Maintenance Work Environment and the Interacting Multidisciplinary Concerns using Multicriteria Techniques

Desmond Eseoghene Ighravwe [1] and Sunday Ayoola Oke [2,*]

[1]Department of Mechanical and Biomedical Engineering, Bells University of Technology, Ota, Nigeria
[2,*] Department of Mechanical Engineering, University of Lagos, Lagos, Nigeria (Corresponding Author)

ighravwedesmond@gmail.com and sa_oke@yahoo.com*

Abstract. *The work environment significantly impacts on the workers' performance in modern-day manufacturing and should be a subject of further investigations for improved manufacturing performance. Nonetheless, the interactions among the physical, organisational and system safety factors remain unclear, amplifying efforts to effectively control the performance of the workforce. In the research, the investigators examined a framework that tests the interaction among fifteen selected factors which indicates work environment. The researchers utilized fuzzy entropy weighting and fuzzy grey relational analysis to develop a model that was tested in four manufacturing systems, using the fifteen factors selected from literature. The investigators conducted normalisation, determination of coefficient for grey relations, membership function determination and class selection procedure with applications to the fifteen factors selected. All maintenance systems had highly conducive environmental aggregates (Company A, Company C and Company D are 0.9400, 0.9442 and 0.8667 respectively) but one failed (Company B=0.7482). This suggests that the three healthy systems can effectively plan for performance improvement programmes such as productivity and quality drives. Work environment plays a crucial function in the corridor of performance analysis of manufacturing concerns. Consequently, the work environmental framework suggested should be a typical appraisal scale for manufacturing systems. Intervention using the proposed framework is necessary to enhance manufacturing system performance. The interactions among the fifteen selected factors of work environment show a healthy status in 75% of the cases considered. The feasibility of modelling the problem using the emerging models of fuzzy-based criteria was confirmed.*

Received by	2 February 2021
Revised by	8 May 2021
Accepted by	25 May 2021

Keywords:

fuzzy environment, fuzzy entropy weighting approach, FGRA

1. Introduction

The foremost objective of the maintenance work environment is to optimally improve the competence of employees, their values, outputs and loyalty to the manufacturing company by offering high–quality work environment [1, 2]. Furthermore, due to the string out work conditions laid out as standards by safety and environmental regulators every day, the scope for the qualification and enhance of maintenance work environment has been growing [3]. In addition, adequate appraisal of possible options in an evaluation perspective is declared to be extremely essential to choose to superior one towards safety and environment programme implementation concerns [4]. In the present situation of an ever-growing work environmental standards by the International Organisation for Standardisation (ISO) on the safety and environmental practices, the selection of maintenance work environment ought to consist of significant factors aimed at addressing the organisation goals at diverse levels and perspectives of the manufacturing company. Without the application of detailed and robust maintenance environment evaluation criteria, it is clearly challenging to conduct an appraisal of the diverse work environment scenarios that may be visualized for maintenance. In addition, the employment of sole multicriteria method along could certainly oversight the benefit of employing joint techniques of multicriteria methods. In addition, since it is known that the real scenario tends more towards a probabilistic nature than a deterministic outlook, without a careful, detailed and robust consideration of fuzziness in appraising the different sub-scenarios, the outcomes of the evaluation process may be inexact and not dependable. As a consequence, all the mentioned factors stimulated the current author to develop a study to appraise and choose the superior one of the main options of maintenance work environment employing ABC methods.

The extant literature on maintenance was reviewed and reveals that although that some models have been published on maintenance criteria and sub-criteria, there is no single article that has established the methodology to appraise the maintenance work environment in a holistic form. There are no papers found on decision making in relation to the maintenance work environment. On an individual basis, a scanty number of articles have solely addressed one criterion of the maintenance work environment or the other. These criteria include noise control, housekeeping (cleanliness) [5], and vibration control [6]. By considering these issues, the subsequent research gaps are established and ought to be tackled:

- It is a necessity to use multicriteria methods subjected to fuzzy conditions to appraise a maintenance work environment
- The appraisal and choice of the appropriate maintenance work environment ought to be tackled using a group or principal criteria coupled with sub-criteria using a hierarchical structure
- The use of the newest method of multicriteria to appraise and choose appropriate maintenance work environment should be strongly pursued and employed with intense efforts

From the perspective of the argument put forward, the research offered in this paper directs attention to the appraisal and choice of a maintenance work environment with the subsequent objectives in mind:

- To appraise and choose the appropriate maintenance work environment employing multicriteria decision making technique subject to fuzzy condition.
- To select superior maintenance work environment, and advance an efficient and effective structure for appraisal.
- To establish the prioritisation scheme of the diverse principle criteria coupled with the sub-criteria taking into account the individual criterion taking into account the individual criterion in the hierarchy
- To prioritize maintenance schemes for the maintenance work environment and to establish the eventual ranking for all the options.

In view of these issues, a research effort is made to build up a structure of multicriteria method by means of fuzziness to attain effective maintenance work environment decision in the company.

2. Literature Review

2.1 An Overview

Work environment, a foremost basis for work performed in manufacturing settings, may be negatively or positively related to workplace turnover, among others [7]. Besides negatively impacting the worker's health, a poor work environment may be a psychological threat to the worker's state of mind during working activities and a principal pointer to workforce performance decline. While the parameters that influence a work environment are well-known to scholars, the interactions among these factors and how they could impact the work environmental outcomes are unclear. A number of studies propose noise as a strong predictor of work environment [8, 9, 10, 11]. Other studies suggest that housekeeping involves cleanliness as a largely predictive parameter for work environment [5, 12, 13, 14].

Nonetheless, the determinants of physical environmental factors upon which cleanliness is an essential component (for instance, the control of noise, vibration, temperature and heightening) and which could be employed to appraise the physical environment are not totally captured (Fig. 1). Likewise, the frequency of reporting a safety problem has been reported [15, 16, 17] as an essential indicator of a work environment. Yet, it does not entirely summarise the work environment influence on worker in terms of system safety factors (i.e., frequency of risk assessment, safety gadget usage, hazard identification and accidents investigation).

There is a deficiency in an understandable agreement on how the physical, organisational, and system safety factors influence a work environment. This poor knowledge reduces the capability of scholars to build up and instigate the largely valuable performance enhancement intervention programmes for manufacturing systems. For example, the current work environment assessment frameworks appear to be directed to a particular factor in a group of influencing factors (for instance, cleanliness where other factors such as noise and vibration control are members of the physical environmental factor group) instead of the whole physical environmental group members, which is a global viewpoint of assessment. Furthermore, although the uniqueness of work environment in maintenance services [18, 19, 20, 21] and its importance in sustaining the manufacturing organisation has since been appreciated in literature and particularly the current journal and substantially promoted in the various issues for more than 30 years now (see [22, 23, 24, 25], this knowledge gap is still opened, it becomes evident that there is an absence of a realistic method to appraise work environment. There is also no way of associating this information into the performance enhancement intervention programmes of manufacturing companies. Although single-factor identification in work environment analysis has revealed usefulness in enhancing workplace performance [26], the absence of generalizability restricts their practical value in manufacturing settings.

2.2 Assessment using Fuzzy Grey Relational Analysis

Insufficient literature information was obtained on fuzzy grey relational analysis (FGRA) as a decision support tool to facilitate the choice of processes. Although the interesting procedure for applying FGRA involving the rating of options and the illustration of weights of criteria in linguistic variables still holds for the very few studies reported in the literature, none was documented for the maintenance process of interest. For example, Karimi et al. [27] offered an optimal route to process selection using FGRA for treatment options of anaerobic wastewater in Iran.

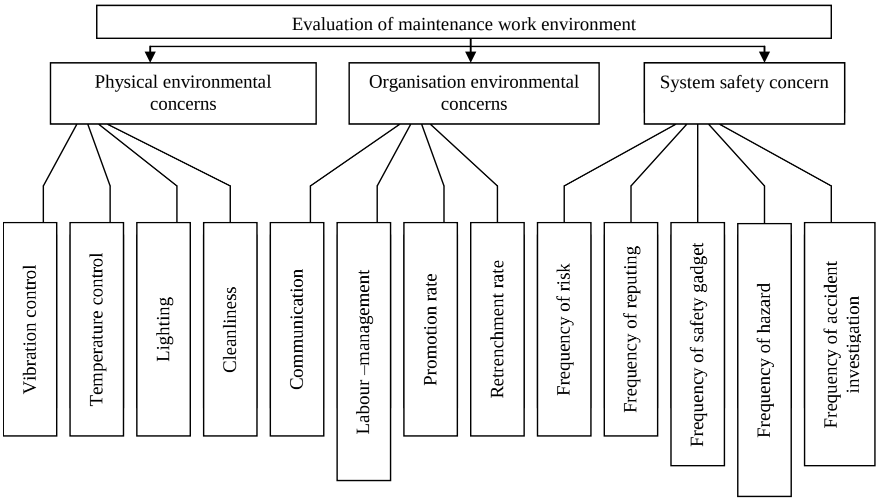

Fig. 1. Hierarchical framework of the maintenance work environment model

Goyal and Grover [28] appraised advanced manufacturing systems with fuzzy grey relational analysis alongside several divergence measures subjected to fuzzy inputs. Azzeh et al. [29] recommended a suitable structure to support decision making in software effort estimation using the fuzzy grey relational analysis. Tamilol et al. [30] combined grey and fuzzy approaches for the end milling of aluminium alloy 6082T6 while the coated insert of aluminium chromo nitride was used. Joshi and Sharma [31] combined the approaches of grey relational analysis and fuzzy logic in a laser cutting experiment on Al 6061–T6 thin sheets to appraise the dimensional exactness of the configuration for the kerf and regions of metallurgical modifications. This method limited the kerf taper and the heat-affected zone of laser cut kerf in the magnitude of 2.52 and 42.32%, respectively. Zhou et al. [32] built up a detailed structure by integrating grey and fuzzy comprehensive evaluation to establish the most advantageous values of the denitration technology in China.

