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AN INVESTIGATION INTO STEPS FOR CONDUCTING ELECTRICAL HAZARDS RISK ASSESSMENT IN NIGERIA CONSTRUCTION INDUSTRY

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Abstract: This research aims to uncover efficient strategies for reducing electrical hazard risks through a thorough analysis of the steps for conducting electrical hazards risk assessment in Nigeria's construction industry, ultimately contributing to safer and more environmentally friendly construction practices in Nigeria. An in–depth examination of the scientific literature was conducted prior to developing a survey questionnaire to collect data to determine the steps for conducting electrical hazards risk assessment, which was administered to construction professionals after expert review. Fuzzy synthetic evaluation (FSE) was used to analyze the received data. The result highlights several important considerations, given the crucial necessity of electrical hazards risk assessment in the construction sector, preparation, hazard identification, risk evaluation, control measures, documentation and communication, implementation and monitoring, and continuous improvement. Construction companies can improve safety outcomes, effectively mitigate risks, and cultivate a culture of safety excellence by prioritizing these steps. This research provides a novel contribution by systematically analyzing and prioritizing the essential steps for conducting electrical hazards risk assessment within the Nigerian construction industry, a context that has received limited attention in existing literature.
Keywords: Accident, Death, Fuzzy Synthetic Evaluation, Injury

1. INTRODUCTION

Nigeria's construction sector is vital to the country's development as it adds substantially to the country's infrastructure. Even so, the industry continues to face many obstacles, the most serious of which is the presence of electrical hazards on construction sites (Oni et al., 2022a). These sites are particularly vulnerable to electrical accidents due to the wide and varied use of electrical equipment, power tools, and wire systems, which poses dangers to project outcomes as well as workers (Adedipe et al., 2021). Globally, a multitude of studies have underscored the importance of electrical dangers in construction. For example, a study conducted by Gambatese et al. (2013) showed that electrical incidents account for a significant percentage of accidents in the construction industry, highlighting the critical need for efficient preventive measures. This research highlights how widespread electrical safety problems are in the construction industry and has global resonance.

It is essential to comprehend the unique issues associated with electrical dangers in the Nigerian setting, where construction activities are increasing. According to a study done in Nigeria by Olaniran and Akinbile (2023), electrical accidents are a major source of injuries in the construction sector. This is consistent with studies conducted in other developing nations, which highlight construction workers' shared susceptibility to electrical hazards. (Hinze et al., 2013). The intricacy of electrical safety on construction sites is further compounded by Nigeria's regulatory environment. Occupational health and safety rules are governed by laws; however, there are differences in the enforcement strategies and degrees of compliance. The necessity of more robust regulatory frameworks to reduce electrical dangers in the Nigerian construction industry was brought to light by Oyetunji et al. (2019). Beyond just causing immediate danger to employees, electrical accidents can have a negative impact on project budgets, schedules, and productivity levels. For those involved in the building sector to prioritize and fund adequate electrical safety measures, they must be aware of these consequences (Oni et al., 2022b).

Through a closer examination of the unique electrical risks encountered by Nigerian construction sites, this study seeks to advance the wealth of knowledge already in existence. This research aims to uncover efficient strategies for reducing electrical hazard risks through a thorough analysis of the steps for conducting electrical hazards risk assessment in Nigeria's construction industry, ultimately contributing to safer and more environmentally friendly construction practices in Nigeria. Comprehending these steps is crucial not just for ensuring the safety of laborers but also

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for cultivating a safety-conscious culture that advances the general prosperity and durability of construction projects in Nigeria.

