A Green Preventive Maintenance Model Incorporating the Green Fuzzy Deployment Method with the WASPAS Approach for Production Lines

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Abstract. *Preventive maintenance assessments are presently obligatory on production lines as they reduce unscheduled downtime requiring major equipment repairs and aid improved asset conservation and the life expectancy of assets. However, the present preventive maintenance models are deficient as they exclude essential environmentally conscious design and manufacturing elements to produce customer-oriented green preventive maintenance programmes. In this paper, the idea is to use the green design principles and then incorporate the voice of customers and producers concurrently to design the preventive maintenance programme in a production line. The proposed green quality function deployment model is based on the philosophy of customers' needs and aspirations, which drive the preventive maintenance programme. At the same time, the manufacturer is compelled to comply with these needs from the perspectives of cost, technical competence and other issues. The WASPAS multi-criterion model is then employed to and the selection process. The applicability of the proposed framework was tested using information obtained from a cement production plant. Three production lines were considered. Based on the results obtained from the case study, the most important requirement for determining the rank of the production lines was the physical life of the equipment. Maintenance workforce cost is the least important requirement for determining the production lines ranks. The results from the WASPAS method showed that production lines 2 and 1 had the highest and least ranking, respectively. The usefulness of this attempt is to help maintenance managers to install effective decisions preventive maintenance programmes at lower costs and zero liability to the company regarding litigation claims.*

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1. Introduction

The dominant practice in preventive maintenance assessments entails deciding the degree to which unscheduled preventive maintenance activities successfully reduce equipment downtime and major repairs. For example, Xiao et al. [1] assessed the optimal preventive maintenance time as a control tool for equipment downtime. Zhang et al. [2] evaluated the maintenance cost in a flows shop by using a preventive maintenance strategy to control equipment downtime and major repairs. Hernandez-Chover et al. [3] deployed efficiency analysis to control repair costs in preventive maintenance. Wang et al. [4] analysed the operational mode of a preventive maintenance process to establish control on the equipment breakdown. Furthermore, additional dominant practice in preventive maintenance evaluates how assets may be better conserved while enhancing the life expectancy of production assets and avoiding early replacements of parts or complete machinery [5].

Unfortunately, the prevailing preventive maintenance assessment models for production lines fail to account for environmentally conscious design and manufacturing elements to produce customer-oriented green preventive maintenance programmes. For example, Imani and Bae [6] considered the life warranty aspect of preventive maintenance but omitted the green aspect of the study. Chopra et al. [7] discussed the prevalent practices of preventive maintenance for Indian society but excluded the green details. The concern failure rate control of preventive maintenance was the chief focus of Davoodi and Amelian [8], but no interest was shown in the green aspects of preventive maintenance. In Wang [9], the development of a maintenance strategy from the lens of preventive maintenance for a single machine was discussed by no highlights on the green aspects were shown. Aldaihani and Darwish [10] linked preventive maintenance and supply chain but excluded concerns about greenness. Alam et al. [11] introduced a 0/1 mixed-integer linear programming method to determine an effective strategy based on preventive maintenance.

However, there was no interest shown in the green aspects of the strategy. In Eslami et al. [12], a preventive maintenance scheduling approach was chosen but no indication of the green aspect was revealed.

But incorporating greenness into preventive maintenance helps maintenance managers to install effective preventive maintenance decisions at lower costs and near-zero or zero level liability to the company concerning the negative activities of the company on the environment regarding environmental pollution, including air, water, soil and noise. Besides, some earlier researchers such as Cristofari et al. [13], Zhang et al. [14] and Mehta and Wang [15] envisioned greenness in manufacturing with solid arguments to consider life cycle assessments. However, subsequent studies after them tend to broaden the scope of analysis, but the application of this concept is completely omitted for preventive maintenance modelling. Mehta and Wang [15] evolved the green quality function deployment III to tackle environmentally conscious manufacturing in choosing a superior product by fusing life cycle influence evaluation, the greenhouse and analytical hierarchy process. While being comprehensive, the article initiated the use of multi-criteria decision making that prompted the use of the weighted aggregated sum product assessment (WASPAS) method in the present study. Furthermore, Zhang et al. [14] introduced a novel method for an environmentally conscious methodology that joined the frameworks of life cycle assessment and life cycle costing into the quality function deployment framework. The considered elements are the technical requirement identification, product concept generation and the product/process design.

