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Optimizing Maintenance Management System: Identification of Critical Risk and Safety Factors in Human Error Based Corrective Maintenance in the SMEs using Fuzzy DEMATEL Approach

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ABSTRACT

A better and optimal maintenance management system is a key source of a sustainable manufacturing environment in the competitive world. In response to improving drastic and competitive manufacturing working environments, many Small and Medium-sized Enterprises (SMEs) wish for an optimal maintenance management system for business success and customer satisfaction. For the purpose of organizing optimal Corrective Maintenance Management (CMM) effectively, some literature and direct industrial surveys have suggested several critical factors of Human Error-Based (HEB) CMM in the working environment of SMEs. HEB accidents and machine breakdowns have always been a major concern in this type of maintenance management system in SMEs, especially in the 3D printing technology applied automotive industries. Such undesirable problems are more prevalent in SMEs of developing countries, especially in the SMEs of southern Tamil Nadu, India. Moreover, ranking the most significant critical factors in HEB maintenance inevitably involves the vagueness of human judgment in the traditional way of approach. This research objective is to predict, analyze, and evaluate the HEB maintenance factors that trigger undesirable machine accidents and corrective maintenance activities of Sensors and switches manufacturing operations in SMEs. Hence, this real-time case study research presents a favorable method for combining fuzzy set theory and the Decision-Making Trial and Evaluation Laboratory (DEMATEL) method to rank the critical factors for optimal CMM implementation in the working environment of SMEs. According to this analysis identified the most critical factors (Meshing around - 0.205, Poorly written procedures and manuals, and work instructions – 0.163) were identified under two major sub-categories, such as environmental and organizational factors generally influenced in the SMEs. Also, an empirical case study is illustrated by presenting the proposed hybrid MCDM technique and demonstrating the application of implications.

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1. Introduction

In the southern region of Tamil Nadu, many SMEs still they are work in the traditional way of approach in the maintenance management system. Most of the SMEs recognize that utilizing optimal maintenance management systems in a competitive manufacturing world. In general, the crucial activity maintenance has been classified into three categories such as design out maintenance, Preventive Maintenance (PM), and Corrective Maintenance (CM).

Among these three classifications, the CM has been most influenced by the Human Error-Based (HEB) machine breakdown in the working environment of the SMEs. Due to the HEB machine breakdown, most of the components and subcomponents of the machine do not achieve the actual useful life and drastically decrease the Remaining Useful Life (RUL) of the machine components and their subcomponents. For that reason, productivity and customer satisfaction would be reduced simultaneously. These increased CM activities lead to the maximized investment of the maintenance management system in the SMEs. Each SME is facing this fundamental issue of the working environment; most of the maintenance and service cost investment is spent on this type of human error-based maintenance activities. The performance and availability of the machine in the production plant have been improved by prioritizing the schedule of the maintenance workforce in the manufacturing plant of the SMEs. In this real-time industrial case, the research collects actual data related to maintenance management activities influenced by human error. These factors are then categorized according to the specific constraints defined for the mathematical analysis. This real-time case study was conducted in an automotive industry located in the southern region of Tamil Nadu, India, to improve the performance of machine-operating employees. This manufacturing sector plays a vital role globally, particularly in the context of the recent Industrial Revolution (Industry 4.0). That type of industry must achieve the required outcomes based on the customers' needs and demands. Then, improve the employee's knowledge through the outcome of the research study. The productivity of the manufacturing plant has been improved by the better performance of the working employee without or minor level of human error-based maintenance, service, and breakdown action in the SMEs. In the initial stage of every SME faces human error-based productivity losses and other problems, such as maximum cost investment in the service and maintenance activities. HEB-related maintenance, service, and breakdown activities often lead to unexpected and unplanned investments in SMEs, as observed in this real-time case study. The chosen industry spends a significant portion of its investment on these activities, which motivated the analysis of HEB maintenance to identify, rank, and predict the most critical and least critical human error factors. Globally, improper maintenance activities cause the most dangerous effects on the manufacturing plant productivity and other management-level activities. It significantly leads to the maximum downtime of the manufacturing machinery and minimum efficiency, and the effectiveness of the unit in the industry. The safe and best maintenance management scheduling is closely dependent on the proper planning of the maintenance activities and categories the workload flow of the maintenance team in the industries. The unplanned maintenance activities led to an unexpected, dangerous machine accident in the workplace. The details Multi-Criteria Decision-Making analysis of the human error factor have been illustrated in the following section of this real-time industrial case study research article, chosen as the automobile production system in the southern region of Tamil Nadu, India.

2. Overview of Maintenance Management Implementations

The implementation of the optimal and smart maintenance management system in the SMEs was the most critical task in the industrial environment, along with the employee and top-level management people's satisfaction. In our region, most of the SMEs were interested in the new upgradation of the working environment. This real-time case research manuscript has been supported by the industrial revolution of the SMEs. This section clearly explained the critical overview of the Multi-Criteria Decision Making (MCDM) method in the maintenance management implementation in the industries through the Systematic Standard Literature Review Process (SSLRP). Gökalp and Eti (Gökalp & Eti, 2025) applied intuitionistic fuzzy DEMATEL to develop strategies for reducing energy costs in hospitals. The study identified key energy factors and their interdependence. The findings offer practical strategies to improve energy efficiency and reduce costs in healthcare facilities. Wang et al. (Wang et al., 2024) created a risk assessment framework for human evacuation on passenger ships by integrating fuzzy DEMATEL, ISM, and Bayesian Networks. This approach addresses the complexities and uncertainties of ship evacuations. The study offers insights to enhance safety protocols and improve evacuation procedures. Irfan et al. (Irfan et al., 2024) utilized the fuzzy-DEMATEL approach to model barriers to metaverse adoption in the construction industry. The study identified key challenges, including technological, financial, and organizational factors. The findings provide valuable insights for overcoming these barriers and accelerating metaverse adoption within the construction industry. Feng et al. (Feng et al., 2024) used a hybrid fuzzy DEMATEL–ISM–MICMAC approach to identify key factors influencing employees' green behavior. The integrated framework analyzes the interdependencies and hierarchy among these factors. The study provides insights into promoting sustainable practices within organizations. Quezada et al. (Quezada et al., 2024) integrated fuzzy DEMATEL with fuzzy VIKOR to formulate manufacturing strategies, addressing uncertainties in decision-making. The approach identifies critical factors, analyzes interdependencies, and selects optimal strategies. The findings offer a robust framework for improving manufacturing strategy formulation. Mohammadfam et al.

