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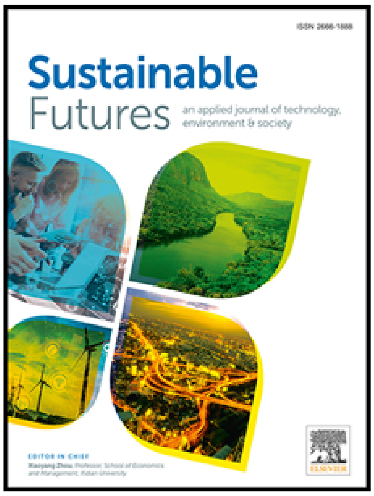

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Hybrid fuzzy AHP-TOPSIS framework on human error factor analysis: Implications to developing optimal maintenance management system in the SMEs

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Abstract

The full performance and involvement of employees in the manufacturing industry can increase the productivity and profitability of that particular industry. Simultaneously the probability of human error presenting the entire production system of specific operations such as Human Error Rate (HER) directly affects the efficiency of the production plant. Because it leads to maximizing the maintenance cost, downtime of the machine, and the service activities in the industry. In the Small and Medium-sized Enterprises (SMEs) significance of service and maintenance management systems has been increased due to the product demand, and customer necessity in the recent world. The optimal Decision Support System (DSS) for maintenance management acts as a vital role in maintaining better product quality, safety requirements, maximum availability, and the effectiveness of the machines in the industry. This research mainly focuses on proposing a consistent, optimal decision support model for the best maintenance management systems by prioritizing the human error factors in the electronic switch and sensors manufacturing industry. The objective of this research is to identify the most critical factors and alternatives influencing the human error rate of SMEs. Through the application of hybrid Multi-Criteria Decision Analysis (MCDA) methods such as Fuzzy Analytic Hierarchy Process (AHP), and Techniques for Order Preference by Similarity to Ideal Solution (TOPSIS) approach. A real-time case study of SMEs demonstrates the effectiveness of this proposed decision-making framework. The outcome of this research unveiled that the alternative job process and working mode (organizational and environmental factors) was a maximum influence on the human error factors that need the utmost attention among all others. To organize the optimal maintenance strategy and maximum productivity in the sensor and electronic switch manufacturing plant of SMEs in the southern region of Tamil Nadu, India.

Keywords

Human error rate, Small and medium-sized enterprises, Optimal decision support system, Maintenance management system, and Hybrid fuzzy AHP-TOPSIS technique

Introduction

The optimal maintenance management system is the most significant activity of all the industries because that directly depends on the entire plant product quality, productivity, and profit of the manufacturing industry. During this industrial revolution (Industry 4.0) maximum OEM manufacturing companies are developed their working environment in smart and autonomous. But SMEs are facing lots of hurdles to achieving that smart manufacturing environment. Particularly most SMEs still follow the traditional maintenance activities because of some critical factors such as knowledge, investment, and awareness of the latest revolution in the maintenance field. The objective of this research is to estimate the human error rate and analyze the individual human error factor for predicting the most significant factors and criteria of the human error rate. Through this identification of the critical factors influencing the repeated or maximum maintenance activities in the SMEs, to develop and initiate the new training process with the optimal scheduling and planning of the maintenance management system in the SMEs. Through this smart and optimal maintenance management system green manufacturing, green supplier selection, and supply chain management activities of the SMEs were also initiated. SMEs are very essential for the dynamics and healthy global economy of the manufacturing industries. Maximum and a greater number of employment opportunities are provided by SMEs and their sister concern or support large scale Industries. Due to the revolution of industry, the application of the advancement of technology, science, and variations in global manufacturing environments is considered the most important category. In this competitive world, process control, risk, and safety requirements are considered to be the most important factor in all manufacturing industries to achieve zero deficiency and zero accidents. The maintenance management system in the industry has dedicated its entire operations to this ideal purpose. In the early days these maintenance processes were generally classified into three main functions (Design out maintenance, Preventive Maintenance, and Breakdown Maintenance) one of which was to achieve the above achievements in the industry with preventive maintenance procedures [44,45,46]. Due to the growing industrial revolution, this preventive maintenance process was further divided into better maintenance measures, and it was named as Predictive maintenance process. These two operations were considered to be almost identical because the two processes were used to detect the failure of production machines and tools before they were repaired but these two have very small differences. In the Preventive maintenance process, defined time interval maintenance activities are carried out on the specified machine and its equipment is monitored and then adjusted before failure. But in the Predictive maintenance process, the machine and its pieces of equipment are constantly monitored and predicted the failure before it occurs based on real-time status. But the performance of an industrial maintenance management system depends on the human error rate, and human error factors, and these factors include the following key functions: high productivity, profitability, customers, and product quality. The human error rate prediction and isolation of the error factor are the most important problems in the smooth operation and maintenance management system of every manufacturing industry. The maximum and unexpected maintenance and service action has been initiated by the human error in the SMEs. Due to that this research has been organized to analyze the various factors influencing the human error rate of the SMEs to overcome the criticality in the maintenance and service actions in the SMEs. This MCDA technique is widely used in various sectors for predicting and ranking the factors to classify the factors and criteria based on the outcome results. The selection of the factors, criteria, and the right decision-makers for this hybrid factor analysis. The data collection was carried out only concerning the experience of the decision-makers. The greater number of decision-makers involved in the data collection leads to a complex situation in the data validation process. The additional analysis method is also needed for the cross-validation of the outcomes. These are some limitations. In this research article, we select a small and medium scale factory located in the southern region of Tamil Nadu in India.

To analyze the trend of human error prevailing, the influence of human error factors in the production plant, and propose the optimal decision support to identify the consequences in advance Human error operating in the industry is classified into five main categories: rule violation, knowledge-based mistake, risk-based mistake, lapse, and slips [6]. We have developed some alternatives to human error factors in two different situations (Environmental and Organizational). By listening to the subjectivities of various industry experts on how these human errors dominate the maintenance management system in the industry. Finally, we analyze that concept through a Fuzzy TOPSIS approach and identify the most important factor that dominates maintenance operations in the industry.