Pandey and Panda [34] employed an integrated grey and fuzzy logic method to establish optimal performance attributes for bone drilling. In their research, Kumaran et al. [33] used the combination of grey and fuzzy to search for the most advantageous values of parameters representing the electrical discharge machining process to limit burr creation in the course of machining. Shunmugesh et al. [35] combined fuzzy logic and grey to attain the desired decision of choosing the most advantageous parameters among the drilling process parameters. Huang and Chu [36] incorporated grey relational analysis into the fuzzy representation platform to permit an understanding of how decisions may be scientifically made in a water cleaning process, using literature data. Zhou and Thai [37] employed an integrated fuzzy logic and grey theories to attain fuzzy risk priority numbers in a process to appraise the probable failures in an industrial system. Wang et al. [38] used a distinctive structure to appraise the efficiency of energy generation of district heating and used a fuzzy–grey model to attain a decision. Palanisamy and Senthil [39] developed the most advantageous machining situations to turn PH stainless steel using grey and fuzzy approaches in a combined manner.

2.3 Assessment using Fuzzy Entropy Weighting

Prakash et al. [40] used fuzzy entropy to optimise appraised values of entropy under the condition that only part of the needed information is available. On similar lines, Qi et al. [41] appraised numerous ratios to reveal the power cluster framework and proposed a novel approach based on combining fuzzy comprehensive appraisal and an entropy weight decision–making approach (Table 1). The adoption of fuzzy set strengthened the model to establish the level of membership for every index to the diverse appraisal outcomes. At the same time, the method of entropy weight aided the acquisition of weighting factors.

S/No.	Decision making tool	Applications
1	Fuzzy grey relational analysis	Wastewater treatment process choice [27]; advanced manufacturing systems [28], software effort approximation [29], conventional machining [30], precision engineering [31], de nitration technology [32], electrical discharge machining [33], drilling [34, 35], water cleaning process [36], district heating system [38], turning [39]
2.	Fuzzy entropy weighting	Prakash et al. [40]; Qi et al. [41]

Table 1 Decision making tools

3. Methodology

In the present era of strict legal requirements to comply with safety measures, periodic evaluation, monitoring and updating of the work environment has become a constant practice for guaranteed trouble-free practice. The fast declining performance of machines and facilities in the environment as a result of inadequate maintenance and mishandling often challenges the safety manager and decision-makers in manufacturing systems particularly poor budgetary implementation has reduced health status of many industrial equipment and facilities. Consequently, to attain the goals of manufacturing plants, modelling and analysis of the maintenance work environment has gained fast momentum. In general, in solving the maintenance work environmental problems the neglect of detailed and constructive evaluation steps make it difficult to come out with rich quantitative values for decision making. From the review of literature, it is clear that the use of multicriteria methods is largely important to arrive at the superior decision.

This section presents information on the conceptual framework, FEWA and the grey relational analysis as well as a number of definitions and explanations on the criteria employed in the research.

3.1 Maintenance Criteria and Their Definitions

The level of assessing how conducive a maintenance worker's work environment is has been conceptualised from an integrated perspective of three principal criteria of the physical environment, the organisational environment and the safety system. The physical environment is described as a critical factor that controls the conditions of a factory in physical terms. Through the defined responsibility of repairs, replacements, and overhaul functions for the machines, the maintenance worker interacts with machines by experiencing several factors. For example, first, noise is a critical factor. The equipment has been designed to operate at a minimum acceptable noise level, and this noise is regularly generated as the machines are on and working. There is often an increased level of noise as the machine ages. Since the maintenance worker is subjected to this noise throughout his/her working hours and maintenance care of the equipment, successful efforts at controlling this noise that militates workers is a crucial concern to the retention of the maintenance workforce. Clearly, the physical well-being of workers is important, and maintenance workers will make all efforts to protect it.

The proposed framework for manufacturing system maintenance environment conduciveness evaluation is based on the concept of fuzzy logic [42, 43] and fuzzy GRA (Fig. 2). The physical environment, organisational environment and safety are considered as three criteria for the evaluation process. These criteria have sub-criteria that are used to compute a single performance index for a maintenance system.

In this sub-section, the various factors and sub-factors considered essential for the research are discussed. The discussion commences with an explanation of the terms and the supporting references from the literature that reveal why those factors were chosen for the put forward representation are given. These justifications and explanations reinforces the arguments put forward of a unifying framework that contains the individual terms. These ideas are presented in a table and listings of previous research that have used those factors are given.

3.2 Structure of the Maintenance Work Environment Model (Hierarchical)

The structure of the hierarchy for the maintenance work environment has been carefully prepared and indicated in Figure 2. The model comprises of three stages in totality where the first stage signifies the total target, the second phase states the group of principal criteria while the third phase reveals the group of sub-criteria subjected to each principal criterion. In addition, as revealed in Figure 2, the comprehensive information relating to the maintenance work environment issue, three principal criteria as well as a group of four, four and five sub-criteria associated with the physical environment, organisation environmental, and system safety principal criteria, respectively are offered in the following sections:

3.2.1 Phase 1 (Total target/goal)

The goal of the current research is to evaluate the interactions and choose among a group of fifteen criteria, those that influence the maintenance work environment the most and in what manner. With the goal in mind, the appraisal and choice of the most impactful group of criteria and sub-criteria are conducted with much dependence on multicriteria methods subjected to fuzzy conditions

3.2.2 Phase 2 (Group of Principal Criteria being Contemplated)

From the critical literature survey of articles, a group of three principal criteria is contemplated in the present research in an attempt to appraise the maintenance work environment for a manufacturing concern. As revealed in Fig. 1, the three principal criteria, i.e. physical environmental concerns, organisation environmental concerns, and system safety concerns are contemplated

3.2.2.1. Physical environmental concerns

In this paper, the principal criterion, i.e. physical environmental concerns reveal the level with which the manufacturing facilities comply with the standards of noise, vibration, temperature, lighting, and cleanliness of the environment. This is in relation to the set standards in an overall Nigerian environment as an example of a developing country

3.2.2.2 Organisation environmental concerns

The principal criterion i.e. organisation environmental concerns is featured as the influence of the organisational characteristics on the environment and employees of the manufacturing

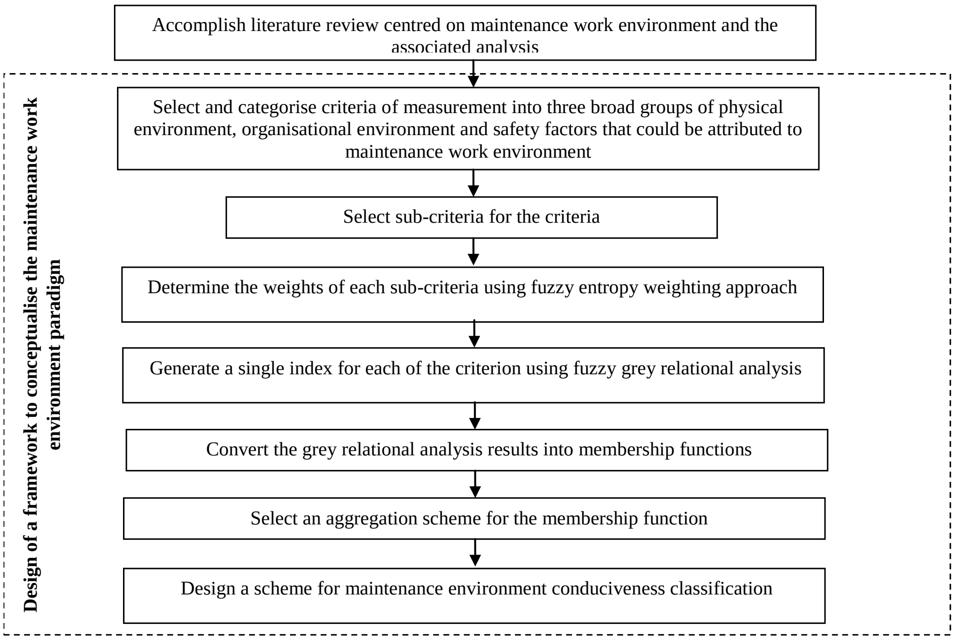

Fig. 2 A framework for maintenance environment conduciveness classification

concern. This is measured in terms of communication, labour–management relationship, promotion rate, and retrenchment rate. In a developing country such as Nigeria, organisational turbulence is continuously growing in view of the ever-expanding communication breakdown among staff and management of manufacturing organisations, labour-management conflicts, promotion denials for staff and unjustifiable retrenchment of staff. The community-management relations is as well as an important issue to enhance organisation to accept labour union's requests on welfare is an important factor to create harmony in the organisation