(Mohammadfam et al., 2019) employed the Fuzzy DEMATEL method to analyze the intricate interplay of factors influencing situation awareness (SA). This approach effectively mitigates uncertainties in expert assessments and elucidates cause-and-effect relationships among variables such as perception, cognitive workload, and environmental complexity. The findings offer valuable insights for enhancing SA in critical domains like aviation and healthcare, while acknowledging the limitations of relying solely on expert judgments and the scalability challenges for larger datasets. Li et al. (Li et al., 2019) investigated accident-causing factors in urban buried gas pipelines using an integrated approach of DEMATEL, ISM, and Bayesian Networks. This method identified critical factors like operational failures, environmental impacts, and human errors while modeling their interrelationships and probabilistic dependencies. The study provides actionable insights into pipeline safety and risk mitigation, offering a robust framework for addressing complex safety challenges in process industries. Demirel (Demirel, 2020) integrated the DEMATEL approach with fuzzy sets to assess critical factors impacting gas turbines in the marine industry. By incorporating fuzzy logic, the study addressed uncertainties and complexities in expert assessments. Key factors influencing gas turbine performance and reliability were identified and analyzed, revealing their interdependencies. The findings offer valuable insights for optimizing maintenance strategies, enhancing operational efficiency, and improving overall system reliability. This research underscores the effectiveness of fuzzy DEMATEL in addressing complex multi-criteria decision-making challenges within intricate engineering systems. Kuzu (Kuzu, 2021) utilized the fuzzy DEMATEL method to assess ship break-in-two accident risks, mitigating inherent uncertainties in maritime risk evaluations. This approach identified critical risk factors, including structural deficiencies, adverse weather, and human errors, and analyzed their interdependencies. By incorporating fuzzy logic, the method enhanced the evaluation of complex interactions, providing valuable insights for improving risk management and maritime safety. Wang et al. (Wang et al., 2018) investigated coal mine production safety by combining DEMATEL and ISM methods to analyze influencing factors and their interdependencies. The study identified key factors such as equipment reliability, worker behavior, and environmental conditions, categorizing them based on their causal relationships and structural importance. This integrated approach provided a clear hierarchy of factors, enabling targeted interventions to enhance safety measures. The research offers valuable insights into improving risk management and promoting safer operations in coal mining.

Mentes et al. (Mentes et al., 2015) developed a novel risk assessment framework for cargo ships operating in Turkish coastal and open sea waters by integrating Formal Safety Assessment (FSA) principles with a fuzzy-based DEMATEL approach. This innovative methodology effectively addresses the inherent uncertainties and complexities associated with maritime risk assessment, providing a more comprehensive and robust evaluation of potential hazards and their interdependencies. Luthra et al. (Luthra et al., 2016) used the fuzzy DEMATEL method to analyze key enablers of solar power development in India, including policies, technology, and financial incentives. The study highlighted their interdependence and provided insights to address uncertainties in expert evaluations. These findings support strategic planning for sustainable energy growth. Akyuz and Celik (Akyuz & Celik, 2015) applied the fuzzy DEMATEL method to assess critical hazards in the gas freeing process of crude oil tankers. This approach tackled operational uncertainties and offered insights to improve safety protocols. The study aids in minimizing accident risks effectively. Lin (Lin, 2013) used the fuzzy DEMATEL method to evaluate green supply chain management practices, identifying key sustainability factors. The study analyzed their interrelationships and causal effects, offering valuable insights for improving sustainability in supply chains. This approach effectively addressed uncertainties in evaluating green practices. Meng et al. (Meng et al., 2019) created a risk assessment framework for offshore platforms by integrating DEMATEL with Bayesian Networks. This approach addresses uncertainties in leakage-induced accidents, offering a robust tool for risk management. The study enhances offshore platform safety through effective risk evaluation. Zhou et al. (Zhou et al., 2011) utilized the fuzzy DEMATEL method to identify critical success factors in emergency management, including decision-making, communication, and resource allocation. The study analyzed the interdependence among these factors, providing valuable insights for enhancing emergency management strategies. Vujanović et al., (Vujanović et al., 2012) integrated DEMATEL and ANP methods to evaluate vehicle fleet maintenance management indicators. The study identified key factors influencing fleet performance and assessed their interrelationships. The findings provide a structured approach to enhance maintenance strategies and fleet management efficiency. Başhan and Demirel (Başhan & Demirel, 2019) used fuzzy DEMATEL to analyze critical operational faults in marine boilers, identifying key issues and their interdependencies. The study offers insights to enhance boiler safety and reliability.