2. LITERATURE REVIEW

The possible risks and dangers connected to electrical systems are referred to as electrical hazards. Risks include burns, electrocution, arc flash, electric shock, and other severe injuries that can result from these hazards. Extreme situations may potentially result in fires or explosions, endangering people's lives, property, and general well-being in the area (Oni et al., 2022b). Electrical dangers on building sites present a serious concern to Nigeria's construction industry. The nature, prevalence, and mitigation techniques of these dangers are clarified by the literature. According to studies, such as that conducted by Olaniran and Akinbile (2023), electrical mishaps are a leading cause of injuries in the Nigerian construction industry, which is consistent with worldwide trends. These mishaps have underlying causes, like inadequate supervision and training. which highlights the need for stronger safety procedures (Hinze et al., 2013). The regulatory environment is crucial, and Oyetunji et al. (2019) stress how important it is for Nigeria to have stronger regulatory frameworks. According to research by Gambatese et al. (2013), the effects of electrical mishaps go beyond concerns for human safety and affect project budgets and schedules. Safety management procedures, such as education and awareness campaigns, stand out as important components. Sufficient training provides construction workers with the necessary skills to recognize and control electrical hazards, which is in line with international initiatives to improve safety oversight (Akinlolu et al., 2020). Innovations in technology provide hopeful solutions. Electrical safety on construction sites may be improved by integrating smart safety devices with real-time monitoring systems (Gambatese et al., 2013). Behavior and culture have an impact on safety results. To lower electrical accidents, research from Nigeria and around the world emphasizes the need of developing a safety culture and encouraging good safety practices (Hinze et al., 2013).

Purohit et al. (2018) state that in order for an industry to succeed, it must be safe, dependable, and sustainable. This is achieved by detecting hazards and evaluating related risks in order to keep them at manageable levels. Hazard Identification and Risk Assessment (HIRA) is critical for identifying unwanted events, assessing their potential risks, and determining the extent and probability of negative consequences. The construction industry has the greatest prevalence of electrical injuries at work, according to Zhao et al. (2016), which calls for thorough risk management inside intricate sociotechnical systems (STS). The study analyzes construction-fatality records using a triangulation approach, identifying three common STSs, pointing out their flaws, and offering suggestions for improvement. According to Adekunle et al. (2016), electrical hazards in Nigeria's construction industry frequently result in electric shocks, fires, and electrocutions, with one worker dying from electrocution on average every day. Six out of ten construction gadgets were found to be unsafe, prompting the proposal of safety precautions to reduce the risk of accidents and fatalities. A multinational engineering, procurement, and construction company's ten-year history of safety occurrences involving both electrical and non-electrical workers is reviewed by Anderson et al. (2021), who also classify the accidents and provide mitigating measures. Additionally, it provides guidelines for minimizing occurrences and suggestions for better reporting. Rehman et al. (2022) use fuzzy multi-criteria decision-making techniques to identify important risk reduction strategies for Pakistan's electric power industry. Among the main concerns it identifies are lack of R&D, energy losses, antiquated infrastructure, circular loans, and corruption. The incorporation of IoT, fostering an investor-friendly environment, improving organizational coordination, and optimizing energy efficiency are among the preferred mitigating techniques.

Similarly, an observational checklist for assessing the risk of falls among high-voltage transmission tower construction workers was created and validated by Chang et al. (2018). After evaluating stability, mobility, and fall prevention strategies, it was discovered that position shifting presented the greatest fall risk because it involved frequent whole-body movements and little use of full-body harnesses. Using the fuzzy analytic hierarchy process (FAHP), Sadeghi-Yarandi et al. (2023) created a novel electrical industry safety risk index (EISRI) for the electricity power distribution industry. The personal component was found to be the most influential among the three components of the EISRI: personal, environmental, and organizational, after it was verified in three-stage Delphi research involving thirty experts. Gholizadeh and Esmaeili's (2015) study aims to improve specialist contractors' safety, performance by creating an attribute-based safety risk assessment tool, particularly for electrical work. A prediction model was produced by creating attribute-based safety risk models and using PCA and GLM to assess them using 323 accident records from the OSHA IMIS database. Khan (2024) looks at electrical safety in the construction sector, using surveys, qualitative insights, and literature reviews to pinpoint frequent risks, accident causes, and efficient preventative measures. The usefulness of the safety precautions in place today and the risk factors are highlighted by an analysis of data from 300 participants. Risk assessment for electrical hazards is essential to maintaining workplace and construction site safety. By recognizing possible electrical hazards, employees may be aware of the risks and take the appropriate safety measures. Preventing mishaps, injuries, and fatalities requires creating a safe working environment (Adedipe et al., 2021).