3.2.2.3 System safety concern

The criterion named system concern establishes the possibility of controlling principal safety pillars with the aim of attaining zero accidents in any period of safety assessment through the following: frequencies of risk assessment, reporting safety problems, safety gadget usage, hazard identification, and accident investigation. The degree to which these factors affect the manufacturing work environment ought to be completely examined and approximated

3.2.3 Phase 3 (Group of sub-criteria)

This section of the paper discusses the sub-criteria that have been established in terms of each principal criterion contemplated in the paper. The features and significance of each sub-criterion are explained in some details subsequently:

3.2.3.1 Group of sub-criteria in terms of physical environmental concerns

For the purpose of appraising the maintenance work environment revealed in Figure 1, a group of four sub-criteria is contemplated under this segment as elaborated subsequently, putting in mind the principal criterion, physical environmental concerns

Noise control (x_{11})

When operating a manufacturing industry, workers are subjected to different environments influenced by the nature and capacities of the equipment, such as fuel engines, pneumatic tools, forging equipment, metal bearings, rollers, etc. Some of this equipment and facilities generate excessive noise that may impair the hearing function of employees. From this perspective, the control of noise from equipment and facilities in the factory is a significant issue in manufacturing industries for the developing country scenario [44, 45, 46, 47].

Vibration control (x_{12})

While operating facilities and equipment in manufacturing plants, their influences on the lifespan of other machines and building structures in seismic matters and structural fitness due to vibration is a pressing concern. From this perception, the quantitative evaluation and the incorporation of vibration control into the work environment scheme are essential. Furthermore, the influences of seismic waves on buildings and vibration effects on the psychology of the work in an uncontrolled environment, leading to devastating states of humans and equipment has been reported in Kumar and Kalita [6], Mezyk et al. [48], Zhang et al. [49], Rahmani and Shenas [50], Guo et al. [11], Ning et al. [51], Xie et al. [52], Tombari et al. [53], Xue et al. [54].

Temperature control (x_{13})

The maintenance of a conducive work climate for high productivity in the form of temperature control is a crucial factor while deciding on workplace environment appraisal. Cooling, dehumidification, and heating schemes directly affect the temperature control of a manufacturing environment. Thus, temperature control is a significant phenomenon when dealing with the work environment concern

Lighting (x_{14})

The best lighting system that enhances service productivity while maintaining a safe workplace is a significant factor that should be considered when analysing the maintenance work environment. As this is linked to the enhancement of morale of the maintenance work as pointed out in the literature, lighting of the workplace for maintenance activities is a significant phenomenon.

Cleanliness (x_{15})

Cleanliness is a significant issue that should be accounted for while considering the evaluation of the maintenance work environment. Right from the facility and equipment installation stage to the disposal phase in the life-cycle management of equipment cleanliness needs to be observed. Often called housekeeping, cleanliness of the maintenance work environment is aided by putting the equipment in a neat fashion to prevent trips and slips on the production floor. The common practice is to get rid of useless materials and putting symbols neatly on risk and hazardous materials. Literature support for cleanliness is stated in Harper et al. [5], Dufort and InFante-Rivard [55], Leivo [56], Lefebvre et al. [14], Aker et al. [57], Liger et al. [58] and Cordeau et al. [13]. If the cleanliness aspect of the maintenance work environment is not adequately tackled, the workers will be pruned to accidents that will affect the organisation's goodwill and profit. Moreover, for an extended lifespan of humans, cleanliness is said to be a critical factor

3.2.2 Group of sub-criteria

For the intention of evaluating the maintenance work environment revealed in Figure 1, a group of five sub-criteria is considered under this sub-division as detailed subsequently, putting in mind the main criterion, organisation environmental factors

Cooperation (x_{21})

The level of cooperation among the workers of a manufacturing concern straightly and indirectly impinges on the attention and commitment of workers to the company. Consequently, while appraising maintenance work environment it is extremely vital to take into account the soft skills of the worker in terms of ability and skills to work together as a team and the training gap to meet the desired cooperation level for the attainment of manufacturing goals

Communication (x_{22})

The possibility to join information as well as communication schemes together in the context of maintenance work environment is an essential issue in the present age of information explosion driven by cutting edge technology

Labour–management relationship (x_{23})

In the process of operating the manufacturing plant for the production of goods, several issues arise on productivity employment, quality and wages. The amicable settlement of these issues leads to policies of the company concerning the same. When issues become complicated and challenging, beyond the capability of the local branch of the union to solve, cases are referred to the national union for help. Consequently while appraising the maintenance work environment it is absolutely necessary to integrate the labour-management relationship factor into the appraisal scheme.

Promotion rate (x_{24})

In order to ascertain uninterrupted production of manufacturing goods in a plant, the welfare of the workers from the perspective of reward in promotion is extremely important. The consequence of the low rate of promotion is a high turnover of staff to other companies. Thus, the consideration of promotion rate becomes important as the maintenance work environment is appraised for the choice of the best option among alternatives

Retrenchment rate (x_{25})

The company's financial status is a direct reflection of its likelihood to retrench workers. Knowledge of the retrenchment rate or employment rate is significant during the operational stage of the manufacturing plant. Thus, the consideration of the retrenchment rate is a worthwhile issue in an attempt to appraise the maintenance work environment for performance enhancement purpose

3.2.3 Group of sub-criteria considering system safety factors

To be able to appraise options in terms of choice of the maintenance work environment, revealed in Figure 1, a group of four sub-criteria is contemplated in this segment of the paper and the details are elaborated subsequently by accounting for the principal criterion, system safety factors

Frequency of risk assessment (x_{31})

Engineering plants consists of several complex mechanisms operated by humans. The process of manufacturing products involves interactions with these risk-pruned machines. All risks must be mitigated to guarantee a safe maintenance work environment. Therefore, knowing the frequency at which risk is assessed becomes important in appraising the maintenance work environment for performance enhancement purposes.

Frequency of reporting safety problems (x_{32})

In maintenance systems, the repair and installation of heavy-duty equipment are very complex and are potentially accompanied by mistakes. Mistakes often result in substantial consequences of injuries, loss of assets and even the death of workers. Consequently, the identification of warnings and signs signifying safety problems is very crucial. The mobile app has added a new dimension to the tracking and reporting of safety problems in manufacturing. Consequently, this factor must be considered in the appraisal of the maintenance work environment for enhancement in performance [16, 17]

Frequency of safety gadgets usage (x_{33})

One of the regulations concerning the operation of a manufacturing plant is the strict enforcement of protective devices, including safety gadget usage to regulate accidents in the plant. Therefore, the knowledge of the frequency at which safety gadgets are used is an important factor in the course of appraising the maintenance work environment.

Frequency of hazard identification (x_{34})

Maintenance jobs include hazards that if triggered, could result in injuries and even death. Hazards such as those related to chemicals, heavy machinery, electrical circuits are major factors that must be avoided in the day–to–day manufacturing practice. Thus, consideration of the rate at which hazards are identified is a meaningful factor even as the appraisal of the maintenance work environment is done [59, 60, 61, 62, 63].

Frequency of accident investigation (x_{35})

Despite all efforts to prevent accidents and substantial financial resources and training invested in accident prevention, it does happen sometimes. Employees are interested in knowing the outcome of investigations so that they are guaranteed that management is taking steps to prevent others from occurring again. Thus, the inclusion of this factor in the set of those considered to appraise maintenance work environment is necessary [64].

3.3 Models

The importance of the sub-criteria for the criteria is evaluated using a triangular fuzzy number. The triangular fuzzy number for the different decision-makers responses are classified into four classes (Table 2). These classes are engaged to establish the weight of the sub-measure with respect to their criterion using FEWA. The membership function for sub-criteria based on decision-makers responses is expressed as Equation (1).

$$\alpha_{ij}, \beta_{ij}, \tau_{ij} = \frac{1}{K}\left(\sum_{k=1}^{K}\alpha_{ijk}, \sum_{k=1}^{K}\beta_{ijk}, \sum_{k=1}^{K}\tau_{ijk}\right) \quad (1)$$

; where K represents to number of decision-makers

Linguistic variable descriptions	Contractions	Fuzzy number
Unimportant	U	(0, 0, 0.2)
Less important	LI	(0, 0.2, 0.4)
Fairly important	FI	(0.2, 0.4, 0.6)
Important	I	(0.4, 0.6, 0.8)
Very important	VI	(0.6, 0.8, 1)

Table 2 Linguistic variable descriptions and membership functions for sub-criteria

To properly implement the related principles to fuzzy set used in the current research, the idea of membership functional creation is incorporated as a stage in the procedural development. A membership function that evolves from a declared fuzzy set operates on the principle of mapping every point related to the input space to a particular adequate membership value, often with a curve, in the array of 0 and 1. Some literature sources refer to the input spaces by naming the universe of discourse while the nomenclature degree of membership is given to membership value. It is common to observe x-axis of plots concerning the membership functions to contain the universe of discourse in which the amount in terms of grade membership for the element of the universal set is specified. On the y-axis the levels of membership in the array of 0 to 1 is specified.