Manyasi (Massami & Manyasi, 2019) employed the DEMATEL modeling approach to evaluate challenges in on-board training in Tanzania, identifying key obstacles such as resource limitations and training inefficiencies. The findings provide valuable insights for improving training programs and enhancing maritime education in Tanzania. Özdemir (Özdemir, 2016) applied fuzzy DEMATEL and TOPSIS methods to investigate occupational accidents in ports, analyzing key factors and their interdependencies. The study provides insights into improving safety measures. These findings contribute to enhancing accident prevention strategies in port operations. Özdemir et al. (Özdemir et al., 2016)used the DEMATEL method to analyze marine pollution from ship operations, identifying key sources like oil spills and air emissions. The study examined their interdependencies to inform pollution prevention strategies. The findings contribute to improving the environmental sustainability of maritime operations. Vujanović et al. (Vujanović et al., 2012) used DEMATEL and ANP to evaluate key vehicle fleet maintenance indicators and their interrelationships. The study offers a structured approach to enhance fleet performance and maintenance strategies. Yang et al. (Yang et al., 2008) introduced a hybrid MCDM model combining DEMATEL and ANP to address complex decision-making challenges. The model's application to real-world scenarios showcased its effectiveness in evaluating interdependent factors. The study offers valuable insights for enhancing decision-making processes in operations research. Yang and Tzeng (Yang & Tzeng, 2011) integrated DEMATEL with a novel cluster-weighted ANP method to enhance multi-criteria decision-making. This innovative approach effectively addresses complex decision problems by identifying interdependencies among criteria. The findings demonstrate the improved accuracy and robustness of this integrated approach. Lin et al. (Lin et al., 2011) used the DEMATEL method to identify core competencies and causal relationships in an IC design service company. The study examined key performance factors and their interdependence. The findings offer strategic insights to enhance competitiveness in the IC design industry.

Although numerous studies on the application of the MCDM approaches in the various fields of the industry were encountered in the detailed systematic literature review process. To fill the gaps in the research of the real-time industrial problem, the factors have been collected from the automobile industry in the southern region of Tamil Nadu. This research has been analyzed through the application of the MCDM approach, like Fuzzy DEMETAL analysis, to identify the cause and effect of the existing problem in the manufacturing industry. Based on the cause-and-effect grouping of factors, suitable actions will be initiated to minimize the corrective maintenance cost. These actions will also help optimize the maintenance process by improving the effectiveness of the employee work schedule in the maintenance department.

In this study, a mainly used fuzzy DEMETAL approach was used to analyze and identify the most influential corrective maintenance factors in the industries. According to the real-time problems, the suitable factors were collected from the respective working environment. The classified cause and effect factors of the corrective maintenance produced the optimal decision-making process of the better maintenance management system in the industries. The detailed methodology of this research approach has been illustrated in the sections below.

3. Methodology

For developing, evaluating, and analyzing a model involving causal relationships between critical factors in HEB maintenance activities, the most widely applied Multi-Criteria Decision-Making approach, the DEMATEL technique, is a potent and comprehensive technique. To extend the MCDM technique for optimal decision-making by combining the fuzzy environments, the essentials of the Hybrid fuzzy DEMATEL techniques are discussed below.

3.1 Fuzzy DEMATEL Method

The fuzzy DEMATEL MCDM approach is widely used as an efficient analysis technique developed to identify the current configuration meaning and the relationship between the real-time factors; in which this approach is based on a binary diagram, charts dividing the requirements factors that cause problems into groups of causes and effects. To deal with confusion, ambiguity, and complexity in human judgment and decision making, Lotfi A. Zadeh (Zadeh, 2015) developed fuzzy reasoning. Real-world decision-making challenges necessitate imprecision because priorities, constraints, and courses of action are not clearly defined. It is the easiest and simplest way to translate linguistic terms into vague numbers rather than combining the many feelings, thoughts, ideas, and motivations of a person or group of decision makers. So, make fuzzy numbers when making decisions. In this context, a triangular fuzzy number is defined as a triple FN = (l, m, u), where l, m, and u represent the lower, middle, and upper numbers of the fuzzy sets. An example of how to express a triangular fuzzy number membership function follows.

$$\mu_{FN} = \begin{cases} 0, \; x < 1 \\ \frac{(x-l)}{(m-l)}, \; l \le x \le m \\ \frac{(u-x)}{(u-m)}, \; m \le x \le u \\ 0, \; x \ge u \end{cases} \tag{1}$$

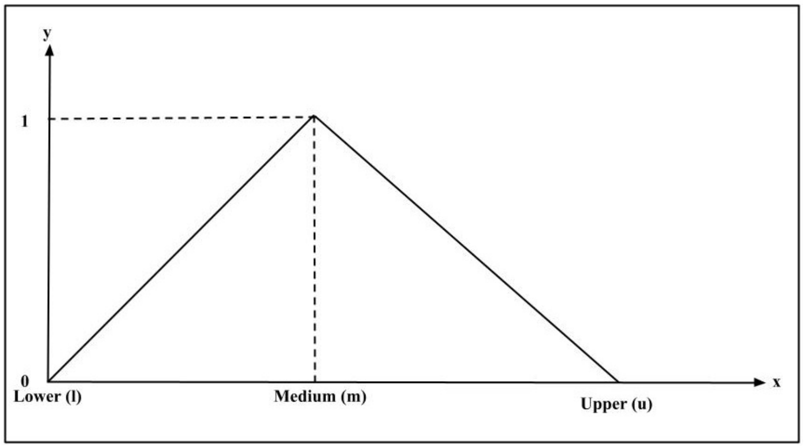

Figure 1: Triangular Fuzzy Number of Factor Analysis

Figure 1 illustrates a triangular fuzzy number. According to Table 1, the corresponding relationship between computational linguistic variables and triangular fuzzy numbers is shown. For any two fuzzy triangular numbers, $FN_1 = (l_1, m_1, u_1)$ and $FN_2 = (l_2, m_2, u_2)$. Their statistical evaluation can be categorized as follows:

The summation of the triangular fuzzy number is.

$$FN_1 + FN_2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \tag{2}$$

The subtraction of the triangular fuzzy number is.

$$FN_1 - FN_2 = (l_1 - l_2, m_1 - m_2, u_1 - u_2) \tag{3}$$

The multiplication of the triangular fuzzy number is.

$$FN_1 \times FN_2 = (l_1 \times l_2, m_1 \times m_2, u_1 \times u_2) \tag{4}$$

Table 1: Rating of the Membership Function

Linguistic Variable	Triangular Fuzzy Number		
	Lower (l)	Medium (m)	Upper (u)
No influence (N)	0	0	0
Very Low Influence (VL)	0	0	0.1
Low Influence (L)	0	0.1	0.3
Medium Influence (M)	0.1	0.3	0.5
High Influence (H)	0.3	0.5	0.7
Very High Influence (VH)	0.5	0.7	0.9

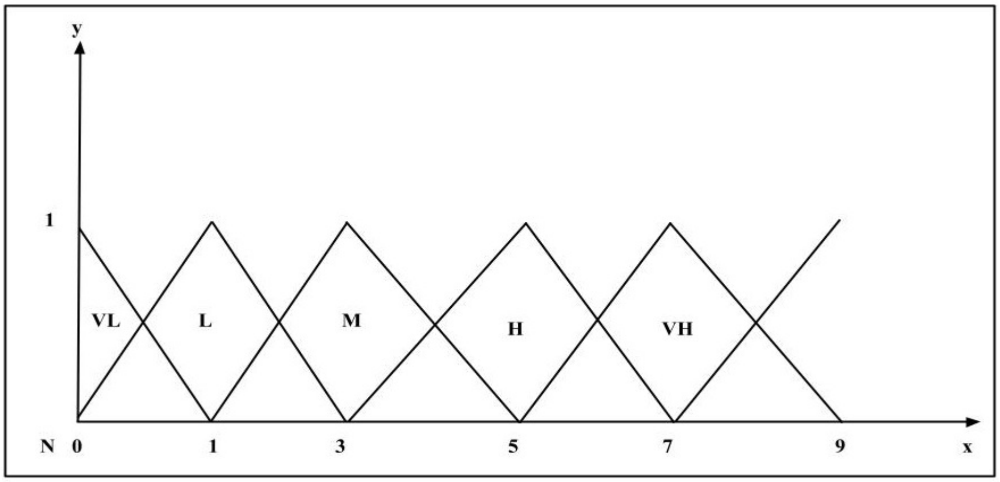

Figure 2: Linguistic Variable Rating of Membership Function

Table 2: Critical Environmental Determinants Affecting Corrective Maintenance Outcomes.

Code	Human Error-Based Critical Factors Affecting Maintenance Management System
F1	Working Environment
F2	Working Shift
F3	Working Mode
F4	Design Of Man-Machine Interface
F5	Disregarding Safety
F6	Messing Around
F7	Fatigue
F8	Speed Working
F9	Equipment Design and Construction Deficiencies
F10	Routine or Repetitive Work.
F11	Poor Communication and Sparse Feedback
F12	Multitasking
F13	Emotional Stress

Table 3: Critical Organizational Determinants Affecting Corrective Maintenance Outcomes.

Code	Human Error-Based Critical Factors Affecting Maintenance Management System
F14	Level of Manpower
F15	Team Collaboration on Quality
F16	Time Constraint in Production
F17	Poorly Written Procedures, Manuals, and Work Instructions
F18	Work Design/Planning/Layout
F19	Poor Management and Supervision
F20	Insufficient Training
F21	Stages of Source Management
F22	Level Of Training and Experience
F23	Blame, Punishment, and Liability
F24	Flaws in Decision Making
F25	Complexity in the Production Process

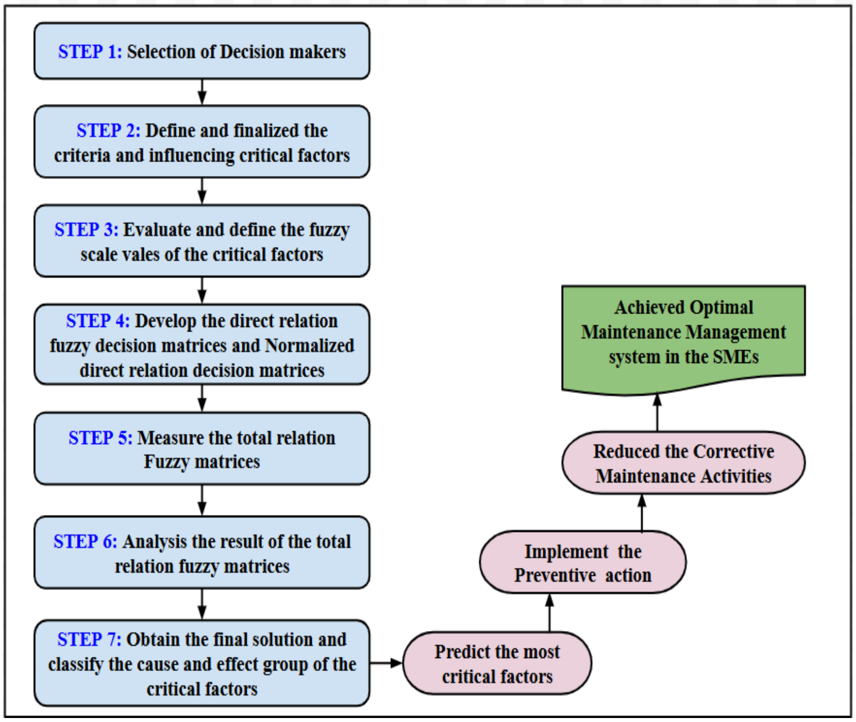

Figure 3: Flow Process of the Fuzzy DEMATEL Analysis

The analysis committee followed this proposed hybrid fuzzy DEMATEL approach and proceeded with the standard four-step procedure. The flow process of the fuzzy DEMETAL analysis has been illustrated in Figure 3.