3. METHODOLOGY

The primary goal of this study is to identify effective strategies for minimizing electrical hazard risks by thoroughly analyzing the steps involved in conducting electrical hazards risk assessments within Nigeria's construction industry. To achieve this, a quantitative research approach was employed, beginning with a comprehensive review of scientific literature to determine the key steps for electrical hazards risk assessment. This was followed by the development of a survey questionnaire to gather data. The identified steps were subsequently categorized into seven distinct groups. To ensure the accuracy of the questionnaire's content, pre-testing was conducted with a group of seasoned researchers who understood questionnaire design in the area covered by the current study. Expert review is a useful pre-testing approach to identify problematic grammatical structures in survey questions and other possible measurement mistakes before questionnaires are disseminated, as recommended by Oni et al. (2024a). Since only a few expert reviewers are needed for validating a questionnaire, the questionnaire was assessed by fifteen expert reviewers with extensive academic and research backgrounds in related fields. All reviewers had to have a minimum of five years of research expertise. and hold an academic position at the university in order to reduce heterogeneity in the experts' background traits. The identities of the reviewers were kept secret from one another, and these specialists were instructed to conduct their evaluation independently. In the area provided on the survey form, reviewers were requested to rate each question and offer thorough written comments and any necessary revisions. Small changes were made. to the questions to improve their clarity in accordance with their feedback. For instance, some reviewers recommended combining some variables and deleting others that did not fit the study. The reviewers also recommended changing the measuring scale from a six-point to a five-point Likert scale because the latter has an obvious midpoint that makes it simple for respondents to express how much they agree with a question.

This particular research strategy was adopted with the intention of managing a large number of respondents, obtaining a wide range of replies from them, and improving the generality of the findings. To accomplish the study's aims, a cross-sectional method of surveying was employed to examine the subject matter. With this approach, investigators can characterize the opinions, beliefs, deeds, or characteristics of the broader public. A survey is performed on the whole populace or on a representative sample of people (Bryman, 2016). To collect the primary data, a convenient sampling procedure was utilized. The strategy is appropriate when there is not enough information obtainable regarding the entire populace and sample size. Even though the findings of the study have the potential to not be broadly applied, they may nevertheless provide a good picture of the larger population. "Following the central limit theorem (CLT), an average of 30 observations is enough for the purpose of statistical assessment (Darko et al., 2017; Chan and Adabre, 2019)," indicating that the 192 responses for this investigation are adequate.

A two-part, closed-ended questionnaire was constructed in order to gather data. Section A provides background information on the respondents, while Section B enumerates the steps for conducting electrical hazard risk assessment in the construction industry. Participants were provided with the opportunity to score their opinion on a Likert scale of one to five, where 5 represented very significant, 4 significant, 3 partially significant, 2 less significant, and 1 not significant. The questionnaire was distributed to professionals working in the construction industry in Nigeria. Nevertheless, after multiple notifications spread through an eight-month time frame, 192 filled-out questionnaires were collected by the due date. To analyze the gathered data, "the fuzzy synthetic evaluation technique (FSE)" was employed. FSE

FSE is an unbiased method of assessing data. that quantifies the language constituent of the information provided in order to support effectual policymaking (Nwaogu et al., 2021). FSE is a technique for assessing various choices that aids in dispelling uncertainty and misleading data regarding choices made by a number of participants (Oni et al., 2023). "Health administration (Oni et al., 2023)" and "construction risk management (Ameyaw and Chan, 2016; Zhao et al., 2016)" are two major fields that have adopted the FSE. Respondents' evaluations of the importance of different criteria are usually based on subjective perceptions (Owusu et al., 2019). FSE, however, can be applied to get rid of this subjectivity. FSE was employed in this research. to classify the important success criteria for sustainable health and safety practices in the construction industry since it is an objective tool for evaluating points of view. According to Oni et al. (2023), the following actions need to be taken in order to perform FSE in factor evaluation: "constructing the primary factors," "establishing an evaluation index structure," "figuring out the variables' membership grade (first level)," "computing the variables' weighing functions," "constructing the multi-criteria and multi-level FSE model," and "estimating the general significance indices of the factor constructs (FACs).".

