-criteria were obtained (Table 5).

Based on Eqs. (2)–(6), the weights for the sub-criteria (local weights) were determined (Table 5). Similarly, Eqs. (2)–(6) were used to determine the global weights for the sub-criteria based on considering the environmental, social and safety, technical and economic criteria (Table 6). From sub-criteria perspective, under environmental criterion, the most important sub-criterion was F_{15} (temperature control). The least important sub-criterion was F_{12} (liquid waste management). The social and safety criterion results showed that F_{21} (operators' safety) and F_{25} (accident rate) had the same importance values (Table 6). The least important social and safety criterion was F_{22} (job satisfaction), while F_{24} (operators' health) was the most important social and safety criterion.

The importance of F_{35} (maintenance error rate) was the least when considering the technical criterion, while F_{33}

Table 12 Preference function values for hierarchy I

	F_{11}	F_{12}	F_{13}	F_{14}	F_{15}	F_{21}	F_{22}	F_{23}	F_{24}	F_{25}
S_1, S_2	0.0000	0.0000	0.0227	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
S_1, S_3	0.1520	0.0833	0.1865	0.1406	0.2269	0.0182	0.0767	0.0000	0.0988	0.0502
S_1, S_4	0.1189	0.1065	0.1547	0.2031	0.1891	0.0000	0.0000	0.0000	0.0000	0.0000
S_2, S_1	0.0462	0.0787	0.0000	0.0000	0.0000	0.1825	0.1186	0.1960	0.0296	0.0125
S_2, S_3	0.1982	0.1621	0.1638	0.1406	0.2269	0.2007	0.1953	0.1960	0.1284	0.0627
S_2, S_4	0.1652	0.1852	0.1319	0.2031	0.1891	0.0547	0.1116	0.1437	0.0000	0.0000
S_3, S_1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0523	0.0000	0.0000
S_3, S_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
S_3, S_4	0.0000	0.0232	0.0000	0.0625	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
S_4, S_1	0.0000	0.0000	0.0000	0.0000	0.0000	0.1277	0.0070	0.0523	0.1086	0.1505
S_4, S_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0790	0.1380
S_4, S_3	0.0330	0.0000	0.0318	0.0000	0.0378	0.1460	0.0837	0.0000	0.2074	0.2007

	F_{31}	F_{32}	F_{33}	F_{34}	F_{35}	F_{41}	F_{42}	F_{43}	F_{44}	F_{45}
S_1, S_2	0.0000	0.0303	0.0000	0.1069	0.0000	0.0000	0.0000	0.0000	0.0000	0.0538
S_1, S_3	0.1592	0.2000	0.1417	0.2012	0.0000	0.0157	0.0828	0.0698	0.0000	0.2152
S_1, S_4	0.0434	0.0303	0.0708	0.1698	0.1235	0.1884	0.0166	0.1279	0.2000	0.0628
S_2, S_1	0.0362	0.0000	0.0708	0.0000	0.0674	0.0000	0.0993	0.0697	0.0000	0.0000
S_2, S_3	0.1954	0.1697	0.2125	0.0943	0.0674	0.0157	0.1821	0.1395	0.0167	0.1614
S_2, S_4	0.0796	0.0000	0.1417	0.0629	0.1909	0.1884	0.1159	0.1976	0.2000	0.0090
S_3, S_1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0167	0.2152
S_3, S_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0167	0.0000
S_3, S_4	0.0000	0.0000	0.0000	0.0000	0.1235	0.1727	0.0000	0.0581	0.2167	0.0000
S_4, S_1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
S_4, S_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
S_4, S_3	0.1158	0.1697	0.0708	0.0314	0.0000	0.0000	0.0662	0.0000	0.2167	0.1524

Table 13 Preference degrees of the Hierarchy I

	Environmental criterion					Social and safety criterion			
	S_1	S_2	S_3	S_4		S_1	S_2	S_3	S_4
S_1	0.0000	0.0227	0.7893	0.7723	S_1	0.0000	0.1372	0.7021	0.4378
S_2	0.1250	0.0000	0.8915	0.8745	S_2	0.1744	0.0000	0.7393	0.4750
S_3	0.0000	0.0000	0.0000	0.0856	S_3	0.0000	0.0000	0.0000	0.1235
S_4	0.0000	0.0000	0.1027	0.0000	S_4	0.0000	0.0000	0.3878	0.0000