3.2 Step 1 (Selection of Decision Maker)

In this initial stage list the decision makers were identified based on their knowledge and expertise in the maintenance management activities in the SMEs. They illustrated the decision-making of ranking the critical factors in human error into the most significant classification to organize the optimal maintenance management system initiative successfully. The decision makers are selected in different fields of working environment in the industry with a minimum of ten years' experience and experts in the field of maintenance management system, such as Production Manager, Production in charge, Plant supervisor, Maintenance manager, Maintenance engineer, and Maintenance employee.

3.3 Step 2 (Define and Finalize the Criteria and Factors)

The committee developed and inspected a list of critical factors based on human error, which was significantly based on the real-time industrial interviews and previously published research articles. The finalized critical factors influencing the human error-based corrective maintenance management system, with two different categories, such as environmental and organizational factors, have been listed and shown in Tables 2 and 3. Most of the factors were collected through the direct interaction of the decision makers with real-time problems in the working environment of the SMEs.

3.4 Step 3 (Define the Fuzzy Scale and Evaluate Critical Factors)

Based on the linguistic variables scale values, the initial pairwise comparison matrices have been obtained. The applied linguistic variables are used on five different fuzzy scales in accordance with (No influence (N), Very Low influence (VL), Low influence (L), Medium influence (M), High influence (H), and Very High influence (VH)). The linguistic variable values are illustrated in Table 1. The rating of the fuzzy membership function has been illustrated in Figure 2. Then, simultaneously, relevant triangular FNs are measured. In addition, the fuzzy evaluations are converted into a crisp value that is defuzzified and aggregated.

3.5 Step 4 (Develop the Direct-Relation Fuzzy Matrices and Normalized Direct-Relation Fuzzy Matrices)

The normalized direct-relation matrices are developed in the presence of the initial direct-relation matrices of the decision-maker's desire. Thereafter, to turn the variables into comparable fuzzy scales, the triangular linguistic variable scale transformation is applied.

3.6 Step 5 (Measure the Total Relation Fuzzy Matrices)

In the fifth step, the total-relation fuzzy matrices are measured. The crisp case of the total-relation fuzzy matrices can be measured through the application of the following equation:
Total relation matrices (T) = Normalized matrices (D) (Identical Matrices (I) -Normalized matrices (D))$^{-1}$

$$T = D(I - D)^{-1} \tag{5}$$

$$T_{ij} = \lim_{k \to +\infty} (x^{-1} + x^{-2} + \ldots . x^{-k})$$

Were,

$$[l_{ij}] = x_l + (I - x_l)^{-1}$$

$$[m_{ij}] = x_m + (I - x_m)^{-1}$$

$$[u_{ij}] = x_u + (I - x_u)^{-1}$$

3.7 Step 6 (Analysis)

Once the total relation matrices (T) have been measured, calculate ri+cj and ˜ri-cj from the total relation matrix (T). ri+cj and positive values indicate the significant cause group of factors in the implementation of optimal maintenance management analysis, and ˜ri-cj and negative values are classified as the effect group of factors in the implementation of optimal maintenance management system in the SMEs.

3.8 Step 7 (Factors Classification)

The total relationship matrix of the critical factors was identified through the analysis operation of these approaches then it will be classified into the different groups of the factors based on the factors' ranks and total relationship matrix values. The cause-and-effect classification was obtained based on the analysis values (ri+cj and ̃ri-cj)

Finally, measure all parameters of the critical factors influencing CBM activities in the SMEs, and generate the cause-and-effect diagram of the analysis approach. In that situation, the cause-and-effect diagram of the individual factors has been illustrated in the mapping diagram of this analysis approach.

4. Empirical Case Study

Being the necessity of enhancing the optimal maintenance management system in the competitive manufacturing world, most SMEs wish to organize and utilize the maintenance management system effectively. In this section, a real-time empirical case study shows how an SME utilized the proposed approach to rank a list of critical human error factors for the successful development of the maintenance management system.

4.1 Problem Description

Case XYZ industry is cited in the southern region of Tamil Nadu, employing more than 500 employees. This industry is one of the leading manufacturing industries in the automobile spare parts production and various electronic components like sensors, sensing solutions, switches, controls, solenoids, electromechanical components, and computer input devices. To improve the traditional maintenance management system in the working environment, it is now a developing industry strategy to apply optimal maintenance management systems to create, share, and utilize the recent industrial revolution technologies. To increase the overall performance of the maintenance management system in the competitive manufacturing environment in the world. Also, the XYZ industry has increased to transform the traditional maintenance management system and leverage its implementation of optimal Corrective Maintenance Management into a competitive working environment. However, that industry ran into trouble when making optimal maintenance management system initiatives, because any latest development activities need to take into account the evaluation of several numbers of critical factors in the human error-based corrective maintenance in the industry.