This research manuscript has been organized into six sections as follows. The present section is introductory types and methods of maintenance management systems in the recent revolution of the industry. Section 2 dealt with the overviews of numerous research articles and literature, research gap, and problem descriptions. Section 3 illustrated the details of the proposed methodology, and mathematical algorithm steps of this research analysis. Section 4 demonstrates a case study of the real-time industrial problems. Section 5 dealt with the numerical and graphical results of the fuzzy AHP & TOPSIS analysis. Section 6 explained the discussions of the research analysis through the tables and graphs. Finally, section 7 describes the conclusion, decision-making, and future scope of this research analysis.

Review of literature

This section of the research article briefly describes the results, applications, challenges, technologies, and mathematical models of various research published last decade in tending to detect human errors. In particular, the results of research that analyzes the diverse issues in the industry with the MCDA techniques are also briefly reviewed.

Comparison of the Group Decision Making (GDM) model Intuitionistic Fuzzy Analytic Hierarchy Process (IF-AHP) and Intuitionistic Fuzzy Technique for Order Preference by Similarity to Ideal Solution (IF-TOPSIS) to the partner selection of the Product Development (PD) was described. This combined theoretical GDM framework to propose better decision support to the PD partner selection problem in the industry [1]. Demonstrate the challenges in the Rank Reversal TOPSIS method by the literature overview of the existing research articles to find out the research gap in the TOPSIS decision-making technique [2]. Sensitivity analysis of service qualities in urban metro transportation is described with the application of the hybrid soft computing approach based on SERVQUAL and fuzzy TOP-SIS. An application of this proposed hybrid sensitivity analysis technique to identify the best service and quality based on the influence of alternative weights on the GDM process in metro transportation in Montreal [3].

The new version of the TOPSIS decision-making technique is demonstrated for the best GDM process of multiple attributes and alternative problems. These proposed approaches resolve the challenge in the Rank Reversal TOPSIS method and implement the new TOPSIS sorting technique to solve the boundary profile problems around the 180 countries in the world [4]. Different research directions of the hesitant fuzzy linguistic term set (HFLTS) have been described. To develop the Multiple Alternatives Decision Making (MADM) method of distance and similarity measure problems with the real-time practical applications of the Sichuan liquor brand assessment in China [5].

Evaluation of the set of suppliers based on conventional and environmental alternatives has been discussed. The proposed integrated MCDA approach used for evaluating the supplier selection problems in the industry is based on the utilization of three different techniques integrated fuzzy Analytical Hierarchy Process (AHP) with the other techniques namely MABAC ("Multi-Attributive Border Approximation Area Comparison"), WASPS ("Weighted Aggregated

Sum-Product Assessment") and TOPSIS. This method will provide better decision support for the green supplier selection process of a real-time case study in the automobile industry [6, 7]

Sustainable performance evaluation of the supply chain management in the agri-food industry has been demonstrated based on the supplier's performance analysis. The proposed model implements the fuzzy decision support (Triangular Fuzzy Number (TFN), AHP, and TOPPIS) for the better green supply chain management with the Triple Bottom Line (TBL) alternatives conditions in the agro-food value chain [8]. Service and quality evaluation of the major restaurants of the University of Palermo has been discussed based on the new model Multi Alternatives Decision Analysis (MCDA) approaches integrated with the DINESERV model along with the hierarchical TOPSIS method [9]. Proposed the optimal procedure of the flexible mass customization with minimum makespan time to organize the flexible schedules that meet the customer requirements and satisfaction in the mass customized order of the original equipment manufacturer product [10]. Described the new optimal model for the supplier evaluation and selection process in the industry through the application of the integrated decision model for evaluating and ranking the suppliers by combining the fuzzy analytical hierarchy process (FAHP) and grey relational analysis (GRA) [11].

Storage Location Assignment Problem (SLAP) of transport and logistic problems has been discussed. The efficiency of the transport system directly depends on the SLAP. In this research applied the combined MCDA approaches TOPSIS is utilized to determine their optimal storage location and ELECTRE TRI is used to assign products to shelf levels based on these two approaches solved the SLAP and improve the efficiency of the transport and logistic activity in the industry [12]. Supply chain management and risk factors in the distribution activity have been explained with the utilization of the hybrid MCDA with a multi-objective program technique. This research proposes the optimal design of resilient and green supply chain management by the application of the multi-objective MCDA approaches [13].

Investigate the factors related to medical tourism in the developed country Malaysia. They have applied the new model MCDA techniques (Decision Making Trial and Evaluation Laboratory (DEMATEL) and Fuzzy TOPSIS), to reveal the interrelation of the medical tourism factors and provide better decision making for the medical tourism plan [14]. Risk-based preventive maintenance planning in the roll milling company has been discussed. This research analyzes the various risk factors of the maintenance by the utilization of the new model MCDA technique (R TOPSIS) to implement the optimal maintenance planning and maximize the availability of the machines in the roll milling company [15]

Supply chain factors (product design, assembly process, and suppliers of the components) in three-dimensional concurrent engineering have been determined. This research applied the integrated approach (Multi-objective Linear Programming, Fuzzy Analytic Hierarchy Process (FAHP), and Fuzzy TOPSIS) to implement better decision-making in the supply chain management system in the industry [16,17,18,19]. Green supply chain management and reverse logistic practices in the industry have been discussed. They utilized the Fuzzy AHP and TOPSIS approach to prioritize the numerous logistics barriers. Based on this decision-making result implement a new model and increase the efficiency logistic system of the electronic industry in Thailand and the steel company [20, 21, 22].

Multiple Attribute Group Decision Making (MAGDM) approach and comparison of the other methods (VIKOR) have been determined hence this re-search analysis develops the integrated new model MAGDM technique for solving the multiple attribute problems in the industry [23]. The Pythagorean Fuzzy TOPSIS method has been discussed for solving the problems in unconventional emergency events. In this research, they have utilized the Covering-based Pythagorean Fuzzy Rough Set (CPFRS) models to investigate the uncertain degree of the problems and effectively handle the complex data in the existing practical examples [24].