4. DATA ANALYSIS

Respondent profile

According to the data presented in Figure I, it can be observed that the survey respondents encompass a diverse range of positions within the company. Site supervisors constitute the largest proportion, accounting for 30.2% of the respondents. Engineers represent 24.0% of the respondents, while project managers make up 6.3% of the sample. Additionally, architects comprise 15.1% of the respondents, quantity Surveyors also comprise 16.1%, and safety officers constitute 8.3% of the sample. These findings indicate that the respondents represent various key positions within the company's upper hierarchy, suggesting that they possess significant knowledge regarding skilled labor in the construction industry.

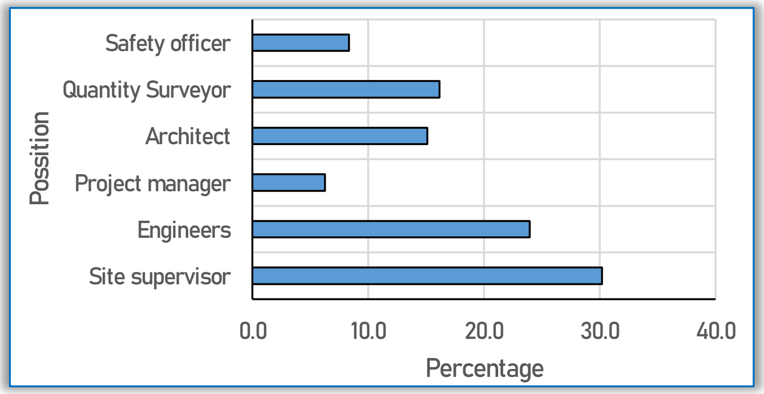

Figure I: Designation of respondents

Furthermore, it was found that 6.3% of the participants possessed over 20 years of professional experience. Additionally, 41.1% of the respondents reported having between 6 and 10 years of experience, while 18.2% of the respondents reported having between 11 and 15 years of experience, and 11.5% had between 16 and 20 years of experience. The figure also shows that only 22.9% indicated having between 1 to 5 years of experience in construction work. This substantial level of experience positions these individuals favorably to provide accurate responses to the survey questions, given their extensive knowledge and expertise in the field (see Figure II).