However, avoiding the incorporation of environmentally conscious design and manufacturing elements underestimates the scope of preventive maintenance activities and could trigger the development of grossly inadequate preventive maintenance assessments models. But, incorporating the green aspects (environmental conscious manufacturing) will produce a superior and more practical picture. Green preventive maintenance is compelled to make the factory environment reliable and safe and enhance resource consumption in repair activities [16]. With eco-friendly maintenance, it was argued that the repair process is credible since each step is implemented safely, with adequate protection given to maintenance workers and other personnel at the work area [16]. Conversely, eliminating eco-friendly maintenance practices from the workplace introduces ill-timed maintenance that could trigger an expansive disaster, leading to substantial damaging outcomes to the environment and human beings [16]. Today, the concern for green preventive maintenance is even more compelling than before to implement in factories since there are incredible and impressive accuracies and advantages expected from introducing the green elements into the preventive maintenance assessments in production lines.

Aside, since the idea of going green in factories has come to the forefront of manufacturing practices, organisations are appreciating customers' desire for green concept and striving to include sustainable practices into all facets of factory operations. In the practitioners' literature, companies take sustainability (green) as a unique enabler of competitiveness, of outstanding economic and environmental value. However, extremely little research is available on green preventive maintenance practices. Consequently, in this article, a novel green preventive maintenance assessment model is proposed to account for the green aspect of maintenance. However, this article uses three methods in an integrated manner: the green quality function deployment method, fuzzy entropy weighing method and the weighted aggregated sum product assessment (WASPAS) method to assess and update the status of knowledge on preventive maintenance assessment. The green quality function deployment (GQFD) theory is an innovative methodology that emphasises environmentally conscious preventive maintenance practices during equipment design and manufacturing. While the case study plant is operational, developing a preventive maintenance scheme that applies environmental criteria to reduce the environmental impact of plants, such as pollution control equipment for facilities emitting volatile organic compounds, is the principal framework of the green quality function deployment based preventive maintenance models. However, it is disturbing that these volatile organic compounds are released into the atmosphere, as chemicals vaporise to damage the environment.

Consequently, the GQFD preventive maintenance model argues that pollution control equipment should be deployed to capture, destroy and reduce toxic compounds to the environment while meeting the strict guidelines of environmental protection agencies in air quality standards. The green preventive maintenance model argues that green design should include the customers' voices (i.e. internal such as production team members, stakeholders in the environment and product users) concurrently with the producers, i.e. equipment designers). This calls for a consensus between the customers and manufacturers to have a robust preventive maintenance model that produces acceptable costs from the customer perspectives.

Furthermore, this study is substantial since it sets a platform to determine the imperative deficiency of greenness in preventive maintenance models for production lines. Besides, it provides important details to preventive maintenance engineers and engineering managers regarding how to reduce imprecision and uncertainty in the estimation produced by the maintenance engineer by adopting the fuzzy entropy weighting method with the unique benefit of eliminating the interference of the evaluation process by human factors by protecting the weights of the indicators and infusing objectivity into the green preventive maintenance model development. Moreover, by incorporating the WASPAS method to establish the solution to the greenish problem of preventive maintenance, the synergic use of the quality function deployment and the WASPAS method to select in a cost-effective manner that minimises substantial time and effort makes the green preventive maintenance model more robust, reliable and useful. Using the technique for order of preference by similarity to ideal solution (TOPSIS), the authors examined the WASPAS performance in the suggested framework.

The contributions of this research to the preventive maintenance assessment literature are as follows:

- Highlighting preventive maintenance idea in research. But such understanding could expand practice and improve the quality of the manufacturing environment.
- Introduction of an uncertainty and imprecision reduction mechanism through the deployment of fuzzy entropy weighting method.
- A unique synergic association of the green quality function deployment and the WASPAS method.

2. Methodology

This study adopts green quality function deployment to infuse environmental and customers' requirements into the preventive maintenance plans for production lines (Fig. 1). The proposed framework is based on the fuzzy entropy weighting method and a combined green quality function deployment and WASPAS method. Explanations on the selected scientific tools are presented as follows:

2.1 Fuzzy Entropy Weighted Method

The environmental and customers' requirements used in determining the relative importance of each factor used for preventive maintenance analysis are mass of air pollution (A_1), the mass of soil pollution (A_2), the mass of water pollution (A_3), quality of the product (A_4) and energy consumption (A_5). Other requirements are vibration level (A_6), production rate (A_7), reliability of production line (A_8) and production line availability (A_9). Sine maintenance information is often in linguistic terms; fuzzy numbers are used to evaluate the importance of each of the customers' requirements (Table 1).