[25] described the Value Stream Mapping and its implementation to achieve the minimum lead time in the inventory of the steel industry. Through the utilization of the Non-Value-added activities of the regular flow process in the steel industry. Presented the occupational risk and safety implementation in the mining industry. Through the application of the improved matrix method to analyze the real-time risk assessment [26]. The estimation of proper participants in the Knowledge-Intensive Crowdsourcing (KI-C) process has been discussed. The task of the participant's KIC has been analyzed through the application of the combined Fuzzy DEMETAL, 2-tuple linguistic method, and Fuzzy TOPSIS approaches for developing the decision-making support of suitable, effective, and easy ways to an estimate the participant's KIC by the ranking activity [27]. Estimation of Human Error Rate (HER) in the mining industry has been discussed by the application of the Fuzzy Rough Set Theory and the relational mapping method. The result of this research is to identify the most critical factor that influences the higher HER in the mining operation based on the fuzzy-based relational mapping region solutions [28, 29,30,31]. The sustainable vehicle routing problems have been analyzed with the utilization of the TOPSIS approach. Based on that research outcome the optimal and sustainable route has been identified for a better experience in vehicle transportation [32,33,34]. The optimal logistics and transport in manufacturing have been illustrated, In this research, the reverse logistic barriers and factors have been analyzed through the hybrid MCDM approach to predict the optimal decision making of the supplier selection and the logistic operation [35,36,37,38]. Measuring the effectiveness of the human workforce in the gas power plant has been dealt with through the application of the hybrid MCDM techniques concerning the environmental risk assessment factors in the plant [39]. The human error factor and maintenance factors were also analyzed by the Fuzzy TOPSIS and Fuzzy AHP techniques for producing sustainable manufacturing in the industry. Through the outcome, the sustainable manufacturing affecting maintenance factors has been identified and the accuracy function was also measured for the optimal manufacturing process [40,41,42].

Research Gap

From the reviews of previous research, and articles works it seems that various MCDA techniques are being used effectively to evaluate human error factors. They are also widely used in the mining industry, ship and aircraft construction industries, etc. It has been identified from a previous research article that no such human error research has been reported in the small and medium-scale manufacturing industry. To fill the research gap of specific research articles from this. This research article aims to pursue research by projecting a small and medium-scale manufacturing industry in the Southern region of Tamilnadu in India. Furthermore, this study analyzed a real-time case study in the SMEs using the integrated MCDA technique of the fuzzy AHP-TOPSIS approach.

Problem description

Manufacturing plants face a lot of challenges to meet customer demand, product quality, and demand for manufactured goods. We aim to explore the service and maintenance challenges that operate in terms of human error rate in one of the small and medium scale manufacturing industries located in the southern region of Tamil Nadu, India. Maintenance operations caused by human errors play a major role in the selected small and medium manufacturing industry. Most of the extensive service and maintenance operations here were largely due to human error. As a result, the production machine and all of its tools have to be repaired by human errors and replaced with new ones before it can complete its full lifespan. Such indefinite maintenance processes greatly increase the maintenance costs of the industry as well as the productivity due to sudden mechanical malfunction and the efficiency of the team overseeing the maintenance operations. The following reasons behind this research most SMEs are spending more investment and facing lots of challenges in the maintenance management activities for the better and smooth manufacturing operation of the working environment. In that situation, the human error rate directly depends on that inappropriate maintenance management system. The research paper is based on this shortcoming. All the maintenance activities so far in the small and medium scale manufacturing factories taken up in it have been visited and consulted directly with the concerned maintenance professionals and industry officials. The main purpose of this research is to analyze the concepts of maintenance operations caused by human error stated by industry experts with innovative mathematical equations and to classify the factors for human error based on its results. Thereby maintenance professionals are advised of the optimal process for correcting classified human error factors. The results of this research are proposed to reduce indefinite maintenance operations caused by human errors, such as a sudden mechanical breakdown. The objective of this research analysis is to introduce an optimal decision-making framework that minimizes the impact of human errors, maintenance costs, etc., and is fully explained in the following sections.

Methodology

In this research, two stages of the methodology have been utilized for developing the optimal decision support of maintenance management systems in SMEs such as a) collecting the subjectivity of the industrial experts (Decision makers), and b) prioritizing and ranking the human error factors alternatives based on the closeness coefficient values. The initial stage visits the SMEs and investigates the real-time problems based on the human error factor. Through the direct interview process industrial experts manually collects their opinions by the Q/A survey method. In this stage select the suitable group of decision makers for choosing and validating the factors, and criteria of the maintenance activities by the human error in the SMEs. This direct interview process met the various level of industry experts like Plant In charge, Production manager, Production head, Manufacturing supervisor, Maintenance Engineer, Maintenance Manager, and Maintenance head of the SMEs. For that data collection process, more than a hundred decision-makers are selected. All the selected decision-makers are linked through the online survey mode like a google derive survey techniques. They are all responding to the factors and criteria influencing the human error in the manufacturing plant by their desire. After collecting the decision maker's opinions of the factors influencing the human error rate have been aggregated through the weight function of the individual factors of this analysis. The data were collected by the more than ten years of experienced decision makers due to the better result of the outcomes. The next and final stage utilized the extended and hybrid MCDA approach such as the Fuzzy AHP-TOPSIS method for prioritizing and ranking the human error factors alternatives, in particular, SMEs in the southern region of Tamilnadu in India. **(Figure 2)** shows the proposed hybrid fuzzy AHP-TOPSIS approach framework to analyze the HER in the SMEs. These proposed fuzzy AHP-TOPSIS analyses can be obtained by the application of the algorithm steps, mathematical Eq. 1 to Eq. 23. The initial step of this proposed approach is to collect the subjectivity of the human error factors influenced by the maximum maintenance cost function in SMEs. The group of decision-makers (Production Manager, Production In Charge, Quality In Charge, Maintenance Manager, and Maintenance Engineer) subjectivities is collected through the direct interview process in the electronic switch and sensor manufacturing SMEs. Based on the collected data (subjectivities) we further investigate the human error factors that influenced the maintenance management system in the SMEs with the application of the integrated MCDA technique such as the Fuzzy AHP-TOPSIS approach. The demonstration of the proposed decision support model is presented in the upcoming sections of this research article.