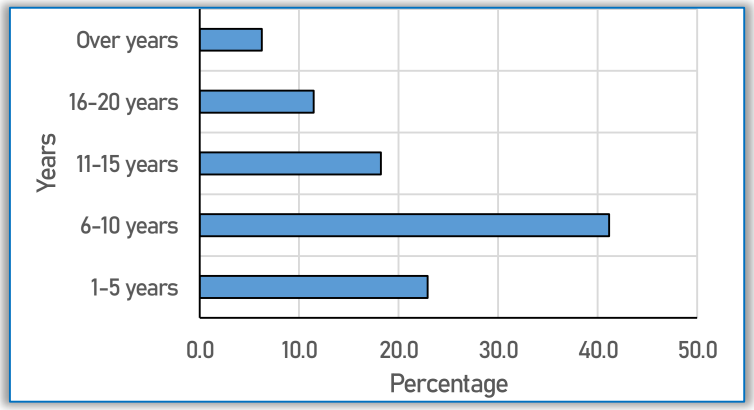

Figure II: Year of experience

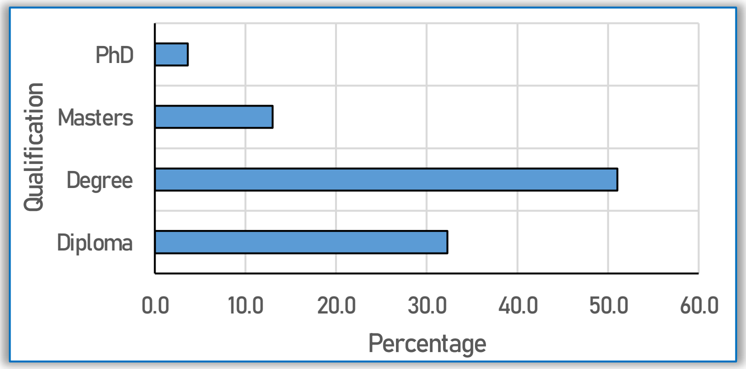

Figure III: Academic qualification

In a similar vein, it can be inferred that only 32.3% of the participants had diplomas while the remaining 67.7% had achieved an advanced educational attainment of degree and above. This finding further enhances the assurance that they possessed sufficient qualification to accurately respond to the survey inquiries (Figure III).

Fuzzy synthetic evaluation technique (FSE)

— Constructing the primary factors

The Cronbach Alpha value for the data was quite high. 0.935, and it was also greater than 0.90 for all the variables if an item was eliminated, validating a good reliability. Additionally, the data's validity is quite good because every variable is significant at a 99% confidence level.

The questionnaire was designed, and the 23 components were divided into seven constructs. Table I contains details about the factor constructs (FACs). Since the factors in the FSE have two primary purposes, they are categorized into constructs: (i) identify the input variables required to calculate the steps for conducting electrical hazards risk assessment and determine which factor constructions are most crucial to consider while making choices.

— Establishing an evaluation index structure

The FACs served as the first stage rating system, stated as vfac = (vFAC1, vFAC2, vFAC3, vFAC4, vFAC5, vFAC6, vFAC7) (Nwaogu et al., 2021, Oni et al., 2023). An assessment procedure was constructed in order to extract the index from the seven constructs. Every component of the second stage rating system is a factor (FA). The FSE's input variables are the first and second systems. The second level rating system is presented as follows: vFAC1 = (vPP1 – vPP3); vFAC2 = (vHI1 – vHI4); vFAC3 = (vRE1 – vRE3); vFAC4 = (vCM1 – vCM3); vFAC5 = (vDC1 – vDC3); vFAC6 = (vIM1 – vIM3); vFAC7 = (vCI1 – vCI3)

Table I. Mean score and Fuzzy Synthetic Evaluation Weightings of the Strategies

Code	Factors (FA) and their Factor Construct (FAC)	Meanof FA	Total mean of FAC	Weighing of FAs W_{FAi}	Weighing of FACs W_{FACi}
FAC1	**Preparation and Planning**				
PP1	Form a team with qualified personnel, including safety officers, electricians, and site supervisors.	4.00		0.34	
PP2	Determine the scope of the assessment, including specific areas, equipment, and activities to be evaluated.	3.95		0.33	
PP3	Gather relevant information (Site plans, electrical schematics, equipment manuals, and relevant safety regulations and standards).	3.97	11.92	0.33	0.13
FAC2	**Hazard Identification**				
HI1	Conduct a thorough inspection of the construction site to identify potential electrical hazards.	3.96		0.25	
HI2	Identify all electrical installations, including temporary power supplies, lighting, machinery, and tools.	3.94		0.25	
HI3	Look for exposed wires, damaged insulation, wet or damp conditions near electrical equipment, and improper grounding.	4.04		0.26	
HI4	Talk to site workers to gain insights into potential hazards they have observed.	3.93	15.87	0.25	0.17
FAC3	**Risk Evaluation**				
RE1	Determine how likely each identified hazard is to occur, considering factors such as frequency of exposure and condition of equipment.	3.98		0.33	
RE2	Assess the potential consequences of each hazard, such as electrical shock, burns, or fires.	4.02		0.34	
RE3	Rank the hazards based on their likelihood and severity to prioritize which risks need immediate attention.	3.95	11.95	0.33	0.13
FAC4	**Control Measures**				
CM1	Where possible, remove the source of the hazard. (Replace faulty equipment or eliminate unnecessary electrical installations).	3.98		0.25	
CM2	Implement physical changes to reduce risks, such as installing proper grounding, using insulated tools, and setting up barriers around live electrical parts.	3.95		0.25	
CM3	Develop safe work procedures, provide training on electrical safety, and establish a lockout/tagout program.	4.01		0.25	
CM4	Ensure workers use appropriate PPE	3.91	15.85	0.25	0.17
FAC5	**Documentation and Communication**				
DC1	Record the identified hazards, risk evaluations, and the control measures implemented.	4.20		0.35	
DC2	Create a comprehensive plan that includes all procedures, controls, and emergency response actions.	3.93		0.33	
DC3	Inform all site workers about the identified hazards and the safety measures in place.	3.97	12.10	0.33	0.13