3.4 Fuzzy entropy weighting approach

The implementation of FEWA involves three basic steps (devise the choice matrix, estimation of entropy values and determination of criterion weight); a brief explanation of FEWA steps is presented as follows:

Step 1: Devise the choice matrix

The triangular fuzzy numbers are normalised rooted in whether a decisive factor is considered as an advantage or cost. For criteria which are advantage-oriented, Equation (2) is used as a normalisation scheme. Equation (3) is the normalisation scheme used for cost-oriented criteria.

$$\bar{\alpha}_{ij}, \bar{\beta}_{ij}, \bar{\tau}_{ij} = \frac{\alpha_{ij}}{\bar{\tau}_j}, \frac{\beta_{ij}}{\bar{\tau}_j}, \frac{\tau_{ij}}{\bar{\tau}_j} \quad (2)$$

$$\bar{\alpha}_{ij}, \bar{\beta}_{ij}, \bar{\tau}_{ij} = \frac{\bar{\alpha}_i}{\tau_{ij}}, \frac{\bar{\alpha}_j}{\beta_{ij}}, \frac{\bar{\alpha}_j}{\alpha_{ij}} \quad (3)$$

$$\bar{\tau}_j = \max_i(\tau_{ij}) \quad (4)$$

$$\bar{\alpha}_j = \min_i(\alpha_{ij}) \quad (5)$$

Step 2: Estimation of entropy values

This step involves the conversion of the normalised triangular membership functions into crisp values. A graded mean integration representation is used for the conversion process. The crisp values are engaged to compute the entropy for each of the sub-decisive factor in Table 2; Equation (6).

$$E_j = -\frac{1}{\ln m}\sum_{i=1}^{m}\frac{d_{ij}}{D_j}\ln\frac{d_{ij}}{D_j} \quad (6)$$

$$D_j = \sum_{i=1}^{m} d_{ij} \quad (7)$$

Step 3: Determination of decisive factor weight

Rooted in the values of the entropy, the weight for the sub-decisive factor with respect to a criterion is expressed as Equation (8).

$$\pi_{ic} = \frac{1-E_{ic}}{\sum_{i=1}^{m}(1-E_{ic})} \quad (8)$$

3.5 Fuzzy Grey Relational Analysis

The membership function for the maintenance criteria is shown in Table 3.

Normalisation for each outcome is often considered the primary measure in GRA. This permits the arrangement of the intended path of the inputs as a maximum or minimum function. The expressions for maximum or minimum functions normalisation is computed with Equations (9) and (10), respectively.

$$\tilde{a}_{ij}^{k} = \left(\frac{\alpha_j^*}{\alpha_{ij}^k}, \frac{\alpha_j^*}{\beta_{ij}^k}, \frac{\alpha_j^*}{\tau_{ij}^k}\right) \quad (9)$$

$$\tilde{a}_{ij}^{k} = \left(\frac{\alpha_{ij}^k}{\tau_j^*}, \frac{\beta_{ij}^k}{\tau_j^*}, \frac{\tau_{ij}^k}{\tau_j^*}\right) \quad (10)$$

; where

$$\tau_j^* = \max\left(\tau_{ij}^k\right) \quad (11)$$

$$\alpha_j^* = \min\left(\alpha_{ij}^k\right) \quad (12)$$

Establishing the grey-associated coefficient of the inputs is often considered as a second measure of GRA use in practice [65]. First, the conversion of normalised triangular membership function to crisp values is carried out (Equation 13). The value of grey relational coefficient is determined with Equation (14).

$$x_{ij}^k = \frac{\alpha_{ij}^k + 4\beta_{ij}^k + \tau_{ij}^k}{6} \quad (13)$$

$$\zeta_i(k) = \frac{\Delta\min + \zeta\Delta\max}{\Delta_{o,i}(k) + \zeta\Delta\max} \quad (14)$$

$$\Delta\min = \min_{\forall j \in i}\min_{\forall k}\left\|x_o^*(k) - x_i^*(k)\right\| \quad (15)$$

$$\Delta\max = \max_{\forall j \in i}\max_{\forall k}\left\|x_o^*(k) - x_i^*(k)\right\| \quad (16)$$

; where, $x_o^*(k)$ and $x_i^*(k)$ are the reference sequence and comparative sequence, ζ is referred to as recognition coefficient and its worth lies between (0,1).

The establishment of the grade for grey relations is the final step of GRA usage [65]. This measure entails approximating the mean values of the entire grey relational coefficient for a process (Equation 17).

$$\bar{c}_k = \frac{1}{n}\sum_{j=1}^{n}\pi_{ik}\zeta_{ij}(k) \quad (17)$$

The grey relational coefficient for each criterion is fuzzified to determine the class which a maintenance environment falls into based on three membership functions (Figure 3). Fuzzy logic is considered as a means for determining the maintenance class of a maintenance system because no empirical study has been reported on mathematical expression for combining the above-mentioned criteria. This study uses triangular membership function to represents a low grey relational coefficient, while moderate and high grey relational coefficients are represented using trapezoidal membership function (Figure 3). The characteristic functions for the various membership functions in Figure 2 are presented in Appendix A.

Terms	Abbreviations	Membership functions
Very low	VL	(0.0, 0.0, 0.2)
Low	L	(0.0, 0.2, 0.4)
Moderate	M	(0.2, 0.4, 0.6)
High	H	(0.4, 0.6, 0.8)
Very high	VH	(0.6, 0.8, 1.0)

Table 3 Membership function for the maintenance criteria

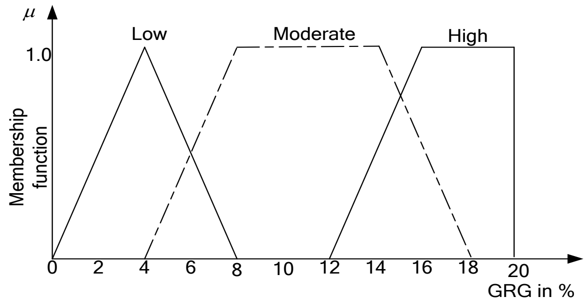

Fig. 3 Membership functions for grey relational grade (GRG) in terms of percentage

In this study, the max-operator aggregation is considered for criterion that has two membership functions (Equation (18). A maintenance environment is classified into three sets. The sets are highly conducive (C_1), conducive (C_2), and in-conducive (C_3). The decision for selecting the class to which a maintenance environment belongs is expressed as Equation (19).

$$c_i\left(\mu_{\bar{a}}(c), \mu_{\bar{b}}(c)\right) = \max\left(\mu_{\bar{a}}(c), \mu_{\bar{b}}(c)\right) \qquad (18)$$

$$D_k = \begin{cases} C_1 & \mu_k > \mu_{\max} \\ C_2 & \mu_{\min} \le \mu_k < \mu_{\max} \\ C_3 & \mu_k < \mu_{\min} \end{cases} \qquad (19)$$

; where D_k is the decision selected for maintenance environment *i*, $\mu_{\max}$ and $\mu_{\min}$ is the maximum and minimum expected membership function, and μ_k is the membership function for maintenance system *k*.

4. Case Study

4.1 Case Discussion

The proposed model was applied in four manufacturing systems. A controlled questionnaire was dealt out to three choice-makers in each of the manufacturing systems. This study considered a maintenance system as been highly conductive when the value of C_1 is between 0.8 and 1. When the value of C_2 is between 0.5 and 0.8, a maintenance system is classified as been conducive. A value of C_3 that is between 0 and 0.5 is considered as in-conducive. This description of classifications of maintenance systems conductive is subjective.

Based on the results obtained the weights for each of the sub-decisive factors for the criteria were evaluated (Table 3). Other results are shown in Tables 4 to 13.

4.2 Contributions

This work contributes to the maintenance literature of the inter-disciplinary linkages of the physical and organisational environment and safety system through the articulation of a small-understood phenomenon of maintenance work environment. It offers a greater understanding of how each maintenance worker feels at the workplace irrespective of position in the ladder of engineering career - the artisans, technicians, supervisors, and the engineering manager. Also, the structure proposed contributes to literature concerning engineering controls, organisational behaviour, and safety system by clarifying the procedure that the maintenance worker engages on daily with an understanding of those activities that could be controlled and those controllable by the maintenance worker.

The maintenance literature showcases different scholarly efforts, each attempting to proper models and examines the manner in which maintenance work environment could be controlled. There is an absence of convergence on a prevailing model in the evaluation of the maintenance work environmental performance and this limits expected reliance on available representations and deepens confusion on the appropriate standards to be used for evaluation in maintenance work environment. Convergence in the way of an accepted framework is achieved if a deep association of the parameters constituting the physical, organisational and safety system maintenance work environment is established. This convergence effort is an important contribution of this paper.