A trapezoidal fuzzy number is seen in Fig. 2. These numbers are divided into three sets since we considered three partitions. The conversion of the trapezoidal fuzzy numbers into crisp values are based on (1). The crisp values that are obtained are used to form the Hesitant decision matrix. These values are normalised using the expression by (2).

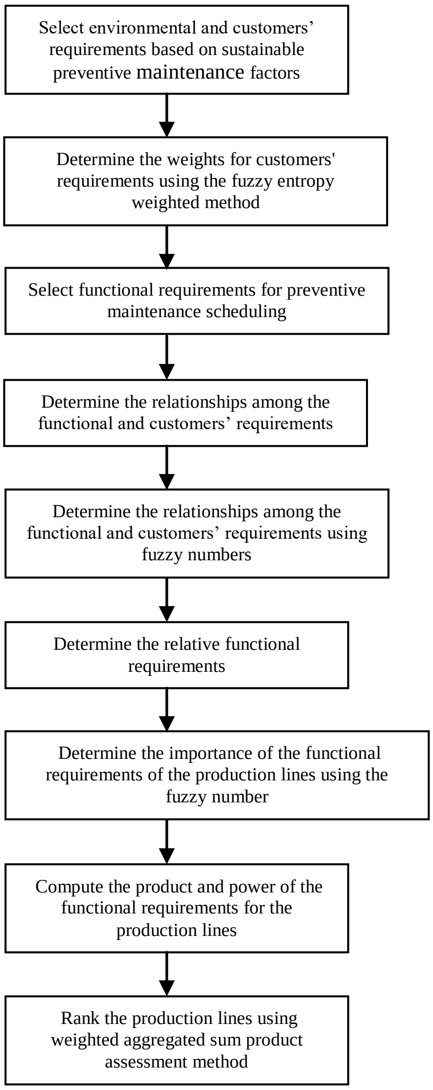

Fig. 1 A framework for ranking preventive maintenance schedule on production lines

Linguistic terms	Symbols	Fuzzy numbers
Slightly important	VI	(1, 2,3,4)
Moderately important	L	(4,5,6,7)
Highly important	M	(7,8,9,10)

Table 1 Linguistic terms and fuzzy numbers [17]

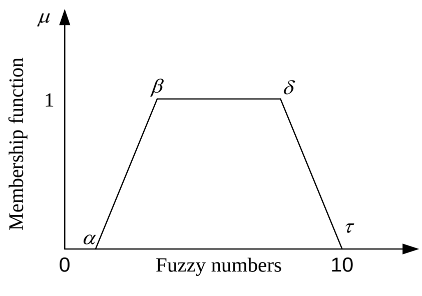

Fig. 2 Trapezoidal fuzzy number

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

where β_{ij}, α_{ij} τ_{ij} and δ_{ij} denote the first, second, third and fourth values of a trapezoidal fuzzy number for customers' requirement *i* value from decision-maker *j*, respectively.

$$\widehat{d}_{ij} = \frac{x_{ij}}{\sum_{j}^{n} x_{ij}} \quad (2)$$

;where $\widehat{d}_{ij}$ is normalised value of environmental and customers' requirement *i* value from decision-maker *j*, and x_{ij} actual value of environmental and customers' requirement *i* value from decision-maker *j*.

To generate the entropy values for the environment and customers' requirements, the normalised values from the different decision-makers are combined based on (3).

$$E_i = -\frac{1}{\ln m}\sum_{i=1}^{m} \frac{\widehat{d}_{ij}}{D_j} \ln \frac{\widehat{d}_{ij}}{D_j} \quad (3)$$

$$D_j = \sum_{i=1}^{m} \widehat{d}_{ij} \quad (4)$$

where E_i is entropy value for environmental and customers' requirement *i*, and *m* represents the total number of requirements

The weights for the selected environmental and customers' requirements are determined by considering the total number of environmental and customers' requirements, total entropy value and individual entropy value for the environmental and customers' requirements as (5).

$$w_i = \frac{1 - E_i}{n - E} \quad (5)$$

$$E = \sum_{i=1}^{n} E_i \quad (6)$$

where w_i is weight for environmental and customers' requirement *i*.

2.2 Green quality function requirements and WASPAS method

Nine requirements for preventive maintenance activities are considered in this study. They are maintenance workforce size (M_1), workforce cost (M_2), spare parts cost (M_3), maintenance time (M_4), MTTF (M_5), M.T.T.R. (M_6), MTBF (M_7), ease of maintenance (M_8) and physical life of equipment (M_9). The relationships between the preventive maintenance (functional) requirements and the environmental and customers' requirements are presented in Fig. 3.