Weight calculation of the human error factors

In this research, initially, we have applied the fuzzy AHP techniques to evaluate the weight function of the individual factors considered as the human error in the shop floor area.

Step 1: Measure the fuzzy synthetic extent values in the ith alternatives of human error in the shop floor area of the manufacturing industry.

$$S_i = \sum_{j=1}^{n} a_{ij} \times \left[\sum_{i=1}^{n} \times \sum_{j=1}^{n} a_{ij}\right]^{-1} \quad (1)$$

The addition of the individual fuzzy number values of the ith alternative is given below

$$\sum_{j=1}^{n} a_{ij} = A_1 + A_2 = (l_1 m_1 u_1) + (l_2 m_2 u_2) \quad (2)$$

The inverse vector of the ith alternatives as shown below

$$\left[\sum_{i=1}^{n} \times \sum_{j=1}^{n} a_{ij}\right]^{-1} = (l_1 m_1 u_1)^{-1} = \frac{1}{l_1}, \frac{1}{m_1}, \frac{1}{u_1} \quad (3)$$

Where

Si is synthetic extent values of the ith alternatives

Ai is an alternative.

li is lower fuzzy number values

ui is upper fuzzy number values

mi is medium fuzzy number values

Step 2: Generate the fuzzified pairwise comparison matrix of human error factor alternatives

$$A^k = \begin{bmatrix} d_{11^k} & d_{12^k} & d_{1n^k} \\ d_{21^k} & d_{22^k} & d_{2n^k} \\ N_{m1^k} & N_{m2^k} & N_{mn^k} \end{bmatrix} \quad (4)$$

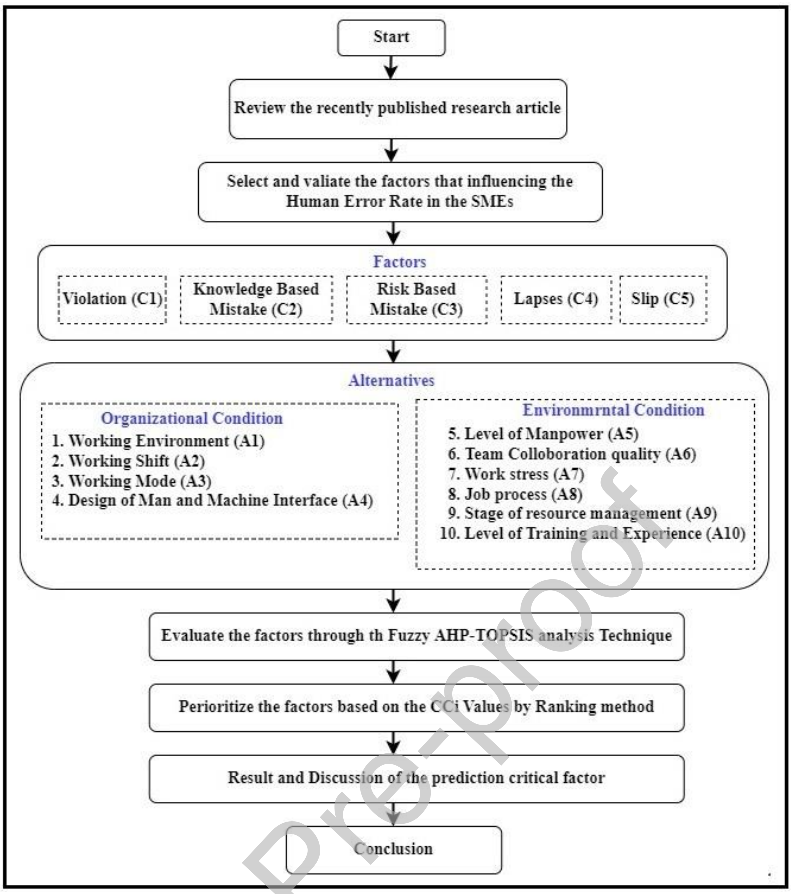

Figure 1: Research methodology of the human error rate analysis of the SMEs.

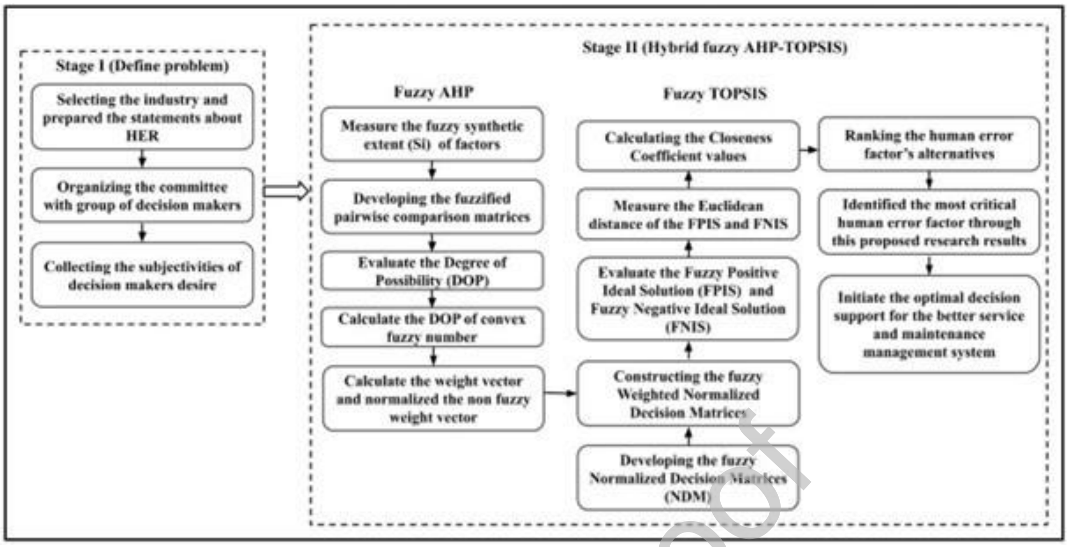

Figure 2: Proposed hybrid Fuzzy AHP-TOPSIS approach framework of the HER analysis in the SMEs.