Although they recognized many critical factors of human error in the successful implementation of the optimal maintenance management system, there arose the problem (since those critical factors were not equally important) of how to rank them into meaningful categories, such as cause and effect. To acquire sensible segments, XYZ industry, therefore, set up an optimal maintenance management committee consisting of the General Manager, Production Manager, Plant In-charge, maintenance manager, and several managers representing production, human resource, and information technology departments. The following section reveals how that industry utilized the proposed hybrid fuzzy DEMATEL method to analyze, evaluate, and rank the list of critical factors in human error for its optimal maintenance management initiative.

4.2 Implication of the Proposed Method

The real-time empirical case study implication in the standard architecture of the MCDM approaches has been illustrated in detail with actual mathematical analysis outcome of this Fuzzy DEMETAL analysis in the maintenance management system. The standard step-by-step procedure of this MCDM analysis outcomes has been discussed in this section.

Step 2: Initially, the linguistic assessment of the decision maker's own desire suggestion was obtained and illustrated in Table 4.

Step 3: Then, the fuzzy evaluation scale of the above assignment data was created based on the above-mentioned linguistic variable scale factors and the decision matrices of the input assessment data. The decision matrices with the actual fuzzy scale of the individual factors are shown in Table 5.

Table 4: Assignment Data of Decision Makers

Factors	F1	F2	F3	F4	F5	…….	F22	F23	F24	F25
F1	0	H	VL	L	L	…….	M	L	L	H
F2	VH	0	VL	VL	VH	…….	VH	M	H	L
F3	H	L	0	VH	H	…….	M	VL	M	H
F4	L	VL	M	0	M	…….	L	VH	VL	H
F5	VL	VH	L	VH	0	…….	H	L	H	M
…….	…….	…….	…….	…….	…….	…….	…….	…….	…….	…….
F22	VL	VL	VH	H	L	…….	0	H	L	L
F23	M	L	M	L	VH	…….	L	0	H	VH
F24	VL	VH	H	M	VL	…….	H	VH	0	H
F25	VL	M	VL	H	VH	…….	M	L	VL	0

Table 5: Decision Matrices

Factors	F1	F2	F3	F4	F5	…….	F22	F23	F24	F25
F1	0	1.5	0.1	0.4	0.4	…….	0.9	0.4	0.4	1.5
F2	2.1	0	0.1	0.1	2.1	…….	2.1	0.9	1.5	0.4
F3	1.5	0.4	0	2.1	1.5	…….	0.9	0.1	0.9	1.5
F4	0.4	0.1	0.9	0	0.9	…….	0.4	2.1	0.1	1.5
F5	0.1	2.1	0.4	2.1	0	…….	1.5	0.4	1.5	0.9
…….	…….	…….	…….	…….	…….	…….	…….	…….	…….	…….
F22	0.1	0.1	2.1	1.5	0.4	…….	0	1.5	0.4	0.4
F23	0.9	0.4	0.9	0.4	2.1	…….	0.4	0	1.5	2.1
F24	0.1	2.1	1.5	0.9	0.1	…….	1.5	2.1	0	1.5
F25	0.1	0.9	0.1	1.5	2.1	…….	0.9	0.4	0.1	0

Table 6: Normalized Decision Matrices

Factors	F1	F2	F3	F4	F5	…….	F22	F23	F24	F25
F1	0	0.075	0.005	0.015	0.018	…….	0.038	0.017	0.021	0.060
F2	0.114	0	0.005	0.004	0.095	…….	0.088	0.039	0.077	0.016
F3	0.081	0.020	0	0.080	0.068	…….	0.038	0.004	0.046	0.060
F4	0.022	0.005	0.044	0	0.041	…….	0.017	0.092	0.005	0.060
F5	0.005	0.105	0.019	0.080	0	…….	0.063	0.017	0.077	0.036
…….	…….	…….	…….	…….	…….	…….	…….	…….	…….	…….
F22	0.005	0.005	0.102	0.057	0.018	…….	0	0.066	0.021	0.016
F23	0.049	0.020	0.044	0.015	0.095	…….	0.017	0	0.077	0.084
F24	0.005	0.105	0.073	0.034	0.005	…….	0.063	0.092	0	0.060
F25	0.005	0.045	0.005	0.057	0.095	…….	0.038	0.017	0.005	0

Table 7: Total Relationship Matrices

Factors	F1	F2	F3	F4	F5	…….	F22	F23	F24	F25
F1	0.021	0.056	0.009	0.003	0.002	…….	0.018	0.002	0.002	0.053
F2	0.103	0.029	0.022	0.027	0.091	…….	0.067	0.016	0.055	0.008
F3	0.062	0.010	0.016	0.060	0.055	…….	0.014	0.018	0.037	0.039
F4	0.007	0.013	0.014	0.022	0.013	…….	0.002	0.079	0.024	0.036
F5	0.018	0.085	0.003	0.068	0.022	…….	0.036	0.008	0.061	0.027
…….	…….	…….	…….	…….	…….	…….	…….	…….	…….	…….
F22	0.023	0.005	0.096	0.038	0.002	…….	0.007	0.041	0.003	0.003
F23	0.032	0.012	0.025	0.014	0.074	…….	0.011	0.017	0.058	0.073
F24	0.029	0.090	0.052	0.014	0.035	…….	0.038	0.069	0.033	0.033
F25	0.006	0.035	0.019	0.032	0.084	…….	0.020	0.000	0.023	0.019

Step 4: Next, calculate the Normalized decision matrices through the application of the standard formula mentioned in the methodology section. Through the decision matrices of the given factors, the normalized decision matrices were calculated, and the outcome is shown in Table 6.