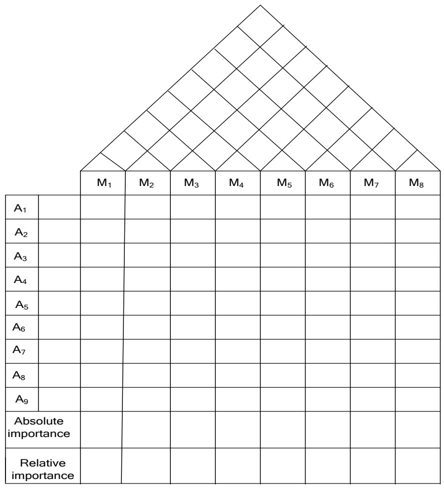

Fig. 3 Green quality function deployment to determine requirements weights for preventive maintenance schedule

Fuzzy numbers are used to express the relationships among the functional requirements and the environmental and customers' requirements (Table 2). The aggregation of the decision-makers responses for the relationships among the functional requirements and the environmental and customers' requirements is different from that of the fuzzy entropy weighting method.

Linguistic terms	Symbols	Fuzzy numbers
Very low	VL	(0.0, 0.0, 0.1, 0.2)
Low	L	(0.1, 0.2, 0.3, 0.4)
Moderate	M	(0.3, 0.4, 0.5, 0.6)
high	H	(0.5, 0.6, 0.7, 0.7)
Very high	VH	(0.7, 0.8, 0.9, 1.0)

Table 2 Linguistic terms and fuzzy numbers

First, values of the data points in a trapezoidal fuzzy number are aggregated as (7). The aggregation process is carried out based on (8) to (11).

$$x_{ij} = \left\{x_{ij1}, x_{ij2}, x_{ij3}, x_{ij4}\right\} \quad (7)$$

$$x_{ij1} = \min\left\{x_{ijk1}\right\} \quad (8)$$

$$x_{ij2} = \frac{1}{k}\sum_{k=1}^{K} x_{ijk2} \quad (9)$$

$$x_{ij3} = \frac{1}{k}\sum_{k=1}^{K} x_{ijk3} \quad (10)$$

$$x_{ij4} = \max\left\{x_{ijk4}\right\} \quad (11)$$

where x_{ijkt} is the value assigned to the relationship between environmental and customers, and maintenance requirement *j* by decision marker *k* at index *t* in fuzzy number, and x_{ijt} is the value for the relationship between environmental and customers and maintenance requirement *j* at index *t* is the fuzzy number.

The defuzzification of the responses from decision-makers is based on the centroid defuzzification scheme [18].

$$x_{ij} = \frac{\int \mu(x)x\delta x}{\int \mu(x)\delta x} \quad (12)$$

$$x_{ij} = \frac{-x_{ij1}x_{ij2} + x_{ij3}x_{ij4} + \frac{1}{3}(x_{ij4} - x_{ij3})^2 - \frac{1}{3}(x_{ij2} - x_{ij1})^2}{-x_{ij1} - x_{ij2} + x_{ij3} + x_{ij4}} \quad (13)$$

After determining the crisp values for each production line performance criteria, selecting the preventive maintenance schedule is carried out using WASPAS [19-21]. First, the relative importance of each production line is determined based on its weighted sum method (14) and weighted product method (15). After which, the rank for each production line schedule is determined based on a constant parameter (λ), which lies between 0 and 1 (16).

$$Q_l^{(1)} = \sum_{i=1}^{m} \bar{x}_i . w_i \quad (14)$$

$$Q_l^{(2)} = \prod_{i=1}^{m} \bar{x}_i^{w_i} \quad (15)$$

$$Q_l = \lambda Q_l^1 + (1-\lambda) Q_l^2 \quad (16)$$

where $Q_l^{(1)}$, $Q_l^{(2)}$ and Q_l represent the alternative's *l* weighted sum, weighted product and WASPAS values, respectively.

3. Case Study and Discussion of Results

The application of the proposed approach for preventive maintenance schedule was applied in a cement production plant. The plant has three production lines. The required information for the proposed methodology implementation was obtained from four decision-makers (D). First, the importance of the various sustainability criteria was determined using the fuzzy entropy weighted approach (Table 3). The results in this table show that the experts' assessments of the importance of the criteria are consistent. A_6 to A_9, for example, was given the same linguistic values. This is also true when it comes to the significance of A_2. The information that is presented in Table 3 is used to determine the crisp values (Table 4) for decision-maker responses based on (1) and (2).