Step 3: Identify the degree of possibility of respective alternatives in the human error factor analysis.

$$M_1 = (l_1 m_1 u_1)\ \&\ M_2 = (l_2 m_2 u_2) \quad (5)$$

$$V(M_1 \geq M_2) = Sup\left[Min\left(\mu_{m2}(x), \mu_{m2}(y)\right)\right] = hgt(M_1 \cap M_2) = \mu_{m2}(d) \quad (6)$$

$$V(M_1 \geq M_2) = hgt(M_1 \cap M_2) = \mu_{m2}(d) = \begin{cases} 1, \ if & M_1 \geq M_2 \\ 0, \ if & l_1 \geq u_2 \\ Others, & \left[\frac{(l_1 - u_2)}{(m_2 - u_2) - (m_1 - l_1)}\right] \end{cases} \quad (7)$$

Step 4: Calculate the degree of possibility for a convex fuzzy number to be greater than the k convex fuzzy number.

$$V(S \geq S_1, S_2, S_3, \dots \dots \dots S_K) = Min\ V(S \geq S_i) \quad (8)$$

Step 5: Measured the weight vector and normalized the non-fuzzy weight vector of the human error factor in the shop floor area through the application of the given equations.

$$d(A_1) = MinV(S_i \geq S_k) \quad (9)$$

$$W' = [d(A_1), d(A_2), d(A_3) \dots \dots d(A_n)]^T \quad (10)$$

Human error factor analysis

Then applied the Fuzzy TOPSIS analysis techniques for revealing the significance of the human error factors alternatives. And predicting the most critical alternatives in the human error factors of the SMEs. The utilized approach is explained in this section. The MCDA techniques are widely used in industrial DSS to solve the critical problems in the day-to-day life of the manufacturing industries. As the MCDA techniques, the Fuzzy TOPSIS approach is best to predict the optimal results under the uncertainty condition through the industrial expert's subjectivity. The step-by-step procedures of this applied approach are illustrated as follows for the HER decision support problems with m criteria, n alternatives, and k decision-makers (k=1, 2, 3, 4, and 5) [14, 43]

Step 6: Develop the Decision Matrix (DM) and fuzzy Normalized Decision Matrices (NDM) of the HER alternatives and criteria (Aij and Nij) by the utilization of the given equations.

$$DM = \begin{bmatrix} A_{11} & A_{12} & A_{1n} \\ A_{21} & A_{22} & A_{2n} \\ . & . & . \\ . & . & . \\ A_{m1} & A_{m2} & A_{mn} \end{bmatrix} \tag{13}$$

To calculate the normalized decision matrices a shown in below

$$N_{ij} = \frac{A_{ij}}{\sqrt{\sum_{J=1}^{n} A_{ij}^{2}}} \tag{14}$$

$$NDM = \begin{bmatrix} N_{11} & N_{12} & N_{1n} \\ N_{21} & N_{22} & N_{2n} \\ . & . & . \\ . & . & . \\ N_{m1} & N_{m2} & N_{mn} \end{bmatrix} \tag{15}$$

Where,

Nij – Normalized decision matrices of alternatives and criteria

DM – Decision Matrices

FWNDM – Fuzzy Weighted Normalized Decision Matrices

Step 7: Construct the Fuzzy Weighted NDM of the criteria and alternatives (N*ij) in the HER problems through the given equations.

$$FWNDM = \begin{bmatrix} N^*_{11} & N^*_{12} & N^*_{1n} \\ N^*_{21} & N^*_{22} & N^*_{2n} \\ . & . & . \\ . & . & . \\ N^*_{m1} & N^*_{m2} & N^*_{mn} \end{bmatrix} \tag{16}$$

$$N^*_{ij} = \left(W_{ij} \times N_{ij}\right) \; where, i = 1,2,3 \ldots m \; and \; J = 1,2,3, \ldots . n \tag{17}$$

Step 8: Determine the Fuzzy Positive Ideal Solution (FPIS) and Fuzzy Negative Ideal Solution (FNIS) of the given criteria and alternatives (Aj+ and Aj-) of the HER problems through the application of the given equations.

$$A_j^{+} = \begin{cases} Max \ldots\ldots N^{*}{}_{ij} \in B \\ Min \ldots\ldots N^{*}{}_{ij} \in C \end{cases} \quad (18)$$

$$A_j^{-} = \begin{cases} Min \ldots\ldots N^{*}{}_{ij} \in B \\ Max \ldots\ldots N^{*}{}_{ij} \in C \end{cases} \quad (19)$$

Where,

i =1,2,3,……m
j =1,2,3,…….n
B = Beneficial
C = Cost

Step 9: Measure the Euclidean distance of each alternative (Si+ and Si-) from the FPIS and FNIS through the application of the given equations

$$S_i^{+} = \sum_{j=1}^{n} d\left(N^{*}{}_{ij} \times A_j^{+}\right) \quad (20)$$

$$S_i^{-} = \sum_{j=1}^{n} d\left(N^{*}{}_{ij} \times A_j^{-}\right) \quad (21)$$

$$d(A,B) = \sqrt{\frac{1}{3}(a_l - b_l)^2 + (a_m - b_m)^2 + (a_u - b_u)^2} \quad (22)$$

Where,

Aj+ – FPIS of human error factors

Aj- – FNIS of human error factors

N*ij – Weighted normalized decision matrices

n – Numbers of alternatives and criteria

A, B – Alternatives

d – Distance between two alternatives

Step 10: Evaluate the Closeness Coefficient (CCi) of the HER alternatives through the utilization of the given equations and rank as per the descending order of the CCi values

$$CC_i = \frac{S_i^{-}}{S_i^{-} + S_i^{+}} \quad (23)$$

Where,

CCi – Closeness Coefficient of alternatives

Si+ – Euclidean distance of FPIS

Si- – Euclidean distance of FNIS

The above algorithms and equations are applied to the proposed fuzzy TOPSIS analysis for identifying the utmost care of alternatives in the human error factors of SMEs.