	Technical criterion					Economic criterion			
	S_1	S_2	S_3	S_4		S_1	S_2	S_3	S_4
S_1	0.0000	0.0000	0.2439	0.0000	S_1	0.0000	0.0538	0.3834	0.5956
S_2	0.5392	0.0000	0.7831	0.3101	S_2	0.1691	0.0000	0.5153	0.7109
S_3	0.0523	0.0000	0.0000	0.0000	S_3	0.2319	0.0167	0.0000	0.4475
S_4	0.4461	0.2170	0.6378	0.0000	S_4	0.0000	0.0000	0.4354	0.0000

(machine waiting time) was the most important technical criterion. The results for the economic sub-criterion showed that F_{44} (cost of damage spare parts) was the most important criterion, while F_{42} (spare parts cost) was the least important economic criterion. In terms of all the sub-criteria (global weights), the most important criterion was F_{45} (Outsourcing cost), while F_{31} (quality of maintenance service) was the least important criterion (Table 6).

Based on the information in Table 2, the linguistic responses from the decision-makers for the various sub-

Table 14 Preference functions for hierarchy II

	F_{11}	F_{12}	F_{13}	F_{14}	F_{15}	F_{21}	F_{22}	F_{23}	F_{24}	F_{25}
S_1, S_2	0.0000	0.0000	0.0060	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
S_1,S_3	0.0383	0.0226	0.0494	0.0350	0.0517	0.0045	0.0196	0.0000	0.0235	0.0126
S_1, S_4	0.0299	0.0289	0.0410	0.0506	0.0431	0.0000	0.0000	0.0000	0.0000	0.0000
S_2, S_1	0.0116	0.0213	0.0000	0.0000	0.0000	0.0446	0.0304	0.0490	0.0071	0.0031
S_2, S_3	0.0499	0.0439	0.0434	0.0350	0.0517	0.0491	0.0500	0.0359	0.0306	0.0157
S_2, S_4	0.0416	0.0502	0.0349	0.0506	0.0431	0.0134	0.0286	0.0359	0.0000	0.0000
S_3, S_1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0131	0.0000	0.0000
S_3, S_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
S_3, S_4	0.0000	0.0063	0.0000	0.0156	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
S_4, S_1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0312	0.0018	0.0131	0.0259	0.0377
S_4, S_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0188	0.0346
S_4, S_3	0.0083	0.0000	0.0084	0.0000	0.0086	0.0357	0.0214	0.0000	0.0494	0.0503

	F_{31}	F_{32}	F_{33}	F_{34}	F_{35}	F_{41}	F_{42}	F_{43}	F_{44}	F_{45}
S_1, S_2	0.0000	0.0074	0.0000	0.0261	0.0000	0.0000	0.0000	0.0000	0.0000	0.0129
S_1, S_3	0.0397	0.0490	0.0339	0.0491	0.0000	0.0042	0.0225	0.0178	0.0000	0.0514
S_1, S_4	0.0108	0.0074	0.0169	0.0414	0.0322	0.0506	0.0045	0.0326	0.0474	0.0150
S_2, S_1	0.0090	0.0000	0.0169	0.0000	0.0175	0.0000	0.0271	0.0178	0.0000	0.0000
S_2, S_3	0.0487	0.0416	0.0508	0.0230	0.0175	0.0042	0.0496	0.0356	0.0000	0.0386
S_2, S_4	0.0198	0.0000	0.0339	0.0153	0.0497	0.0506	0.0316	0.0504	0.0474	0.0021
S_3, S_1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0039	0.0000
S_3, S_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0039	0.0000
S_3, S_4	0.0289	0.0000	0.0000	0.0077	0.0322	0.0464	0.0180	0.0148	0.0513	0.0000
S_4, S_1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
S_4, S_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
S_4, S_3	0.0289	0.0416	0.0169	0.0077	0.0000	0.0000	0.0180	0.0000	0.0000	0.0364