In this research, the authors formulate the maintenance work environment problem as a multi-component criterion-oriented problem with three combination windows. The research could be widely grouped under the label of work enhancement studies and contributes to the expanding body of knowledge that multi-criteria decision-making techniques are applied to the concerns of maintenance systems. The work also appends an extra dimension to the broad studies on organisational literature by tackling the maintenance work environmental problem by including promotion rate as an important criterion for evaluating the organisational work environmental factors. The promotion rate captures certain intricacies inherent in the organisation. It reveals the attitude of the management of the maintenance organisation to staff welfare [66, 67]. Can the promotion of the maintenance crew be affected negatively because of specific damages to an asset, cause monetary losses [68] due to the carelessness of a member of the team?

Sub-criterion	Company A			Company B			Company C			Company D		
x_{11}	0.2000	0.4000	0.6000	0.4000	0.6000	0.8000	0.2000	0.4000	0.6000	0.4000	0.6000	0.8000
x_{12}	0.4000	0.6000	0.8000	0.3000	0.5000	0.7000	0.2000	0.4000	0.6000	0.4000	0.6000	0.8000
x_{13}	0.4000	0.6000	0.8000	0.4000	0.6000	0.8000	0.4000	0.6000	0.8000	0.2000	0.3000	0.4000
x_{14}	0.5000	0.7000	0.9000	0.5000	0.7000	0.9000	0.4000	0.6000	0.8000	0.4000	0.6000	0.8000
x_{15}	0.5000	0.7000	0.9000	0.5000	0.7000	0.9000	0.6000	0.8000	1.0000	0.4000	0.6000	0.8000
x_{21}	0.6000	0.8000	1.0000	0.6000	0.8000	1.0000	0.6000	0.8000	1.0000	0.3000	0.5000	0.7000
x_{22}	0.4000	0.6000	0.8000	0.5000	0.7000	0.9000	0.6000	0.8000	1.0000	0.5000	0.7000	0.9000
x_{23}	0.2000	0.3000	0.5000	0.5000	0.7000	0.9000	0.2000	0.4000	0.6000	0.4000	0.6000	0.8000
x_{24}	0.3000	0.4000	0.6000	0.5000	0.7000	0.9000	0.0000	0.0000	0.2000	0.4000	0.6000	0.8000
x_{25}	0.1000	0.3000	0.5000	0.4000	0.6000	0.8000	0.0000	0.0000	0.2000	0.4000	0.6000	0.8000
x_{31}	0.5000	0.7000	0.9000	0.6000	0.8000	1.0000	0.4000	0.6000	0.8000	0.5000	0.7000	0.9000
x_{32}	0.5000	0.7000	0.9000	0.5000	0.7000	0.9000	0.6000	0.8000	1.0000	0.4000	0.6000	0.8000
x_{33}	0.5000	0.7000	0.9000	0.6000	0.8000	1.0000	0.2000	0.4000	0.6000	0.5000	0.7000	0.9000
x_{34}	0.5000	0.7000	0.9000	0.5000	0.7000	0.9000	0.4000	0.6000	0.8000	0.5000	0.7000	0.9000
x_{35}	0.5000	0.7000	0.9000	0.6000	0.8000	1.0000	0.4000	0.6000	0.6000	0.5000	0.7000	0.9000

Table 4 Aggregated fuzzy number for each sub-criterion weights

Sub-criterion	Company A			Company B			Company C			Company D		
x_{11}	0.2500	0.5000	0.7500	0.5000	0.7500	1.0000	0.2500	0.5000	0.7500	0.5000	0.7500	1.0000
x_{12}	0.5000	0.7500	1.0000	0.3750	0.6250	0.8750	0.2500	0.5000	0.7500	0.5000	0.7500	1.0000
x_{13}	0.5000	0.7500	1.0000	0.5000	0.7500	1.0000	0.5000	0.7500	1.0000	0.2500	0.3750	0.5000
x_{14}	0.5556	0.7778	1.0000	0.5556	0.7778	1.0000	0.4444	0.6667	0.8889	0.4444	0.6667	0.8889
x_{15}	0.5000	0.7000	0.9000	0.5000	0.7000	0.9000	0.6000	0.8000	1.0000	0.4000	0.6000	0.8000
x_{21}	0.6000	0.8000	1.0000	0.6000	0.8000	1.0000	0.6000	0.8000	1.0000	0.3000	0.5000	0.7000
x_{22}	0.4000	0.6000	0.8000	0.5000	0.7000	0.9000	0.6000	0.8000	1.0000	0.5000	0.7000	0.9000
x_{23}	0.2222	0.3333	0.5556	0.5556	0.7778	1.0000	0.2222	0.4444	0.6667	0.4444	0.6667	0.8889
x_{24}	0.3333	0.4444	0.6667	0.5556	0.7778	1.0000	0.0000	0.0000	0.2222	0.4444	0.6667	0.8889
x_{25}	0.1250	0.3750	0.6250	0.5000	0.7500	1.0000	0.0000	0.0000	0.2500	0.5000	0.7500	1.0000
x_{31}	0.5000	0.7000	0.9000	0.6000	0.8000	1.0000	0.4000	0.6000	0.8000	0.5000	0.7000	0.9000
x_{32}	0.5000	0.7000	0.9000	0.5000	0.7000	0.9000	0.6000	0.8000	1.0000	0.4000	0.6000	0.8000
x_{33}	0.5000	0.7000	0.9000	0.6000	0.8000	1.0000	0.2000	0.4000	0.6000	0.5000	0.7000	0.9000
x_{34}	0.5556	0.7778	1.0000	0.5556	0.7778	1.0000	0.4444	0.6667	0.8889	0.5556	0.7778	1.0000
x_{35}	0.5000	0.7000	0.9000	0.6000	0.8000	1.0000	0.4000	0.6000	0.6000	0.5000	0.7000	0.9000

Table 5 Normalised aggregated fuzzy number for each sub-criterion weights

Sub-criterion	Company A	Company B	Company C	Company D
x_{11}	0.5000	0.7500	0.5000	0.7500
x_{12}	0.7500	0.6250	0.5000	0.7500
x_{13}	0.7500	0.7500	0.7500	0.3750
x_{14}	0.7778	0.7778	0.6667	0.6667
x_{15}	0.7000	0.7000	0.8000	0.6000
x_{21}	0.8000	0.8000	0.8000	0.5000
x_{22}	0.6000	0.7000	0.8000	0.7000
x_{23}	0.3519	0.7778	0.4444	0.6667
x_{24}	0.4630	0.7778	0.0370	0.6667
x_{25}	0.3750	0.7500	0.0417	0.7500
x_{31}	0.7000	0.8000	0.6000	0.7000
x_{32}	0.7000	0.7000	0.8000	0.6000
x_{33}	0.7000	0.8000	0.4000	0.7000
x_{34}	0.7778	0.7778	0.6667	0.7778
x_{35}	0.7000	0.8000	0.5667	0.7000

Table 6 Crisp values of Normalised aggregated for each sub-criterion weights

Sub-criterion	E_{ij}	d_{ij}	w_{ij}
x_{11}	0.7685	0.2315	0.2232
x_{12}	0.7866	0.2134	0.2057
x_{13}	0.7771	0.2229	0.2149
x_{14}	0.8208	0.1792	0.1728
x_{15}	0.8097	0.1903	0.1834
x_{21}	0.8358	0.1642	0.1279
x_{22}	0.8373	0.1627	0.1267
x_{23}	0.7747	0.2253	0.1755
x_{24}	0.6379	0.3621	0.2820
x_{25}	0.6302	0.3698	0.2879
x_{31}	0.8003	0.1997	0.1961
x_{32}	0.7971	0.2029	0.1993
x_{33}	0.7671	0.2329	0.2287
x_{34}	0.8214	0.1786	0.1754
x_{35}	0.7959	0.2041	0.2005