Criteria	D_1	D_2	D_3	D_4
A_1	VH	VH	VH	VH
A_2	H	H	H	H
A_3	M	M	H	M
A_4	VH	VH	VH	VH
A_5	VH	VH	VH	VH
A_6	VH	VH	VH	VH
A_7	VH	VH	VH	VH
A_8	VH	VH	VH	VH
A_9	VH	VH	VH	VH

Table 3 Decision-makers linguistic responses for the sustainability criteria

Criteria	D_1	D_2	D_3	D_4
A_1	0.1700	0.1700	0.1700	0.1700
A_2	0.1300	0.1300	0.1300	0.1300
A_3	0.0900	0.0900	0.1300	0.0900
A_4	0.1700	0.1700	0.1700	0.1700
A_5	0.1700	0.1700	0.1700	0.1700
A_6	0.1700	0.1700	0.1700	0.1700
A_7	0.1700	0.1700	0.1700	0.1700
A_8	0.1700	0.1700	0.1700	0.1700
A_9	0.1700	0.1700	0.1700	0.1700

Table 4 Decision-makers crisp responses for the sustainability criteria

By considering (3) to (5), the weights for each of the sustainability criteria were determined (Table 5). The fuzzy entropy weighting approach results showed that apart from the mass of water pollution weight, the other sustainability criteria are the same (Table 5).

Criteria	Entropy	Weights
A_1	0.6309	0.1109
A_2	0.6309	0.1109
A_3	0.6255	0.1126
A_4	0.6309	0.1109
A_5	0.6309	0.1109
A_6	0.6309	0.1109
A_7	0.6309	0.1109
A_8	0.6309	0.1109
A_9	0.6309	0.1109

Table 5 Fuzzy entropy parameters for the criteria

The decision-makers responses for the relationships between the sustainability criteria and the preventive maintenance schedule requirements showed that most of the relationships were moderately important (Table 6). According to the experts, most consumers' requirements are moderately important, as shown in Table 6. On the other side, we discovered that experts believe M_6 is very high for production line 1. On the contrary, M_1 important was considered as low for the same production line.

Description	Lines	D_1	D_2	D_3	D_4
	L_1	L	L	L	L
M_1	L_2	M	M	M	M
	L_3	M	M	M	M
	L_1	M	M	M	M
M_2	L_2	M	M	M	M
	L_3	M	M	M	M
M_3	L_1	H	H	M	M
	L_2	H	H	H	H
	L_3	M	M	M	M
	L_1	M	M	M	M
M_4	L_2	M	M	M	M
	L_3	M	M	M	M
	L_1	L	L	M	L
M_5	L_2	L	L	M	L
	L_3	L	L	M	L
	L_1	VL	VH	VH	VH
M_6	L_2	H	H	H	H
	L_3	M	M	M	M
	L_1	M	M	L	M
M_7	L_2	M	M	M	M
	L_3	H	H	M	H
	L_1	M	M	H	M
M_8	L_2	M	H	M	M
	L_3	M	H	M	M
	L_1	H	M	M	H
M_9	L_2	H	M	H	H
	L_3	M	M	V.H.	M

Table 6 Linguistics variables for the production lines

The aggregated crisp values (Table 7) for the preventive maintenance schedule requirements are generated using (8) to (13). The results obtained for the selected preventive maintenance requirements showed that the most important requirement for determining the importance of a preventive maintenance schedule is the physical life of equipment (Table 8). Spare parts cost is the least important requirement for the preventive maintenance schedule for the case study (Table 8).

The values for each production line's preventive maintenance schedule requirements were determined based on the information presented in Table 9. First, the aggregated trapezoidal fuzzy number for each production line was determined using (7) to (10). We then used (13) to determine the crisp values for each production line's preventive maintenance schedule requirements (Table 10).

Description	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8	M_9
A_1	2.5000	2.5000	2.5000	7.2900	2.5000	2.5000	6.0500	8.5000	8.5000
A_2	2.5000	5.5000	2.5000	6.3700	7.0000	4.2900	3.7700	6.7100	7.0000
A_3	8.5000	2.5000	2.5000	8.5000	5.5000	8.5000	8.5000	8.5000	8.5000
A_4	7.2900	3.7100	7.2900	6.7100	8.5000	8.5000	8.5000	8.5000	8.5000
A_5	5.2300	3.7100	5.2300	6.3700	7.0000	4.0000	6.0900	5.2300	3.7100
A_6	8.5000	8.5000	5.7800	6.3700	7.2900	8.5000	8.5000	7.6500	8.5000
A_7	8.5000	7.6500	7.0000	7.2900	8.5000	8.5000	8.5000	7.2900	8.5000
A_8	8.5000	4.6000	4.6000	8.5000	8.5000	8.5000	8.5000	8.5000	8.5000
A_9	5.5000	5.5000	2.5000	7.0000	6.7100	8.5000	8.5000	8.5000	8.5000