FAC6	**Implementation and Monitoring**				
IM1	Put the identified control measures into practice, ensuring all necessary changes are made on–site.	3.88		0.32	
IM2	Regularly inspect the site to ensure control measures are effective and adhered to	4.22		0.35	
IM3	Establish a system for reporting electrical incidents and near–misses to continually improve safety practices.	3.95	12.05	0.33	0.13
FAC7	**Continuous Improvement**				
CI1	Periodically review the risk assessment process and update it based on new hazards, incidents, or changes in regulations.	4.15		0.35	
CI2	Gather feedback from workers and other stakeholders to identify areas for improvement.	3.94		0.33	
CI3	Continuously educate and train workers on electrical safety and the importance of adhering to safety protocols.	3.94	12.03	0.33	0.14

— **Figuring out the variables' membership grade FA and FAC (first level)**

According to fuzzy set theory, a component's extent of membership in a particular fuzzy set, denoted by a value ranging from 0 to 1, indicates the extent to which the component belongs to the fuzzy set (Owusu et al., 2019). In accordance with the participants' degree of concurrence with each component, a 5-point evaluation system ranging from not significant (1) to very significant (5) was used to define the linguistic word employed in assessing the input variables (i.e., factors) against their significance (Ameyaw and Chan, 2016; Owusu et al., 2019). S = (1,2,3,4,5) is the rating scale that is used to determine the criticality level according to the parameters. S1 stands for not significant, S2 for less significant, S3 for partially significant, S4 for significant, and S5 for very significant. Based on this rating system, the membership function (MF) of any particular FA, SF_{Ain}, is computed utilizing formula (1)below:

$$MF_{SFAin} = \frac{X1_{FAin}}{S1}, \frac{X2_{FAin}}{S2}, \frac{X3_{FAin}}{S3}, \frac{X4_{FAin}}{S4}, \frac{X5_{FAin}}{S5} \tag{1}$$

Whereby n stands for the nth factors of a certain FAC i (i = sFAC1, sFAC2, sFAC3, sFAC4, sFAC5, sFAC6, sFAC7); $X1_{FAin}/S1$ is expressed as a proportion, and Xj_{FAin} (j = 1,2,3,4,5). Following substitution, the membership function for any given FA will thus be written as given in Eq. (2):

$$MF_{SFAin} = X1_{FAin}, X2_{FAin}, X3_{FAin}, X4_{FAin}, X5_{FAin} \tag{2}$$

As mentioned before, MF_{SFAin} normally ranges between [0,1] and has to add up to one, which denotes unity.
Therefore:

$$\sum_{j=1}^{5} Xj_{FAin} = 1 \tag{3}$$

As a result, using PP1 as a stereotyped representation and entering it into Eq. (1) based on respondents' evaluations (i.e., 0.00%, 0.01%, 0.22%, 0.54%, 0.23%), we obtain:

$$MF_{pp1} = MF_{FAC1} = \frac{0.00}{\text{Not significant}}, \frac{0.01}{\text{Less significant}}, \frac{0.22}{\text{Partially significant}}, \frac{0.54}{\text{Significant}}, \frac{0.00}{\text{Very significant}} \tag{4}$$

Hence, the MF is expressed as MF_{SFAin} = (0.00, 0.01, 0.22, 0.54, 0.23) in the form of Eq. (3). The FAs for the remaining membership functions were calculated using the same procedure, as shown in Eqs. (2) and (3).