Case Study

This research investigates a real-time case study in the production plants of XYZ sensors and electronic switch manufacturing SMEs southern region of Tamilnadu in India. The opinions of industry experts on human error factors collected in this real-time industrial case study article are defined using the latest extended MCDA techniques [20]. In this study, two different mathematical models have been integrated and analyzed, for example, using the fuzzy AHP method to retrieve the weight function of the individual factors based on the opinions of the industrial experts and then integrating the fuzzy TOPSIS mathematical modeling for re-analyze the human error factors. This is because undefined human error factors increase maintenance costs and unnecessary production delays. The proposed conclusion of this study points out the factors of human error that need to be looked into as well as the ways to control it. All of these have been implemented directly in the selected small and medium scale manufacturing industry and their pros and cons have been verified. Here we organize the committee with a group of decision-makers such as the Production Manager, Production In Charge, Quality In Charge, Maintenance Manager, and Maintenance Engineer. To gather the (qualitative or quantitative) subjectivity, opinions of the worker performance, and human error factors in the two different situations. In this research, we initially consider the ten number (m=10) of alternatives from A1 to A10 with two different conditions are shown in **(Figure 1)**.and five criteria (n=5) such as Violation (C1), Knowledge-Based Mistake (KBMs) (C2), Rule-Based Mistake (RBMs) (C3), Lapses (C4), and Slips (C5). This HER analysis of the numerous alternatives is evaluated based on the qualitative subjectivities of the decision-makers with the utilization of the fuzzy linguistic variables. The proposed research methodology of this human error rate analysis is shown in **(Figure. 1)** The linguistic variables with the triangular fuzzy numbers are shown in **(Table 1)**. The graphical illustration of the membership function of linguistic variables is shown in **(Figure. 3).** The research analysis and numerical results and discussion are presented in the following sections.

Table 1: Linguistic variables and fuzzy rating of the human error factors alternatives

Importance (Y)	Fuzzy weight Values			Fuzzy rating (X) (l, m, u)
	Lower	Medium	Upper	
Extremely Low (EL)	0	0	0.1	(0,0,0.1)
Very Low (VL)	0	0.1	0.3	(0,0.1,0.3)
Low (L)	0.1	0.3	0.5	(0.1,0.3,0.5)
Medium (M)	0.3	0.5	0.7	(0.3,0.5,0.7)

High (H)	0.5	0.7	0.9	(0.5,0.7,0.9)
Very High (VH)	0.7	0.9	1	(0.7,0.9,1)
Extremely High (EH)	0.9	1	1	(0.9,1,1)

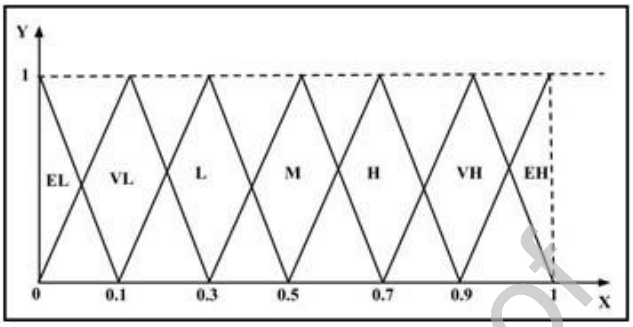

Figure 3: Membership function of Linguistic variables

Numerical Results

This research analyzes the human error factors of the production plant in the SMEs with the utilization of the integrated Fuzzy AHP- TOPSIS analysis techniques. Based on the standard steps and procedures collecting the decision-makers subjectivities of the human error factors in the industry. The subjectivity or opinion of the decision-makers is shown in **(Table 2)**. Then start the next steps in the Fuzzy AHP approach to measuring the fuzzy synthetic extend the value of the human error factors as shown in **(Table. 3)**. Then identified the weight function of the individual human error factors based on the standard steps of procedure Eq. 1 to Eq.10 and combined decision matrices (as shown in **Table. 4**) with concerned the different decision-makers subjectivities through the application of Eq. 16 to Eq. 17. After the alternatives of the human error factors, decision matrices are constructed then the normalized decision matrices of the given problems are developed through the application of Eq. 19. The results of the normalized decision matrices of the human error factors in the SMEs are shown in **(Table 5).** In the next steps in the proposed approaches after getting the normalized decision matrices of each alternative in the human error factors of the SMEs. The individual weight function of the different criteria is applied based on the decision maker's desire.

Table. 2: Subjectivity of decision-makers

Factors	Violation	RBM	KBM	Lapses	Slip
Violation (F1)	H	M	L	VL	VH
RBM (F2)	L	L	H	M	EH
KBM (F3)	H	VL	M	H	M
Lapses (F4)	L	M	EH	M	VL
Slip (F5)	EL	H	VH	H	L

Table. 3: Synthetic extent value of the humn error factors

Factors	F1	F2	F3	F4	F5	Si
F1	0.5,0.7,0.9	0.3,0.5,0.7	0.1,0.3,0.5	0,0.1,0.3	0.7,0.9,1	.093,.195,.386
F2	0.3,0.5,0.7	0.1,0.3,0.5	0.5,0.7,0.9	0.3,0.5,0.7	0.9,1,1	.111,.218,.409
F3	0.5,0.7,0.9	0,0.1,0.3	0.3,0.5,0.7	0.5,0.7,0.9	0.3,0.5,0.7	.093,.195,.397
F4	0.3,0.5,0.7	0.3,0.5,0.7	0.9,1,1	0.3,0.5,0.7	0,0.1,0.3	.093,.187,.363
F5	0,0,0.1	0.5,0.7,0.9	0.7,0.9,1	0.5,0.7,0.9	0.1,0.3,0.5	.105,.203,.386

Table. 4: Weight function of the human error factors

Factors	Fuzzy Si	Non-fuzzy Weight of factors
F1	0.093,0.195,0.386	0.254
F2	0.111,0.218,0.409	0.276
F3	0.093,0.195,0.397	0.256
F4	0.093,0.187,0.363	0.200
F5	0.105,0.203,0.386	0.261

This analysis collects the opinions on human error factor alternative weight values based on the benefits and cost function in the production plant of the SMEs. These fuzzy weight ratings are applied in the normalized decision matrices to develop the fuzzy weighted normalized decision matrices of each alternative in the human error factors of the SMEs. The fuzzy positive and negative ideal solutions of the different alternatives in the human error factors were also measured through the application of Eq. 18 to Eq. 22. The final solution of the weighted fuzzy normalized decision matrices is illustrated in **(Table 5)**. The Euclidean distance of each alternative of the human error factors in the production plant of the SMEs is calculated through the utilization of Eq. 20 to Eq. 22. The results are illustrated in **(Table 6)**.