Table 7 Entropy-based weights for the sub-criteria

	Company A			Company B			Company C			Company D		
x_{11}	0.2000	0.4000	0.6000	0.6000	0.8000	1.0000	0.4000	0.6000	0.8000	0.4000	0.6000	0.8000
x_{12}	0.2000	0.4000	0.6000	0.4000	0.6000	0.8000	0.4000	0.6000	0.8000	0.5000	0.7000	0.9000
x_{13}	0.4000	0.6000	0.8000	0.3000	0.5000	0.8000	0.6000	0.8000	1.0000	0.5000	0.7000	0.9000
x_{14}	0.5000	0.7000	0.9000	0.5000	0.7000	0.9000	0.6000	0.8000	1.0000	0.5000	0.7000	0.9000
x_{15}	0.6000	0.8000	1.0000	0.5000	0.7000	0.9000	0.6000	0.8000	1.0000	0.4000	0.6000	0.8000
x_{21}	0.5000	0.7500	1.0000	0.5556	0.7778	1.0000	0.6000	0.8000	1.0000	0.5000	0.7000	0.9000
x_{22}	0.5000	0.7500	1.0000	0.5556	0.7778	1.0000	0.6000	0.8000	1.0000	0.4000	0.6000	0.8000
x_{23}	0.0000	0.0000	0.2500	0.2222	0.4444	0.6667	0.4000	0.6000	0.8000	0.2000	0.3000	0.5000
x_{24}	0.0000	0.0000	0.2500	0.2222	0.4444	0.6667	0.2000	0.4000	0.6000	0.2000	0.4000	0.6000
x_{25}	0.3750	0.6250	0.8750	0.5556	0.7778	1.0000	0.0000	0.0000	0.2000	0.3000	0.4000	0.6000
x_{31}	0.2500	0.5000	0.7500	0.5000	0.7000	0.9000	0.4000	0.6000	0.8000	0.6000	0.8000	1.0000
x_{32}	0.1250	0.3750	0.6250	0.6000	0.8000	1.0000	0.6000	0.8000	1.0000	0.6000	0.8000	1.0000
x_{33}	0.5000	0.7500	1.0000	0.6000	0.8000	1.0000	0.4000	0.6000	0.8000	0.6000	0.8000	1.0000
x_{34}	0.3750	0.6250	0.8750	0.6000	0.8000	1.0000	0.4000	0.6000	0.8000	0.6000	0.8000	1.0000
x_{35}	0.2500	0.5000	0.7500	0.6000	0.8000	1.0000	0.4000	0.6000	0.8000	0.5000	0.7000	0.9000

Table 8 Aggregated triangular fuzzy number for the different maintenance systems

Sub-criterion	Company A			Company B			Company C			Company D		
x_{11}	0.2000	0.4000	0.6000	0.6000	0.8000	1.0000	0.4000	0.6000	0.8000	0.4000	0.6000	0.8000
x_{12}	0.2222	0.4444	0.6667	0.4444	0.6667	0.8889	0.4444	0.6667	0.8889	0.5556	0.7778	1.0000
x_{13}	0.4000	0.6000	0.8000	0.3000	0.5000	0.8000	0.6000	0.8000	1.0000	0.5000	0.7000	0.9000
x_{14}	0.5000	0.7000	0.9000	0.5000	0.7000	0.9000	0.6000	0.8000	1.0000	0.5000	0.7000	0.9000
x_{15}	0.6000	0.8000	1.0000	0.5000	0.7000	0.9000	0.6000	0.8000	1.0000	0.4000	0.6000	0.8000
x_{21}	0.5000	0.7500	1.0000	0.5556	0.7778	1.0000	0.6000	0.8000	1.0000	0.5000	0.7000	0.9000
x_{22}	0.5000	0.7500	1.0000	0.5556	0.7778	1.0000	0.6000	0.8000	1.0000	0.4000	0.6000	0.8000
x_{23}	0.0000	0.0000	0.3125	0.2778	0.5555	0.8334	0.5000	0.7500	1.0000	0.2500	0.3750	0.6250
x_{24}	0.0000	0.0000	0.3750	0.3333	0.6666	1.0000	0.3000	0.6000	0.9000	0.3000	0.6000	0.9000
x_{25}	0.3750	0.6250	0.8750	0.5556	0.7778	1.0000	0.0000	0.0000	0.2000	0.3000	0.4000	0.6000
x_{31}	0.2500	0.5000	0.7500	0.5000	0.7000	0.9000	0.4000	0.6000	0.8000	0.6000	0.8000	1.0000
x_{32}	0.1250	0.3750	0.6250	0.6000	0.8000	1.0000	0.6000	0.8000	1.0000	0.6000	0.8000	1.0000
x_{33}	0.5000	0.7500	1.0000	0.6000	0.8000	1.0000	0.4000	0.6000	0.8000	0.6000	0.8000	1.0000
x_{34}	0.3750	0.6250	0.8750	0.6000	0.8000	1.0000	0.4000	0.6000	0.8000	0.6000	0.8000	1.0000
x_{35}	0.2500	0.5000	0.7500	0.6000	0.8000	1.0000	0.4000	0.6000	0.8000	0.5000	0.7000	0.9000

Table 9 Normalised aggregated triangular fuzzy number for the different maintenance systems

Sub-criterion	Company A	Company B	Company C	Company D
x_{11}	0.4000	0.8000	0.6000	0.6000
x_{12}	0.4444	0.6667	0.6667	0.7778
x_{13}	0.6000	0.5167	0.8000	0.7000
x_{14}	0.7000	0.7000	0.8000	0.7000
x_{15}	0.8000	0.7000	0.8000	0.6000
x_{21}	0.7500	0.7778	0.8000	0.7000
x_{22}	0.7500	0.7778	0.8000	0.6000
x_{23}	0.0521	0.5555	0.7500	0.3958
x_{24}	0.0625	0.6666	0.6000	0.6000
x_{25}	0.6250	0.7778	0.0333	0.4167
x_{31}	0.5000	0.7000	0.6000	0.8000
x_{32}	0.3750	0.8000	0.8000	0.8000
x_{33}	0.7500	0.8000	0.6000	0.8000
x_{34}	0.6250	0.8000	0.6000	0.8000
x_{35}	0.5000	0.8000	0.6000	0.7000

Table 10 Crisp values of sub-criteria for the different maintenance systems

Criterion	Company A	Company B	Company C	Company D
C_1	0.1467	0.1284	0.1467	0.1100
C_2	0.0795	0.1415	0.1028	0.1048
C_3	0.1108	0.1561	0.1280	0.1560

Table 11 Crisp values of grey relational coefficient in for the case studies

Criterion	Company A	Company B	Company C	Company D
C_1	0.8325, 0.4400	1.0000, 0.1400	0.8325,0.4400	1.000, 0.000
C_2	0.9875	0.6425, 0.3583	1.0000,0.0000	1.000, 0.000
C_3	1.000, 0.000	0.5975, 0.6020	1.0000,0.1333	0.6000, 0.6000

Table 12 Membership functions of criteria

Based on the classifications that were specified, it could be deduced that all the maintenance systems are highly conductive, except maintenance system for Company B which had a classification value of conductive (Table 13). To show that the model works with acceptable satisfaction, a comparison was made with existing work in the literature. The work by lghravwe and Oke (2017) is similar to the present study since it is a multi-criteria study that contains fuzzy elements and its application is in the maintenance domain. This work by lghravwe and Oke (2017) showed the final values of the closeness coefficients of the maintenance strategies for four criteria as 0.38970, 0.50761, 0.50790 and 0.50827, respectively. But in the current paper, the results for maintenance system conduciveness for the four companies studied are 0.38970, 0.50761, 0.50790 and 0.50827, respectively. These values are also in the range of 0 to 1, similar to the outcome revealed by lghravwe and Oke (2017). Thus this result suggests the workability of the present method with acceptable satisfactions.

Criterion	Company A	Company B	Company C	Company D
C_1	0.8325	1.0000	0.8325	1.0000
C_2	0.9875	0.6425	1.0000	1.0000
C_3	1.0000	0.6020	1.0000	0.6000
Aggregated value	0.9400	0.7482	0.9442	0.8667

Table 13 Maintenance system conduciveness

4.3 Implications and limitations of the study

This research calls attention to the significance of three different platforms (for instance, physical, organisational and safety systems). It highlights the need for additional studies that combine understanding of earlier research in the fields of classification systems with contemporary studies on work environment with the possibility of novel creations. In this perspective, an exciting opportunity for upcoming research may be to gain insight into the association among the various factors of those fifteen considered using combined factor analysis and fuzzy classification system. For example, it may be expected that certain factors such as frequency of reporting safety problems, which depends on a number of other factors, may be fuzzy in nature. Other factors mentioned here will be the reporting route, the facilities provided for reporting and the training given to the personnel in reporting the necessary problematic areas. An attractive question for future research may be to analyse the influence of any of these factors, such as training, on the outcomes. The inference here is that the worker may not carry out the duties when untrained effectively. For instance, if an assignment is given to enhance the work environment, the deficiency in training makes the employee contribute less to the expectation.

By considering the limitations of the study, the proposed model was tested using four manufacturing companies. However, little concern was given to the category of manufacturing companies as stated in the manufacturing association of Nigeria (MAN) directory. In this directory several sectoral represented. To be representative future studies could pick study target companies from each sectional group. This implies that more companies will be surveyed. Furthermore, fifteen factors were selected in the present study. However, more accurate results could be achieved by adding other relevant concerned factors too. Besides, the analytical results on weighting factors that affect worker's performance in terms of physical, organisational, and system safety work environment using restricted membership functions were reported more robust studies could consider other forms of membership functions in the fuzzy developmental aspect of the study. This is expected to bring a deeper understanding and facilitate the comparison of results.

5. Conclusions

A conceptual framework for the classification of manufacturing systems maintenance environment has been proposed in this study. The issue of aggregation of maintenance environment criterion basic components was addressed using grey relational analysis. In addition, the weights for the criteria used for maintenance system environment were determined using a fuzzy entropy weighting approach. The proposed framework is based on integrated fuzzy entropy weighting approach and fuzzy grey relational analysis. The results obtained from the framework application showed that its feasibility for maintenance system environment conduciveness classification. The number of sub-criteria that were considered could be either reduced or increased based on the characteristics of the manufacturing system maintenance environment where the proposed framework is applied.