Step 5: After calculating the normalized decision matrices of the decision makers' factors, the fuzzy total relationship matrices were calculated by using the standard formula, which was introduced in the methodology section. Before calculating the total relationship matrices, include the identical matrices and then multiply the inverse of the normalized decision matrices to result in the final total relationship matrices, as mentioned in the methodology section. The final result of the total relationship matrices is shown in Table 7.

Step 6: Finally, calculate the row and column average values by using the standard formula provided in the methodology section. The analysis outcome results were shown in Table 8. Based on this cause-and-effect diagram to build and conclude the case research study, and implement this empirical research for a better maintenance management system in the SMEs.

Table 8: Summary of the Key Analysis Results and Evaluated Performance Metrics

Factors	Ri	Ci	Ri + Ci	Ri -Ci
F1	0.429	0.498	0.928	-0.069
F2	0.531	0.500	1.030	0.031
F3	0.513	0.499	1.012	0.013
F4	0.528	0.501	1.030	0.027
F5	0.447	0.499	0.946	-0.051
F6	0.735	0.501	1.236	0.235
F7	0.518	0.500	1.018	0.018
F8	0.531	0.500	1.031	0.031
F9	0.413	0.499	0.912	-0.087
F10	0.528	0.503	1.031	0.025
F11	0.565	0.501	1.066	0.064
F12	0.344	0.500	0.844	-0.156
F13	0.539	0.501	1.040	0.039
F14	0.448	0.503	0.950	-0.055
F15	0.503	0.499	1.002	0.004
F16	0.401	0.501	0.902	-0.100
F17	0.659	0.498	1.157	0.161
F18	0.451	0.499	0.950	-0.048
F19	0.372	0.496	0.868	-0.124
F20	0.505	0.501	1.005	0.004
F21	0.477	0.504	0.981	-0.027
F22	0.408	0.497	0.905	-0.089
F23	0.560	0.501	1.061	0.060
F24	0.645	0.501	1.146	0.143
F25	0.449	0.498	0.947	-0.049

5. Findings

The most significant relationship between environmental and organizational factors in the maintenance management system has been clearly explained in the cause-and-effect diagram. In that graphical representation of the cause-and-effect diagram, ri+cj is considered on the horizontal axis, and ̃ri-cj is considered as the vertical axis. The interaction of each axis value is pointed in the coordinate of the diagram. The pictorial representation of the cause-and-effect diagram is shown in Figure 4. Through this cause-and-effect diagram, the final analysis results of the factors were classified into two different groups, like cause-and-effect factor groups.

5.1 Cause Factors

According to the standard procedure of this MCDM analysis, positive values in the ri-ci are considered as the cause group of factors in the Human Error-Based maintenance management systems. The following factors are classified into the cause group there are F2, F3, F4, F6, F7, F8, F10, F11, F13, F15, F17, F20, F23, F24. Among all these cause groups of factors, the environmental-related factor Meshing Around (F6) has the highest ri-ci value (0.235). This means the F6 significantly leads the HEB maintenance inside the SMEs. Furthermore, the organizational related factor Poorly written procedures, manuals, and work instructions (F17) has the next highest ri-ci value (0.161). It shows F17 as the most critical factor in the organization-related factors to lead the HEB maintenance inside the manufacturing plant of the SMEs. Likewise, all other cause group factors were rearranged and ranked based on the ri-ci values. Table 9 illustrates the ranked group of cause factors and highlights the five most critical factors that lead to HEB maintenance activities in the manufacturing plant of the SME.

Table 9(a): Ranked Cause Groups Highlighting the Influence of Human Error-Related Factors.

Code	Factors	Rank	Ri-Ci
F2	Working Shift	8	0.031
F3	Working Mode	12	0.013
F4	Design of Man-Machine Interface	9	0.027
F6	Messing Around	1	0.235

Table 9(b): Ranked Cause Groups Highlighting the Influence of Human Error-Related Factors.

Code	Factors	Rank	Ri-Ci
F7	Fatigue	11	0.018
F8	Speed Working	7	0.031
F10	Routine or Repetitive Work.	10	0.025
F11	Poor Communication and Sparse Feedback	4	0.064
F13	Emotional Stress	6	0.039
F15	Team Collaboration on Quality	13	0.004
F17	Poorly Written Procedures, Manuals, and Work Instructions	2	0.161
F20	Insufficient Training	14	0.004
F23	Blame, Punishment, and Liability	5	0.060
F24	Flaws in Decision Making	3	0.143

5.2 Effect Factors

Among all the HEB maintenance-related factors following list of factors, F1, F5, F9, F12, F14, F16, F18, F19, F21, F22, and F25, consist of the negative value of the ri-ci. Based on the cause-and-effect diagram, all these factors were grouped into the effect criteria. According to the actual ri-ci value ranked all the factors were ranked and illustrated in Table 10. The organizational-related factor stages of source management (F21) obtained the least negative ri-ci value (-0.027) in this effect factor group due to F21 being considered as the most critical factor among all these effect group factors. Furthermore, the factor Work design/Planning/Layout (F18) consists of the next least ri-ci value (-0.048). Likewise, all other effect groups of factors have been ranked based on the ri-ci values and ranked and the five critical effect group factors leading to the HEB maintenance activities in the manufacturing plant of the SMEs.

Table 10: Ranked Effect Groups Highlighting the Influence of Human Error-Related Factors.