Table 5: Fuzzy Weighted Normalized Decision Matrices of the human error factor alternative in the SMEs

	F1	F2	F3	F4	F5
A1	0,.072,.083	.029,.063,.085	.047,.103,.091	0,.055,.062	0,.089,.091
A2	.058,.093,.092	0,.048,.066	.047,.087,.091	0,.058,.069	0,.057,.082
A3	.714,.118,.083	.147,.111,.095	.142,.118,.091	0,.046,.062	0,.048,.064
A4	0,.072,.092	.088,.075,.095	0,.024,.045	.129,.096,.069	.180,.118,.091
A5	0,.089,.092	.147,.139,.095	.142,.112,.091	0,.026,.048	0,.016,.064
A6	0,.055,.084	.029,.063,.085	0,.060,.082	.077,.073,.069	.180,.109,.091
A7	0,.038,.064	.147,.111,.095	0,.051,.064	0,.038,.062	.060,.118,.091
A8	.174,.114,.092	.029,.045,.066	.142,.103,.091	.129,.093,.069	0,.064,.084
A9	0,.067,.064	0,.054,.085	0,.033,.064	0,.038,.048	0,.048,.064
A10	0,.033,.064	.029,.102,.095	0,.045,.082	.025,.064, 069	0,.086,.091
Aj+	.174,.118,.092	.147,.139,.095	.142,.118,.091	.129,.096,.069	.180,.118,.091
Aj-	0,.033,.064	0,.045,.066	0,.024,.045	0,.026,.048	0,.016,.064

Table 6: Euclidean distance of the human error factor alternatives in the SMEs

S – FPIS						
	C1	C2	C3	C4	C5	S+
A1	0.2948	0.1091	0.0237	0.1267	0.2036	0.7581
A2	0.1926	0.1388	0.0296	0.1245	0.2207	0.7064
A3	0.0209	0.0284	0	0.1331	0.2333	0.4159
A4	0.2940	0.0760	0.0878	0	0	0.4579
A5	0.2847	0	0.0040	0.1557	0.2603	0.7049
A6	0.3134	0.1091	0.0515	0.0551	0.0149	0.5442
A7	0.3294	0.0284	0.0634	0.1404	0.1324	0.6942
A8	0.0086	0.1297	0.0102	0.0032	0.2166	0.3685
A9	0.3035	0.1287	0.0726	0.1458	0.2333	0.8842
A10	0.3338	0.0830	0.0596	0.1001	0.2048	0.7815
S – FNIS						
	C1	C2	C3	C4	C5	S-
A1	0.0886	0.0384	0.0748	0.0503	0.1268	0.3791
A2	0.1652	0.0031	0.0679	0.0615	0.0742	0.3722
A3	0.3305	0.1229	0.0878	0.0402	0.0497	0.6313
A4	0.1002	0.0762	0	0.1557	0.2603	0.5926
A5	0.1291	0.1410	0.0849	0	0	0.3551
A6	0.0433	0.0384	0.0479	0.1041	0.2515	0.4854
A7	0.0086	0.1229	0.0276	0.0322	0.1808	0.3723
A8	0.3294	0.0184	0.0807	0.1536	0.0830	0.6653
A9	0.0694	0.0294	0.0215	0.0161	0.0497	0.1862
A10	0	0.0755	0.0436	0.0724	0.1223	0.3140

Finally, after calculating the Euclidean distance of the human error factor alternative and criteria in the SMEs. Then measured the closeness coefficient of the human error factor alternative in the SMEs through the utilization of Eq. 23. Then prioritized the human error factor alternatives based on the closeness coefficient values in the descending order. From this hybrid MCDM approach outcomes, the most and least critical factors influencing the human error rate analysis have been identified through the positive, and negative closeness coefficient values. The prioritized alternatives of the human error factors in the SMEs are shown in **(Table 7)**. The percentage of closeness coefficient values of the individual alternatives of human error factors in the SMEs is shown in **(Figure. 4)**. That pictorial representation reveals the individual alternative CCi values concerning the percentage. Then differentiate the maximum percentage of CCi occurs in the Job process alternative (A8) of human error factors in the SMEs.

Table 7: Closeness Coefficient values of alternative in the human error factors

Alternatives	S+	S-	CCi	Rank
A1	0.4243557014	0.1706437696	0.2867965064	7
A2	0.4149882958	0.153250471	0.2696937977	8
A3	0.2134767771	0.3420330212	0.6157101499	2
A4	0.2565124294	0.2895243536	0.5302286634	3
A5	0.3118376568	0.2379253076	0.4327779844	4
A6	0.3165408098	0.2363239584	0.4274534606	5
A7	0.3712303026	0.1967966565	0.3464565429	6
A8	0.2094421112	0.3415507142	0.619882326	1
A9	0.4967672625	0.06854140432	0.1212459818	10
A10	0.4446542537	0.1380240779	0.2368786865	9

Discussion

This section consists of a detailed illustration of the discussion of the research outcome. The result and analysis of the different alternatives and criteria of the human error factors in the SMEs are revealed in the above section of this research article. The final solution of this analysis predicted the most critical human error factors alternatives in the production plant of the SMEs through the application of the proposed fuzzy TOPSIS approach with the ranking of the closeness coefficient values. The prioritized alternatives of the human error factors in the SMEs are illustrated in **(Table 8)**. The graphical representation of the ranked alternatives of human error factors in the SMEs is shown in **(Figure 5)**. This graphical representation shows the ranked alternatives based on their CCi values. The alternatives 8, 3, 4, 5, 6, and 7 achieve the top order in the ranking process. From this prioritization of human error factors alternatives to suggest the optimal decision support system for the service and maintenance management in the SMEs.