References

[1] J.A. Botke, P.G.W. Janesen, S.N. Khapora, M. Tims, "Work factors influencing the transfer stages of soft skills training: A literature review," *Educational Research*, vol. 24, pp. 130-147, 2018.

[2] V. Pascal, A. Tonfik, A. Manuel, D. Florent, K. Frederic, "Improvement indicators for total productive maintenance policy," *Control Engineering Practice*, vol. 82, pp. 86–96, 2019.

[3] A. Azadeh, Z. Gaeini, B. Moradi, "Optimisation of HSE in maintenance activities by integration of continuous improvement cycle and fuzzy multivariate approach: A gas refinery," *Journal of Loss Prevention in the Process Industries*, vol. 32, pp. 415 – 427, 2014.

[4] J. Geng, D. Zhou, C. Lv, Z. Wang, "A modeling approach for maintenance safety evaluation in a virtual maintenance environment," *Computer-Aided Design*, vol. 45, no. 5, pp. 937-949, 2013.

[5] A.C. Harper, C. Gunson, L. Robinson, N.H. de Klerk, D. Osborn, P. Sevastos, J.L. Cordery, E. Geelhoed, M. Sutherland, J. Colquhoun, "Gutin industrial safety trial: Methods and safe practice and housekeeping outcomes," *Safety Science*, vol. 24, no.3, pp. 159-172, 1996.

[6] G. Kumar, K. Kalita, "Vibration control using BCW induction motor," *Procedia Engineering*, vol. 144, pp. 94-101, 2016

[7] N.A. Razak, H. Ma'amor, N. Hassan, "Measuring reliability and validity instruments of work environment towards quality work-life," *Procedia Economics and Finance*, vol. 37, pp. 520-528, 2016.

[8] J. Hays, M. McCawley, S.B.C. Shonkoff, "Public health implications of environmental noise associated with unconventional oil and gas development," *Science of the Total Environment*, vol. 580, pp. 448-456, 2017.

[9] J.C. Rubio-Romero, J.A. Carrillo-Castrillo, M. Soriano-Sewano, F. Galindo-Reyes, J. de la Varga-Salto, "A longitudinal study of noise exposure and its effects on the hearing of olive oil mill workers," *International Journal of Industrial Ergonomics*, vol. 67, pp. 60-66, 2018.

[10] P. Nassiri, M.R. Monazzam, M. Asghari, S.A. Zakerian, S.F. Dehghan, B. Folladi, K. Azam, "The interactive effect of industrial noise type, level and frequency characteristics on occupational skills," *Performance Enhancement and Health*, vol. 3, pp. 61-65, 2015.

[11] L. Guo, P-H. Li, H. Li, E. Colicino, S. Colicino, Y. Wen, R. Zhang, X. Feng, T.M. Barrow, A. Cayir, A.A. Baccarelli, H.M. Byun, "Effects of environmental noise exposure on DNA methylation in the brain and metabolic health," *Environmental Research*, vol. 153, pp. 73-82, 2017.

[12] A. Ehleiter, F. Jaehn, "Housekeeping: Foresightful container responding," *International Journal of Production Economics*, vol. 179, pp. 203-211, 2016.

[13] J.-F. Cordeau, P. Legato, R.N. Mazza, R. Trunfio, "Simulation-based optimisation for housekeeping in a container transshipment terminal," *Computers and Operations Research*, vol. 53, pp. 81-95, 2015.

[14] X. Lefebvre, P. Trabuc, K. Liger, C. Perrais, A. Santucci, "Preliminary results from a detritiation facility dedicated to soft housekeeping waste," *Fusion Engineering and Design*, vol. 87, No 7-8, pp. 1040-1044, 2012.

[15] M. Jausan, J. Silva, R. Sabatini, "A holistic approach to evaluating the effect of safety barriers on the performance of safety reporting systems in aviation organisations," *Journal of Air Transport Management*, vol. 63, pp. 95-107, 2017.

[16] D. Oswald, F. Sherratt, S. Smith, "Problems with safety observation reporting: A construction industry case," *Safety Science*, vol. 107, pp. 35-45, 2018.

[17] L. Tanguy, N. Tulechki, A. Urieli, E. Hermann, C. Raynal, "Natural Language processing for aviation safety reports: From classification to interactive analysis," *Computers in Industry*, vol. 78, pp 80-95, 2016.

[18] A. Angius, M. Colledani, L. Silipo, A. Yemane "Impact of preventive maintenance on the service level of multi-stage manufacturing systems with degrading machines," *IFAC-PapersOnLine*, vol. 49, no. 12, pp. 568-573, 2016.

[19] M. Holgado, M. Macchi, L. Fumagalli, "Value-in-use of e-maintenance in service provision: survey analysis and future research agenda," *IFAC-PapersOnLine*, vol. 49, no. 28, pp. 138-143, 2016.

[20] J. Bokrantz, A. Skoogh, C. Berlin, J. Stahre, "Maintenance in digitalised manufacturing: Delphi-based scenarios for 2030," *International Journal of Production Economics*, vol. 191, pp. 154-169, 2017.

[21] A. Angius, M. Colledani, A. Yemane, "Impact of condition based maintenance policies on the service level of multi-stage manufacturing systems," *Control Engineering Practice*, vol. 76, pp. 65-78, 2018.

[22] M. Hassim, "Reliability concepts applied to service industries," *International Journal of Quality and Reliability Management*, vol. 1, no. 1, pp. 39-50, 1984.

[23] M. Goh, G.-H. Tay, "Implementing a quality maintenance system in a military organisation," *International Journal of Quality and Reliability Management*, vol. 12, no. 4, pp. 26-39, 1995.

[24] M. Bartolini, M. Bevilacqua, M. Braglia, M. Frosolini, "An analytical method for maintenance outsourcing service selection," *International Journal of Quality and Reliability Management*, vol. 21, no. 7, pp. 772-788, 2004.

[25] R. Ab-Wahib, J. Corner, P.-L. Tan, "ISO 9000 maintenance in service organisations; tales from two companies," *International Journal of Quality and Reliability Management*, vol. 28, no. 7, pp. 735-757, 2011.

[26] S.P. Desselle, B. Andrews, J. Lui, G.L. Roja, "The scholarly productivity and work environments of academic pharmacists," *Research in Social and Administrative Pharmacy*, in press, pp. 1-9, 2017.

[27] A. Karimi, B. Ahmadpour, M.R. Marjani, "Using the fuzzy grey relational analysis method in wastewater treatment process selection," *Iranian Journal of Health, Safety and Environment*, vol.5, pp. 1041 – 1050, 2018.

[28] S. Goyal and S. Grover, "Applying fuzzy grey relational analysis for ranking the advanced manufacturing systems," *Grey Systems: Theory and Application*, vol.2, no.2, pp. 284–298, 2012.

[29] M. Azzeh, D. Neagu, P.I. Cowling, "Fuzzy grey relational analysis for software effort estimation," *Empirical Software Engineering*, vol. 15, no.1, pp.60–90, 2010.

[30] N. Tamiloli, J. Venkatesan, B.V. Rammath, "A grey–fuzzy modeling for evaluating surface roughness and material removal rate of coated end milking insert," *Measurement*, vol. 84, pp.68 – 82, 2016.

[31] P. Joshi and A. Sharma, "Simultaneous optimisation of kerf taper and heat affected zone in Nd–YAG laser cutting of Al 6061–T6 sheet using hybrid approach of grey relational analysis and fuzzy logic," *Precision Engineering*, vol.54, pp.302–313, 2018.

[32] J. Zhou, Y. Wang, B. Li, "Study on optimisation of denitration technology based grey–fuzzy comprehensive evaluation model," *Systems Engineering, Procedia*, vol.4, pp. 210–218, 2012.

[33] S.T. Kumaran, T.J. Ko, R. Kurniawan, "Grey fuzzy optimisation of ultrasonic–assisted EDM process parameters for deburring CFRP composites," *Measurement*, vol.123, pp.203 – 212, 2018.

[34] R.K. Pandey and S.S. Panda, "Optimisation of bone drilling parameters using grey–based fuzzy algorithm," *Measurement*, vol.47, pp.386–392, 2014.

[35] K. Shunmugesh, K.T. Akhil, S. Aravind, M. Pramodkumar, "Optimisation of drilling characteristics using grey – fuzzy logic in glass fiber reinforced polymer (GFRP)," *Materials Today: Proceedings*, vol.4, pp. 8938 – 8947, 2017.

[36] Y.–P. Huang and H.–C. Chu, "Simplifying fuzzy modelling by both grey relational analysis and data transformation methods," *Fuzzy Sets and Systems*, vol.104, pp.183 – 197, 1999.

[37] Q. Zhou and V.V. Thai, "Fuzzy and grey theories in failure mode and effect analysis for tanker equipment failure prediction," *Safety Science*, vol. 83, pp. 74–79, 2016.