Table 7 Aggregated crisp values of the importance of the preventive maintenance requirements

Description	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8	M_9
A_1	0.2773	0.2773	0.2773	0.8085	0.2773	0.2773	0.6709	0.9427	0.9427
A_2	0.2773	0.6100	0.2773	0.7064	0.7763	0.4758	0.4181	0.7441	0.7763
A_3	0.9571	0.2815	0.2815	0.9571	0.6193	0.9571	0.9571	0.9571	0.9571
A_4	0.8085	0.4114	0.8085	0.7441	0.9427	0.9427	0.9427	0.9427	0.9427
A_5	0.5800	0.4114	0.5800	0.7064	0.7763	0.4436	0.6754	0.5800	0.4114
A_6	0.9427	0.9427	0.6410	0.7064	0.8085	0.9427	0.9427	0.8484	0.9427
A_7	0.9427	0.8484	0.7763	0.8085	0.9427	0.9427	0.9427	0.8085	0.9427
A_8	0.9427	0.5101	0.5101	0.9427	0.9427	0.9427	0.9427	0.9427	0.9427
A_9	0.6100	0.6100	0.2773	0.7763	0.7441	0.9427	0.9427	0.9427	0.9427
Relative weight	6.3380	4.9027	4.4292	7.1564	6.8297	6.8670	7.4348	7.7087	7.8007
Absolute weight	0.1066	0.0824	0.0745	0.1203	0.1148	0.1155	0.1250	0.1296	0.1312

Table 8 Weights of the preventive maintenance requirements

	Lines	D_1	D_2	D_3	D_4	Aggregated values
	L_1	(0.1,0.2,0.3,0.4)	(0.1,0.2,0.3,0.4)	(0.1,0.2,0.3,0.4)	(0.1,0.2,0.3,0.4)	(0.1,0.2,0.3,0.4)
M_1	L_2	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)
	L_3	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)
	L_1	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)
M_2	L_2	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)
	L_3	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)
M_3	L_1	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,.6)	(0.3,0.5,0.6,0.8)
	L_2	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)
	L_3	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)
	L_1	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)
M_4	L_2	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)
	L_3	0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)
	L_1	(0.1,0.2,0.3,0.4)	(0.1,0.2,0.3,0.4)	(0.3,0.4,0.5,0.6)	(0.1,0.2,0.3,0.4)	(0.1,0.25,0.35,0.6)
M_5	L_2	(0.1,0.2,0.3,0.4)	(0.1,0.2,0.3,0.4)	(0.3,0.4,0.5,0.6)	(0.1,0.2,0.3,0.4)	(0.1,0.25,0.35,0.6)
	L_3	(0.1,0.2,0.3,0.4)	(0.1,0.2,0.3,0.4)	(0.3,0.4,0.5,,0.6)	(0.1,0.2,0.3,0.4)	(0.1,0.25,0.35,0.6)
	L_1	(0,0,0.1,0.2)	(0.7,0.8,0.9,1.0)	(0.7,0.8,0.9,1)	(0.7,0.8,0.9,1)	(0.00,0.6,0.7,1.0)
M_6	L_2	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7, .8)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.50,0.6,0.7,0.8)
	L_3	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)	(0.30,0.4,0.5,0.6)
	L_1	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)	(0.1,0.2,0.3,0.4)	(0.3,0.4,0.5,0.6)	(0.1,0.35,0.45,0.6)
M_7	L_2	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)
	L_3	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.3,0.4,0.5,0.6)	(0.5,0.6,0.7,0.8)	(0.3,0.55,0.65,0.8)
	L_1	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)	(0.5,0.6,0.7,0.8)	(0.3,0.4,0.50.6)	(0.3,0.45,0.55,0.8)
M_8	L_2	(0.3,0.4,0.5,0.6)	(0.5,0.6,0.7,0.8)	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)	(0.3,0.45,0.55,0.8)
	L_3	(0.3,0.4,0.5,0.6)	(0.5,0.6,0.7,0.8)	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)	(0.3,0.45,0.55,0.8)
	L_1	(0.5,0.6,0.7,0.8)	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)	(0.5,0.6,0.7,0.8)	(0.3,0.5,0.6,0.8)
M_9	L_2	(0.5,0.6,0.7,0.8)	(0.3,0.4,0.5,0.6)	(0.5,0.6,0.7,0.8)	(0.5,0.6,0.7,0.8)	(0.3,0.55,0.65,0.8)
	L_3	(0.3,0.4,0.5,0.6)	(0.3,0.4,0.5,0.6)	(0.7,0.8,0.9,1)	(0.3,0.4,0.5,0.6)	(0.3,0.5,0.6,1.0)