Table 15 Preference degrees for Hierarchy II

	S_1	S_2	S_3	S_4
S_1	0.0000	0.0524	0.5248	0.4523
S_2	0.2555	0.0000	0.7148	0.5991
S_3	0.0170	0.0039	0.0000	0.2211
S_4	0.1097	0.0534	0.3317	0.0000

criteria were converted into triangular fuzzy number (Table 7). The information in Table 7 showed that most of the responses from the decision-makers favour fair good and good responses (Table 7). Based on Eq. (7), the information in Table 7 were aggregated (Table 8). Equation (8) was used to convert the aggregated triangular fuzzy numbers into crisp values (Table 9).

Since the information in Table 1 is structured in a way in which the benefit or non-benefit based sub-criterion value is assigned towards a positive direction, Eq. (9) is used to normalise all the crisp values of the sub-criteria (Table 10). The normalised values were used during the evaluation of the preference values of the maintenance sustainability strategies (Table 11).

Table 16 Positive (ϕ^+), negative (ϕ^-) as well as net (ϕ) flows considering hierarchy I

	Environmental criterion			Social and safety criterion		
	ϕ^+	ϕ^-	ϕ	ϕ^+	ϕ^-	ϕ
S_1	0.5281	0.0417	0.4864	0.0813	0.3459	−0.2646
S_2	0.6303	0.0076	0.6228	0.5441	0.0723	0.4718
S_3	0.0285	0.5945	−0.5660	0.0174	0.5549	−0.5375
S_4	0.0342	0.5775	−0.5432	0.4336	0.1034	0.3303

	Technical criterion			Economic criterion		
	ϕ^+	ϕ^-	ϕ	ϕ^+	ϕ^-	ϕ
S_1	0.4257	0.0581	0.3676	0.3443	0.13364	0.2106
S_2	0.4629	0.0457	0.4172	0.4651	0.02349	0.4416
S_3	0.0412	0.6097	−0.5686	0.2320	0.44471	−0.2127
S_4	0.1293	0.3454	−0.2162	0.1451	0.58467	−0.4396

Based on the information in Table 11, this study calculates the preference function values for Hierarchy I using the weights obtained for Hierarchy I in Table 6 (Table 12).

Table 17 Positive (ϕ^{+}), negative (ϕ^{-}) as well as net (ϕ) flows considering Hierarchy II

	ϕ^{+}	ϕ^{-}	ϕ
S_1	0.3432	0.1274	0.2158
S_2	0.5231	0.0366	0.4866
S_3	0.0807	0.5238	−0.4431
S_4	0.1649	0.4242	−0.2592

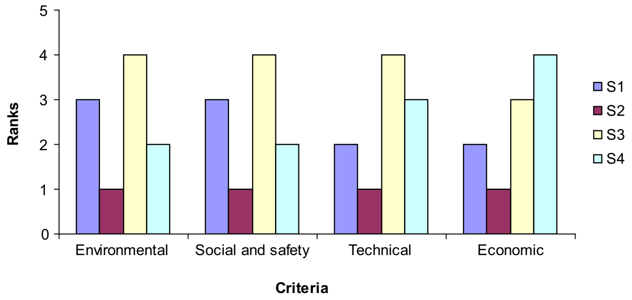

Fig. 3 Net flow ranking of the maintenance strategies using Hierarchy I

This enables us to get the preference degrees for the maintenance sustainability strategies (Table 13).

This work calculates the preference function values for Hierarchy II using the global weights that were obtained for Hierarchy II in Table 6 and the information in Table 11 (Table 14). By analysing the information in Table 14, the maintenance sustainability strategies preference degrees were obtained (Table 15).