[38] H. Wang, L. Duanmu, R. Lahdelma, X. Li, "A fuzzy–grey multicriteria decision making model for district heating system," *Applied Thermal Engineering*, vol. 128, pp. 1051–1061, 2018.

[39] D. Palanisamy, and P. Senthil, "Application of CNC turning process, *Materials Today: Proceedings*, vol.5, pp. 6645 –6654, 2018.

[40] O. Prakash, P.K. Sharma, R. Mahajan, "New measures of weighted fuzzy entropy and their applications for the study of maximum weighted fuzzy entropy principle," *Information Sciences*, vol.178, no.11, pp. 2389–2395, 2008.

[41] Y. Qi, F. Wen, K. Wang, L. Li, S.N. Singh, "fuzzy comprehensive evaluation and entropy weight decision – making based method for power network structure assessment," *International Journal of Engineering, Scientific and Technology*, vol.2, no.5, pp.92–99, 2010.

[42] H.-I. Zimmermann, and P. Zysno, "Latent connectives in human decision making," *Fuzzy Sets and Systems*, vol. 4, pp. 37-51, 1980.

[43] R. R. Yager, "Families of OWA operators," *Fuzzy Sets and Systems*, vol. 59, no. 2, pp. 125-148, 1993.

[44] N. Auger, M. Duplaix, M. Bilodeau-Bertrand, E. Lo, A. Smargiassi, "Environmental noise pollution and risk of preeclampsia," *Environmental Pollution*, vol. 239, pp. 599-606, 2018.

[45] J. Jiang, Y. Li, "Review of active noise control techniques with emphasis on sound quality enhancement," *Applied Acoustics*, vol. 136, pp. 139-148, 2018 .

[46] P. Song and H. Zhao, "Filtered-x generated mixed worm (FXGMN) algorithm for active noise control," *Mechanical Systems and Signal Processing*, vol. 107, pp. 93-104, 2018.

[47] B. Lam, S. Elliott, J. Cheer, W.-S. Gan, "Physical limits on the performance of active noise control through open windows," *Applied Acoustics*, vol. 137, pp. 9-17, 2018.

[48] A. Mezyk, W. Klein, M. Pawlak, J. Kania, "The identification of the vibration control system parameters designed for continuous miner machines," *Journal of Non-Linear Mechanics*, vol. 91, pp. 181-188, 2017.

[49] Y.-W. Zhang, S. Hou, K.-F. Xu, T.-Z. Yang, L.-Q. Chen, "Forced vibration control of an axially moving beam with an attached nonlinear energy sink," *Acta Mechanical SolidaSinica*, vol. 30, No. 6, pp. 674-682, 2017.

[50] B. Rahmani, A.G. Shenas, "Robust vibration control of laminated rectangular composite plates in hygrothermal and thermal environment," *Composite Structures*, vol. 179, pp. 665-681, 2017.

[51] D. Ning, S. Sun, H. Du, W. Li, N. Zhang, "Vibration control of an energy regenerative seat suspension with variable external resistance," *Mechanical Systems and Signal Processing*, vol. 106, pp. 94-113, 2018.

[52] Y. Xie, H. Shi, F. Bi, J. Shi, "A MIMD data-driven control to suppress structural vibration," *Aerospace Science and Technology*, vol. 77, pp. 429-438, 2018.

[53] A. Tombari, M.G. Espinosa, N.A. Alexander, P. Cacciola, "Vibration control of a cluster of buildings through the vibrating barrier," *Mechanical Systems and Signal Processing*, vol. 101, pp. 219-236, 2018.

[54] K. Xue, A. Igarashi, T. Kachi, "Optimal sensor placement for active control of floor vibration considering spillover effect associated with modal filtering," *Engineering Structures*, vol. 165, pp. 198-209, 2018.

[55] V.M. Dufort, C. Infante-Rivard, "Measuring housekeeping in manufacturing industries, *The Annals of Occupational Hygiene*," vol. 43, no. 2, pp. 91-97, 1999.

[56] A. Leivo, "Field study of the effects of a self-implemented feedback program on housekeeping performance," *International Journal of Industrial Ergonomics*, vol. 35, no. 5, pp. 471-485, 2005.

[57] E. Aker, V. Patoglu, E. Erdem, "Answer set programming for reasoning with semantic knowledge in collaborative housekeeping robotics," *IFAC Proceedings Volumes*, vol. 45, no 22, pp. 77-83, 2012.

[58] K. Liger, P. Trabuc, J. Mascarde, M. Troulay, F. Borgogoni, "Preliminary results from a detritiation facility dedicated to soft housekeeping waste and tritium valorisation," *Fusion Engineering and Design*, vol. 89, nos 9-10, pp. 2103-2107, 2014.

[59] N. Paltrinieri, A. Tugnoli, V. Cozzani, "Hazard identification for innovative LNG regasification technologies," *Reliability Engineering and System Safety*, vol. 137, pp. 18-28, 2015.

[60] P. Xin, F. Khan, S. Ahmed, "Dynamic hazard identification and scenario mapping using Bayesian Network," *Process Safety and Environmental Protection*, vol. 105, pp. 143-155, 2017.

[61] I. Camenon, S. Mannan, E. Nemeth, S. Park, H. Pasinan, W. Rogers, B. Selimann, "Process hazard analysis, hazard identification and scenario definition: Are the conventional tools sufficient, or should and can we do much better?" *Process Safety and Environmental Protection*, vol. 110, pp. 53-70, 2017.

[62] N. de Galvez, J. Marsot, P. Martin, A. Siadat, A. Etienne, "EZID: A new approach to hazard identification during the design process by analyzing energy transfers," *Safety Science*, vol. 95, pp. 1-14, 2017.

[63] V.C. Moren, V. Cozzani, "Integrated hazard identification within the risk management of industrial processes," *Safety Science*, vol. 103, pp. 340-351, 2018.

[64] B. Strauch, "Can we examine safety culture in accident investigations, or should we?" *Safety Science*, vol. 77, pp. 102-111, 2015.

[65] H. Hasani, S.A. Tabatabaei and G. Amiri, "Grey relational analysis to determine the optimum process parameters for open-end spinning yarns," *Journal of Engineered Fibers and Fabrics*. vol. 7, no. 2, pp. 81-86, 2012.

[66] B. Iung, E. Levrat, "Advanced maintenance services for promoting sustainability," *Procedia CIRP*, vol. 22, pp. 15-22, 2014.

[67] E. Sari, A.M. Shaharoun, A. Ma'aram, A.M. Yazid, "Sustainable maintenance performance measures: a pilot survey in Malaysian automotive companies," *Procedia CIRP*, vol. 26, pp. 443-448, 2015.

[68] N. Salikin, N. Ab Wahab, I. Muhammad, "Strengths and weaknesses among Malaysian SMEs: Financial management perspectives," *Procedia - Social and Behavioral Sciences*, vol. 129, pp. 334-340, 2014.

Appendix A

$$\mu_{low} = \begin{cases} \frac{\bar{c}_i^k}{2} & 0 \le \bar{c}_i^k \le 2 \\ \frac{4-\bar{c}_i^k}{2} & 2 \le \bar{c}_i^k \le 4 \\ 0 & \bar{c}_i^k > 4 \end{cases}$$

$$\mu_{moderate} = \begin{cases} 0 & 0 \le \bar{c}_i^k \le 4 \\ 1-\frac{8-\bar{c}_i^k}{4} & 4 \le \bar{c}_i^k \le 8 \\ 1 & 8 \le \bar{c}_i^k \le 14 \\ \frac{18-\bar{c}_i^k}{4} & 14 \le \bar{c}_i^k \le 18 \\ 0 & \bar{c}_i^k > 18 \end{cases}$$

$$\mu_{high} = \begin{cases} 0 & 0 \le \bar{c}_i^k \le 12 \\ 1-\frac{18-\bar{c}_i^k}{6} & 12 \le \bar{c}_i^k \le 18 \\ 1 & \bar{c}_i^k > 18 \end{cases}$$

$$c_i\left(\mu_{\bar{a}}(c), \mu_{\bar{b}}(c)\right) = \frac{\mu_{\bar{a}}(c).\mu_{\bar{b}}(c)}{1+\mu_{\bar{a}}(c)-\mu_{\bar{b}}(c)+2\mu_{\bar{a}}(c).\mu_{\bar{b}}(c)}$$

Biographies

Desmond Eseoghene IGHRAVWE is a lecturer at the Department of Mechanical and Biomedical Engineering, Bells University of Technology, Ota, Nigeria. He holds a PhD in Mechanical Engineering from Ladoke Akintola University of Technology, Nigeria. He is a graduate of the University of Ibadan, Nigeria, where he did his B.Sc. and M.Sc. programmes at the Department of Industrial and Production Engineering. Some of his research areas are operations research, energy and waste management, and multi-criteria analysis.

Sunday Ayoola OKE received his Ph.D. in Industrial Engineering from the University of Ibadan, Nigeria in 2008. He lectures at the Department of Mechanical Engineering, University of Lagos, Lagos, Nigeria. His research interests include manufacturing and optimisation studies.