Code	Factors	Rank	Ri-Ci
F1	Working Environment	6	-0.069
F5	Disregarding Safety	4	-0.051
F9	Equipment design and construction deficiencies	7	-0.087
F12	Multitasking	11	-0.156
F14	Level of Manpower	5	-0.055
F16	Time constraint in production	9	-0.100
F18	Work design/planning/layout	2	-0.048
F19	Poor management and supervision	10	-0.124
F21	Stages of source management	1	-0.027
F22	Level of Training and Experience	8	-0.089
F25	Complexity in the production process	3	-0.049

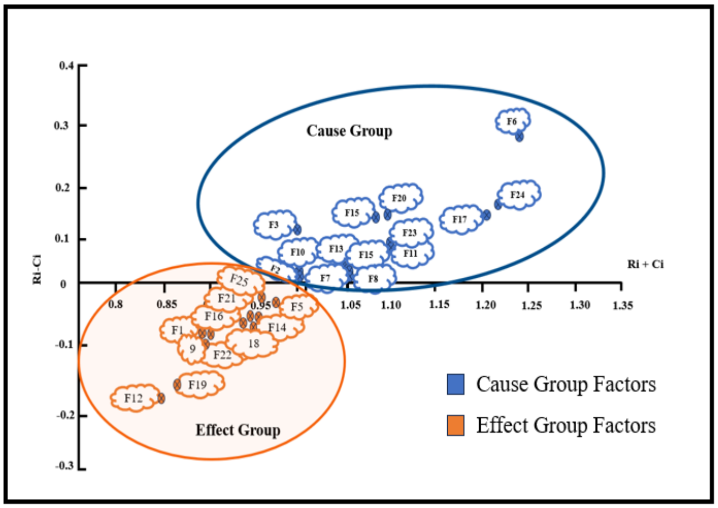

Figure 4: Cause and Effect Diagram

5.3 Implementation & Preventive Measures

As a result of this empirical real-time case study research, identify the maximum critical factors influencing the Human Error-Based maintenance activities in the manufacturing plant of the SME. In order to eliminate the HEB maintenance activities, we initiated this case research and, through this outcome implementation, optimized the maintenance management system in the SMEs. Accordingly, the optimal decision-making process for maintenance management is. The most critical factors in the cause group figured out and planned the suitable task to minimize the HEB maintenance activities, because of that discussed detailed suggestions for reducing HEB maintenance activities. The design, developed and implementation of the preventive measures in the manufacturing plant of the SMEs has been illustrated in the following Table 11. Based on this empirical case study, research outcomes implementations optimally reduced the HEB maintenance activities as well as the frequent Corrective Maintenance activities in the manufacturing plants in the SMEs

Table 11: Implementation of Preventive Measures

Critical Factors	Preventive Measure
F6	Avoid roaming around while doing the manufacturing operation, then minimize the HEB maintenance activities in the manufacturing plant of the SMEs. Through this case study results implementation, we design and develop a Man and Machine connectivity card through the application of the IoT kit. That connectivity card must be worn by the machine operator while running the machine and connect with the machine through the wired connection between the operator and the machine.
F12	Designed, developed, and implemented the new Standard Operating Procedure (SOP) in multiple languages for better understanding of the machine operator. Instruct the new operator before starting the machine must read the SOP and follow the mentioned industrial standards for the machine operations.
F24	Discussed with responsible team members and developed the standard flow process for the maintenance management system and implementation of the new model maintenance request flow process. Based on this implementation, the maintenance activities are classified, and decision-making is also classified based on the critical situation of the manufacturing plant.
F21	Based on the implementation of the standard maintenance flow process, streamline the resources like spare parts, tools, and other machine accessories purchase and maintenance material requests from the manufacturing plant. Suggest connecting the IoT-based smart inventory management system that will optimize the availability of resources based on the previous maintenance request data of the manufacturing plant in the SMEs
F18	Optimized the maintenance workforce through the input data of the smart maintenance request, availability of maintenance employees, and the resource availability in the inventory, through this defined flow process and planning of the preventive and corrective maintenance system, reduced the unexpected downtime and HEB maintenance activities in the SMEs.
F25	Based on the new model SOP and other manufacturing flow processes, eliminate the complexity in the manufacturing and testing environment in the SMEs. That will be allocated to the better level of manpower able to handle the complicity work in the manufacturing plant.

6. Conclusion

This presented empirical case study effectively finds out the significance of each influencing factor of the Human Error-Based maintenance activities and ranks the individual factors based on the closeness coefficient value, then clusters them into cause–and–effect groups. Based on the outcome of this real-time industrial empirical case analysis, twenty-five critical factors of human error-based maintenance management are evaluated for successful and optimal maintenance management system implementation in SMEs. In SMEs, top-level management people spend more money and attention on achieving the optimal maintenance management system in a phase-wise approach under the limitations of accessible resources. This empirical MCDM analysis is the first of its kind effort, according to the best of the author's knowledge, to classify the influencing human error factors in the maintenance management system into the cause–and–effect cluster. The result of this real-time empirical case study analysis makes the complexity of a problem easier for the optimal decision-making process in the maintenance management system of the SMEs. Through this outcome, the smart maintenance management system was developed with the help of the IoT architecture in the SMEs.

The outcome of this industrial case study research can be used by the decision makers, such as Production in charge, Production supervisor, Maintenance managers, Maintenance engineers, and maintenance employees in the SMEs to analyze, predict, and prevent the Human Error-Based maintenance activities in the manufacturing plant. This MCDM approach can be utilized to analyze optimal manufacturing flow processes in SMEs. The future research study focuses on the implementation of smart maintenance activities in the SMEs and different MCDM analyses to take preventive measures against the critical factors in the HEB maintenance activities in the SMEs. This real-time case study research only focuses on the Corrective Maintenance factors, but other types of maintenance can also be analyzed by utilizing this MCDM method.

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