This work uses the information in Tables 13 and 15 to evaluate the various types of PROMETHEE flows (Tables 16, 17). The Hierarchy I results for net flows showed that maintenance consumables optimisation was the highest ranked maintenance sustainability strategy using the different sustainability criteria (Fig. 3). The results obtained as the ranks for the different maintenance sustainability strategies showed that there is different in the ranks using Hierarchy I results (Fig. 3). Based on Hierarchy I result, the order of ranking the maintenance sustainability strategies using environment sub-criteria were the same with those obtained using social and safety sub-criteria (Fig. 3). From the above discussion, the lowest ranked maintenance sustainability strategy was workforce training (Fig. 3). In terms of the technical sub-criteria, the lowest ranked maintenance sustainability strategy was workforce training (Fig. 3). The results from the economic sub-criteria showed that the lowest ranked maintenance sustainability strategy was waste reduction and disposal (Fig. 3).

In terms of all the selected criteria (Hierarchy II), the results for the positive, negative and net flows showed that maintenance consumables optimisation is the best strategy for sustaining the case study maintenance system

Table 18 Normalised decision matrix for fuzzy TOPSIS method

	S_1	S_2	S_3	S_4
F_{11}	(0.5556, 0.7222, 0.7778)	(0.5556, 0.7778, 1.0000)	(0.3889, 0.4444, 0.8333)	(0.4444, 0.5000, 0.8333)
F_{12}	(0.5000, 0.6667, 0.8333)	(0.6111, 0.8333, 1.0000)	(0.3889, 0.4444, 0.8333)	(0.3889, 0.3889, 0.7778)
F_{13}	(0.6875, 0.8750, 0.9375)	(0.5625, 0.8125, 1.0000)	(0.3125, 0.3750, 0.7500)	(0.3750, 0.4375, 0.8750)
F_{14}	(0.5333, 0.7333, 1.0000)	(0.5333, 0.7333, 1.0000)	(0.3333, 0.5333, 0.8000)	(0.3333, 0.4000, 0.8000)
F_{15}	(0.5333, 0.7333, 1.0000)	(0.5333, 0.7333, 1.0000)	(0.2667, 0.4667, 0.7333)	(0.4000, 0.4667, 0.8667)
F_{21}	(0.5556, 0.6111, 0.8333)	(0.5556, 0.6111, 1.0000)	(0.4444, 0.6111, 0.8333)	(0.5556, 0.7778, 0.9444)
F_{22}	(0.5556, 0.7222, 0.8333)	(0.5556, 0.6667, 1.0000)	(0.3889, 0.6111, 0.8333)	(0.5000, 0.7222, 0.9444)
F_{23}	(0.4444, 0.5000, 0.7778)	(0.6667, 0.6111, 1.0000)	(0.4444, 0.6111, 0.8333)	(0.3889, 0.6444, 0.7778)
F_{24}	(0.5882, 0.7647, 0.8824)	(0.6471, 0.4706, 0.9412)	(0.4706, 0.6471, 0.8824)	(0.6471, 0.8824, 1.0000)
F_{25}	(0.5000, 0.7500, 0.8750)	(0.5000, 0.5000, 0.9375)	(0.5000, 0.6875, 0.8750)	(0.6250, 0.8750, 1.0000)
F_{31}	(0.6667, 0.8889, 1.0000)	(0.7222, 0.7222, 1.0000)	(0.4444, 0.6667, 0.8889)	(0.6111, 0.8333, 0.9444)
F_{32}	(0.7222, 0.9444, 1.0000)	(0.6667, 0.8889, 1.0000)	(0.3889, 0.6111, 0.8333)	(0.6667, 0.8889, 1.0000)
F_{33}	(0.8667, 0.7333, 0.9333)	(0.8667, 0.8667, 1.0000)	(0.4667, 0.7333, 0.9333)	(0.4667, 0.7333, 1.0000)
F_{34}	(0.7222, 0.6111, 1.0000)	(0.5556, 0.7778, 0.8889)	(0.4444, 0.6111, 0.8333)	(0.5000, 0.6667, 0.8333)
F_{35}	(0.4667, 0.7333, 0.9333)	(0.5333, 0.8000, 1.0000)	(0.4667, 0.7333, 0.9333)	(0.3333, 0.6000, 0.8667)
F_{41}	(0.5294, 0.7647, 1.0000)	(0.5294, 0.7647, 1.0000)	(0.5294, 0.7647, 0.9412)	(0.4118, 0.6471, 0.8824)
F_{42}	(0.5556, 0.7778, 0.9444)	(0.6111, 0.8333, 1.0000)	(0.5000, 0.7222, 0.9444)	(0.5556, 0.7778, 0.8889)
F_{43}	(0.5556, 0.7778, 0.9444)	(0.5556, 0.7778, 1.0000)	(0.5000, 0.7778, 0.8889)	(0.4444, 0.6667, 0.8889)
F_{44}	(0.5556, 0.7778, 0.9444)	(0.5556, 0.7222, 0.9444)	(0.5556, 0.7778, 1.0000)	(0.4444, 0.6667, 0.8333)
F_{45}	(0.5556, 0.7778, 1.0000)	(0.5000, 0.7222, 0.9444)	(0.3333, 0.5556, 0.7778)	(0.5000, 0.7222, 0.8889)