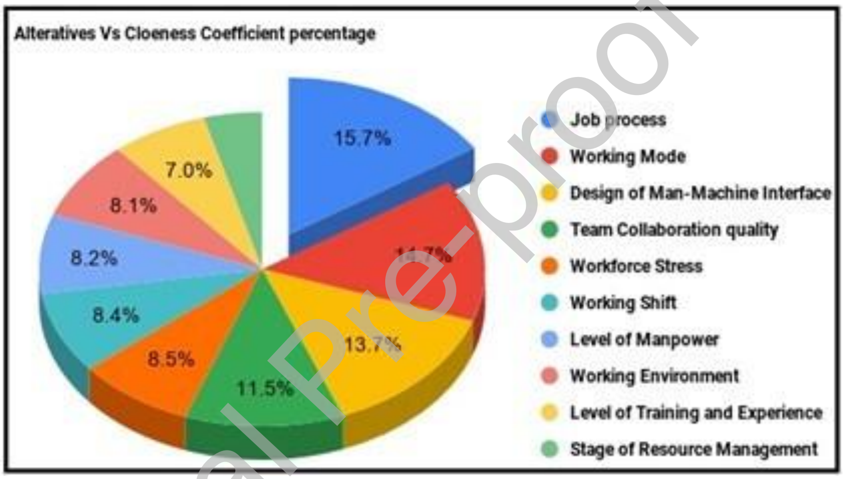

Figure 4: Percentage of Closeness Coefficient values in human error factors alternatives of the SMEs

Based on the outcome of this integrated factor analysis identified the most influencing factors of the human error factor in the working environment in the organizational condition Job process (A8) is the topmost concentrated alternative among all others in the production plant of the SMEs. So, we suggest the industrial expert committee classify the job process into three different categories as Hard, Medium, and Easy based on the utilization of the critical machines and product manufacturing process in the SMEs. Then prepare the work schedule of workers concerned with the working experience to minimize the production loss, sudden breakdown, service, and maintenance activities in the SMEs. In the environmental condition working mode (A3) and the design of the Man-Machine interface (A4) are the next most concentrated alternatives among all others in the production plant of the SMEs.

Table 8: Prioritized alternatives of the human error factors in the SMEs

Alternatives	Ranked Alternatives	Rank
A8	Job process	1
A3	Working Mode	2
A4	Design of Man-Machine Interface	3
A5	Level of Manpower	4
A6	Team Collaboration quality	5
A7	Workforce Stress	6
A1	Working Environment	7
A2	Working Shift	8
A10	Level of Training and Experience	9
A9	Stage of Resource Management	10

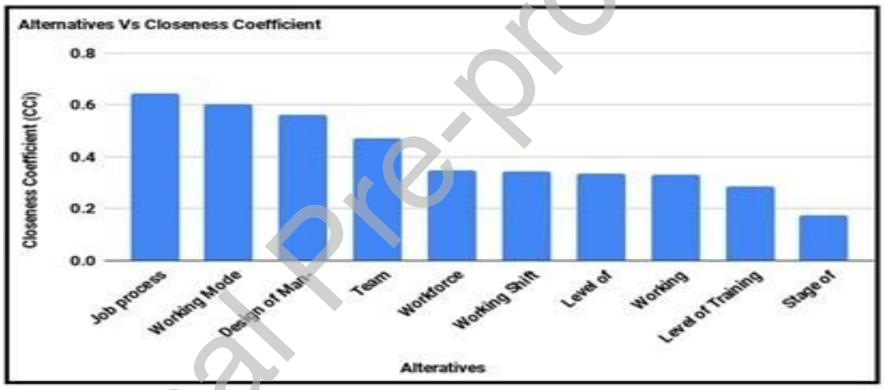

Figure 5: Closeness coefficient effect of the human error factors alternatives

So, we insist the industrial expert committee categorize the working mode in three sections (Manual, Semi-automated, and fully automated) based on the manufacturing process and the design of the Man-Machine interface in two sections (Appropriate, Inappropriate) based on the utilization of the machine in the production plant of the SMEs. Then generate the production planning and workload scheduling of the workers concerned with the knowledge, willpower, and educational qualifications for operating the failure-free production process in the SMEs.

Conclusion

This research analysis has been made for the implementation of the optimal decision support model for the better maintenance management systems of the SMEs in the southern region of Tamilnadu in India. This decision-making analysis includes the numerous human error factors and alternatives that were collected from the five different decision-makers (Production Manager, Production In Charge, Quality In Charge, Maintenance Manager, and Maintenance Engineer) in the electronic switch and sensor production plants of the SMEs. We utilized the extended and hybrid MCDA techniques such as hybrid Fuzzy AHP-TOPSIS analysis to achieve our aim of this research. The results of this analysis illustrate the most important human error factors that have most influenced and increased maintenance activities in SMEs according to their ranking. The application of this factor hybrid or integrated analysis approach in the human error rate analysis differs from the present state works. Because this primary research utilizes of recent revolution of industry (Industry 4.0) activities in the maintenance management system also differ from the previous research works. This modified ranking of each of the alternatives in human error factors (A8> A3> A4> A5> A6>A7…) guides the maintenance department employees and supports optimal decision-making for better service and maintenance management systems in SMEs. Based on the proposed decision-making process organize the smart machine for reducing the maximum human error throughout the job process in the industry. The maximum error achieved plant has been converted into the semi-digital or fully digital manufacturing process. Finally, the sensitivity and specificity investigation is suggested for future research to reveal the robustness of Fuzzy TOPSIS, Fuzzy AHP, and its results by varying the human error factor alternatives weights in different situations. In this research, only limited alternatives to organizational and environmental factors are investigated for the HER prediction in SMEs.

The future research direction of these studies may further investigate the more alternatives with the utilization of other MCDA techniques and integrated approaches such as Fuzzy ANP, Fuzzy DEMTAL, VIKOR, and combined Fuzzy ANP-TOPSIS, etc. The Predictive Maintenance management-related problems are also considered for identifying the criticality of the implementation of the industry 4.0 through the application of the various factor analysis techniques and comparing that result with the hybrid MCDM techniques.

Data Availability

The detailed input numerical data used in this Human error rate analysis of the real-time industrial case study are available from the corresponding author upon request. Since data were collected from the industry, it is used for research purposes only.

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Declaration of Competing Interest

The authors declare that there are no conflicts of interest regarding the publication of this research article

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