Table 9 Aggregated fuzzy number for the production line

	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8	M_9
Weight	0.107	0.082	0.075	0.120	0.115	0.116	0.125	0.130	0.131
L1	0.250	0.450	0.550	0.450	0.331	0.555	0.369	0.531	0.550
L2	0.450	0.450	0.650	0.450	0.336	0.650	0.450	0.531	0.569
L3	0.450	0.450	0.450	0.450	0.331	0.450	0.569	0.531	0.613

Table 10 Crisp value for the production lines criteria

The WASPAS value for each production line was determined by first computing the sum and product crisp values for the various preventive maintenance schedule requirements (Table 11). Based on the information in Table 11, the WASPAS values for different λ were generated (Table 12). The various values of λ in Table 12 showed that the highest-ranked production line is production line 2, while production line 1 is the least ranked production line (Table 12).

To validate the ranking order in Table 12, we used a TOPSIS algorithm to evaluate the data in Table 10 [22]. First, using Equation, weighted normalised values for the options were created (17). The findings for these values are summarised in Table 13.

$$V_{is} = w_i r_{is} \quad \forall i \in m; \forall s \in S \tag{17}$$

where V_{is} represents the weighted normalised value of criterion i for production line s, and w_i represents the importance of criterion i.

The authors calculated the positive and negative ideal solutions for each of the criteria using these normalised values (Table 14) – see (18) and (19).

$$D^{+} = \{v_1^{+}, \cdots, v_i^{+}\} = \left\{ \left(\max v_{is} \middle| i \in I' \right), \left(\min_{s} v_{is} \middle| i \in I'' \right) \right\} \tag{18}$$

$$D^{-} = \{v_1^{-}, \cdots, v_i^{-}\} = \left\{ \left(\min v_{is} \middle| i \in I' \right), \left(\max_{s} v_{is} \middle| i \in I'' \right) \right\} \tag{19}$$

where D^{+} and D^{-} represents the matrix for the ideal positive and negative solutions, respectively.

		M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8	M_9
	L1	0.0267	0.0371	0.0410	0.0541	0.0380	0.0640	0.0462	0.0688	0.0722
$\overline{x}_i.w_i$	L2	0.0480	0.0371	0.0484	0.0541	0.0380	0.0751	0.0563	0.0688	0.0747
	L3	0.0480	0.0371	0.0335	0.0541	0.0380	0.0520	0.0712	0.0688	0.0804
	L1	0.8626	0.9363	0.9564	0.9084	0.8807	0.9342	0.8830	0.9211	0.9246
$\overline{x}_i^{w_i}$	L2	0.9184	0.9363	0.9684	0.9084	0.8807	0.9515	0.9050	0.9211	0.9288
	L3	0.9184	0.9363	0.9422	0.9084	0.8807	0.9119	0.9320	0.9211	0.9377

Table 11 Sum and product crisp values for the production lines criteria

Description	Q_l^1	Q_l^2	Q_l								
			Λ=0.1	λ=0.2	λ=0.3	λ=0.4	λ=0.5	λ=0.6	λ=0.7	Λ=0.8	λ=0.9
L1	0.4479	8.2073	7.4314	6.6554	5.8795	5.1035	4.3276	3.5517	2.7757	1.9998	1.2239
		Rank	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)
L2	0.5004	8.3186	7.5368	6.7550	5.9731	5.1913	4.4095	3.6277	2.8458	2.0640	1.2822
		Rank	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)
L3	0.4829	8.2888	7.5082	6.7277	5.9471	5.1665	4.3859	3.6053	2.8247	2.0441	1.2635
		Rank	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)

Table 12 Preventive maintenance schedule WASPAS results for different values of λ

Description	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8	M_9
L1	0.0268	0.0369	0.0413	0.0540	0.0381	0.0644	0.0461	0.0690	0.0721
L2	0.0482	0.0369	0.0488	0.0540	0.0386	0.0754	0.0563	0.0690	0.0745
L3	0.0482	0.0369	0.0338	0.0540	0.0381	0.0522	0.0711	0.0690	0.0803