Table 19 Weighted normalised decision matrix for fuzzy TOPSIS method

	S_1	S_2	S_3	S_4
F_{11}	(0.0277, 0.0360, 0.0388)	(0.0277, 0.0388, 0.0499)	(0.0194, 0.0222, 0.0416)	(0.0222, 0.0250, 0.0416)
F_{12}	(0.0251, 0.0335, 0.0418)	(0.0307, 0.0418, 0.0502)	(0.0195, 0.0223, 0.0418)	(0.0195, 0.0195, 0.0390)
F_{13}	(0.0340, 0.0432, 0.0463)	(0.0278, 0.0401, 0.0494)	(0.0154, 0.0185, 0.0371)	(0.0185, 0.0216, 0.0432)
F_{14}	(0.0270, 0.0371, 0.0506)	(0.0270, 0.0371, 0.0506)	(0.0169, 0.0270, 0.0405)	(0.0169, 0.0202, 0.0405)
F_{15}	(0.0276, 0.0379, 0.0517)	(0.0276, 0.0379, 0.0517)	(0.0138, 0.0241, 0.0379)	(0.0207, 0.0241, 0.0448)
F_{21}	(0.0273, 0.0300, 0.0409)	(0.0273, 0.0300, 0.0491)	(0.0218, 0.0300, 0.0409)	(0.0273, 0.0382, 0.0464)
F_{22}	(0.0278, 0.0361, 0.0417)	(0.0278, 0.0333, 0.0500)	(0.0194, 0.0306, 0.0417)	(0.0250, 0.0361, 0.0472)
F_{23}	(0.0218, 0.0245, 0.0381)	(0.0327, 0.0299, 0.0490)	(0.0218, 0.0299, 0.0408)	(0.0191, 0.0316, 0.0381)
F_{24}	(0.0291, 0.0378, 0.0436)	(0.0320, 0.0232, 0.0465)	(0.0232, 0.0320, 0.0436)	(0.0320, 0.0436, 0.0494)
F_{25}	(0.0252, 0.0377, 0.0440)	(0.0252, 0.0252, 0.0472)	(0.0252, 0.0346, 0.0440)	(0.0314, 0.0440, 0.0503)
F_{31}	(0.0325, 0.0433, 0.0487)	(0.0352, 0.0352, 0.0487)	(0.0216, 0.0325, 0.0433	(0.0298, 0.0406, 0.0460
F_{32}	(0.0354, 0.0463, 0.0490)	(0.0327, 0.0436, 0.0490)	(0.0191, 0.0299, 0.0408)	(0.0327, 0.0436, 0.0490)
F_{33}	(0.0440, 0.0373, 0.0474)	(0.0440, 0.0440, 0.0508)	(0.0237, 0.0373, 0.0474)	(0.0237, 0.0373, 0.0508)
F_{34}	(0.0355, 0.0300, 0.0491)	(0.0273, 0.0382, 0.0436)	(0.0218, 0.0300, 0.0409)	(0.0246, 0.0327, 0.0409)
F_{35}	(0.0232, 0.0364, 0.0464)	(0.0265, 0.0398, 0.0497)	(0.0232, 0.0364, 0.0464)	(0.0166, 0.0298, 0.0431)
F_{41}	(0.0268, 0.0387, 0.0506)	(0.0268, 0.0387, 0.0506)	(0.0268, 0.0387, 0.0476)	(0.0208, 0.0327, 0.0446)
F_{42}	(0.0276, 0.0386, 0.0468)	(0.0303, 0.0413, 0.0496)	(0.0248, 0.0358, 0.0468)	(0.0276, 0.0386, 0.0441)
F_{43}	(0.0280, 0.0392, 0.0476)	(0.0280, 0.0392, 0.0504)	(0.0252, 0.0392, 0.0448)	(0.0224, 0.0336, 0.0448)
F_{44}	(0.0285, 0.0399, 0.0485)	(0.0285, 0.0371, 0.0485)	(0.0285, 0.0399, 0.0513)	(0.0228, 0.0342, 0.0428)
F_{45}	(0.0286, 0.0400, 0.0514)	(0.0257, 0.0371, 0.0485)	(0.0171, 0.0286, 0.0400)	(0.0257, 0.0371, 0.0457)

Table 20 Fuzzy TOPSIS: final outputs

Strategy	d_i^+	d_i^-	c_i
S_1	8.3254	0.3435	0.0396
S_2	8.3256	0.3211	0.0371
S_3	8.3516	0.3186	0.0367
S_4	8.3618	0.3077	0.0355

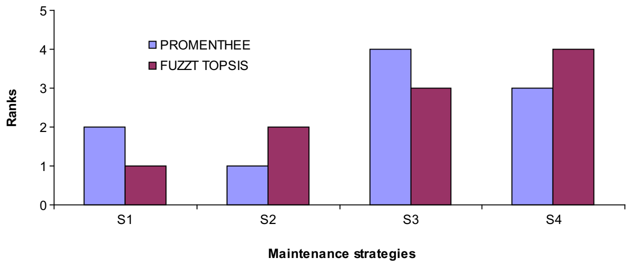

Fig. 4 Maintenance strategies ranking using different methods

(Table 17). The decision of ranking maintenance consumables optimisation as the best maintenance strategy for sustainable maintenance system using Hierarchy II was consistent with those obtained using Hierarchy I (Tables 16, 17). However, the least ranked maintenance strategy using Hierarchies I and II were different. Based on Hierarchy II results, the least ranked maintenance strategy was workforce training (Table 17).

The work carries out the implementation of the fuzzy TOPSIS method using the global weights of the criteria. The information in Table 8 was used to generate the normalisation decision matrix for the fuzzy TOPSIS implementation (Table 18). After which Eq. (16) was used to combine the information in Tables 6 and 18 in order to generate a weighted normalised decision matrix (Table 19). The positive and negative ideal solutions of the alternatives were determined using Eqs. (24) and (25). The results obtained were used to compute the alternatives closeness coefficients (Table 20).

The PROMETHEE net flow results for Hierarchy II and fuzzy TOPSIS ranks for the maintenance sustainability strategies ranks are not the same (Fig. 4).

5 Conclusions

In this study, we have presented a new framework for maintenance sustainability strategy choice based on an outranking approach (PROMETHEE methods). The proposed framework permits how to choose maintenance sustainability strategy from two perspectives (multi-criteria and multi-hierarchy). This proposed framework uses the fuzzy entropy weight method to find the criteria weights. The information obtained from a cement manufacturing company illustrates the applicability of the proposed framework.

Based on the results from the proposed framework, the Hierarchies I and II ranking for the best maintenance sustainability strategies were the same. The best maintenance sustainability strategy was maintenance consumables optimisation. This result was different from fuzzy TOPSIS result that identified maintenance policy as the best maintenance strategy. The fuzzy TOPSIS and Hierarchy II net flow identified waste reduction and workforce training and disposal as the worst ranked maintenance sustainability strategies, respectively.

The proposed framework could be useful in other maintenance functions. This could entail retaining the number of sub-criteria or adjusting it (increase or decrease) to comply with a maintenance system's requirements. The proposed framework could be extended to maintenance productivity strategies choice. This will entail consideration of type of maintenance strategy. A study which considered the proposed framework as a ranking tool for maintenance performance evaluation practices could be considered as a further study.

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