Table 13 Weighted normalised values for the alternative

Solutions	M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8	M_9
Positive	0.0482	0.0369	0.0488	0.0540	0.0386	0.0754	0.0711	0.0690	0.0803
Negative	0.0268	0.0369	0.0338	0.0540	0.0381	0.0522	0.0461	0.0690	0.0721

Table 14 Positive and negative ideal solutions for each of the criteria

The positive as (20) and negative as (21) solutions were utilised to calculate the distances between the production lines solutions. The results of these calculations are shown in Table 15 for the scenarios under consideration. Also contained in this table is the production lines closeness coefficients as (22).

$$D_s^+ = \sqrt{\sum_{i=1}^{m} \left(v_{is} - v_i^+\right)^2} \quad \forall s \in S \tag{20}$$

$$D_s^- = \sqrt{\sum_{i=1}^{m} \left(v_{is} - v_i^-\right)^2} \quad \forall s \in S \tag{21}$$

$$D_s = \frac{D_s^-}{D_s^- + D_s^+} \qquad \forall s \in S \tag{22}$$

where D_s^+ and D_s^- represents the production line s distance from the ideal positive and negative solutions, respectively, and D_s represents the production line s closeness coefficient.

Description	Positive solutions	Negative solutions	Closeness coefficients
L1	0.0365	0.0143	0.2818
L2	0.0468	0.0365	0.4379
L3	0.0498	0.0339	0.4050

Table 15 Distances from the positive and negative solutions

The TOPSIS approach ranks the manufacturing lines as L2 > L3 > L1 using a higher-cum-preferred principle to process the proximity coefficient in Table 15. When looking at the results in Table 13, it can be seen that the ranking orders for both the WASPAS and TOPSIS approaches are the same.

4. Limitations and Future Scope

The key limitations of the present work are as follows. While data from companies with production lines were used to analyse the green preventive maintenance model, it is not clear whether the attainment of the green preventive maintenance programme otherwise was aided or not by the company outsourcing its maintenance services to the third party. To deepen the understanding of the maintenance engineer, future studies may specify whether maintenance services are outsourced to third parties and in what percentage? Then analysis may be extended to the influence of the outsourcing third party contractor on the performance of green activities within the company. From the results, the policy may be formulated on what types of jobs may be outsourced and the agreement to be reached with the contractor before the outsourcing contract is signed. Besides, the integration of the green quality function deployment, fuzzy entropy weighting method and WASPAS was attempted in this article. However, the validation of the results is required by the fuzzy axiomatic design model to replace the fuzzy entropy weighting method such that the combination of methods will be the green quality function deployment, fuzzy axiomatic design and WASPAS for the same problem of green preventive maintenance modelling.

The insight may reveal the strength of the fuzzy entropy weighting method to capture uncertainty and imprecision less or better than the fuzzy axiomatic design method in the combination. Third, depending on the production capacity attained in a previous period, the level of preventive maintenance activities may be dynamic. Thus, it may be interesting to understand the dynamics of the preventive maintenance work capacity for different production companies, such as those producing seasonal products regulated by climatic conditions such as food and drinks and outside this group, those producing machine parts and heavy engineering equipment.

5. Conclusions

This study has presented an approach to understanding the interactions among maintenance sustainability factors, including requirements for maintenance, environment and customers, using the QFD concept, multi-criteria, fuzzy weighted entropy and WAPAS methodology. The proposed methodology was applied in a cement production plant. The results obtained showed that the rank of preventive maintenance schedule on production line 2 was higher than those of production lines 1 and 3. This result demonstrated the effectiveness of the proposed methodology for preventive maintenance schedule ranking of production lines.

To summarise the advancement made by this study, a three-fold statements are made. First, the proposed methodology considered the need for a green manufacturing environment during the ranking of production lines for preventive maintenance schedule. Secondly, the use of fuzzy logic to address ambiguity in decision-makers' opinions during the ranking of production lines preventive maintenance schedule was incorporated in the methodology. Thirdly, the use of QFD in determining the weight for evaluating maintenance activities on production lines is another advancement made by this study.

This study established the feasibility of the approach in the case cement industry, triggering more understanding and provoking more inquiries into this virgin area of research—for example, how to determine the most suitable maintenance performance measurement practice. Determining the type of maintenance outsourcing service relationships for a production system using sustainability and maintenance performance criteria is another area of further study. In addition, a study that considers the replacement of fuzzy entropy weighting method with Step-wise Weight Assessment Ratio Analysis is another direction of research.

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