— **Computing the variables' weighing functions for the FAs and FACs**

The standardized mean method was employed to ascertain the relative weights of every factor in the component construct. Therefore, the individualized weighting of the FA and FAC was obtained using the formulae given in (Owusu et al., 2019):

$$\frac{M_i}{\sum_{i=1}^{5} M_i}, 0 < W_i < 1 \; and \sum_{i=1}^{n} W_i = 1 \tag{5}$$

where a factor's (FA) or factor construct's (FAC) weighting function is represented by W_i; A particular FA's or FAC's mean score, as determined by the respondents' answers, is represented by M_i. The weighting function set is provided as follows:

$$W_i = (W_1, W_2, W_3, \ldots\ldots\ldots W_n) \tag{6}$$

We view the mean score substitution in Eq. (5) as crucial, using PP1 as a template to show how to calculate the weightings of various components within a factor construct. Subsequently, Equation (5) is applied to derive Equation (7):

$$W_{pp1} = \frac{4.00}{4.00 + 3.95 + 3.97} = \frac{4.00}{11.92} = 0.34 \tag{7}$$

The weightings of the outstanding FAs inside individual FAC were gotten by utilizing the processes detailed in Eqs. (5) and (7) (refer to Table I), which can then be entered into Eq. (6) and verified to make sure that $\sum_{i=1}^{n} W_i = 1$

$$W_{FAC1} = (0.34, 0.33, 0.33)$$

$$\sum_{i=1}^{n} W_i = 1 = (0.34 + 0.33 + 0.33) = 1.00$$

Table II. Weightings and MF for the FAs and FACs based on Fuzzy Synthetic Evaluation

Code	Weighin gof FAs	Weighing of FACs	MF of each FA at level3	MF of each FACs at level 2	CL for FACs	MF of all FACs at level 1	Over allCL
FAC1		0.13		0.00, 0.01, 0.23, 0.55, 0.21	3.97	0.00, 0.01, 0.25, 0.54, 0.20	3.92
PP1	0.34		0.00, 0.01, 0.22, 0.54, 0.23				
PP2	0.33		0.00, 0.01, 0.25, 0.54, 0.21				
PP3	0.33		0.00, 0.02, 0.22, 0.56, 0.20				
FAC2		0.17		0.00, 0.01, 0.24, 0.56, 0.19	3.97		
HI1	0.25		0.00, 0.01, 0.23, 0.54, 0.21				
HI2	0.25		0.00, 0.00, 0.27, 0.53, 0.21				
HI3	0.26		0.01, 0.01, 0.25, 0.53, 0.20				
HI4	0.25		0.00, 0.01, 0.21, 0.61, 0.17				
FAC3		0.13		0.00, 0.00, 0.26, 0.55, 0.19	3.92		
RE1	0.33		0.00, 0.01, 0.28, 0.52, 0.20				
RE2	0.34		0.00, 0.01, 0.25, 0.56, 0.19				
RE3	0.33		0.00, 0.00, 0.25, 0.58, 0.18				
FAC4		0.17		0.00, 0.03, 0.24, 0.53, 0.20	3.92		
CM1	0.25		0.00, 0.03, 0.25, 0.50, 0.22				
CM2	0.25		0.00, 0.03, 0.23, 0.54, 0.20				
CM3	0.25		0.00, 0.02, 0.23, 0.56, 0.19				
CM4	0.25		0.00, 0.03, 0.25, 0.50, 0.22				
FAC5		0.13		0.00, 0.02, 0.26, 0.51, 0.21	3.94		
DC1	0.35		0.01, 0.01, 0.26, 0.53, 0.20				
DC2	0.33		0.00, 0.03, 0.25, 0.49, 0.23				
DC3	0.33		0.00, 0.01, 0.27, 0.51, 0.21				
FAC6		0.13		0.00, 0.01, 0.27, 0.52, 0.20	3.90		
IM1	0.32		0.00, 0.02, 0.26, 0.53, 0.20				
IM2	0.35		0.00, 0.02, 0.28, 0.49, 0.22				
IM3	0.33		0.00, 0.01, 0.27, 0.54, 0.18				
FAC7		0.14		0.00, 0.01, 0.27, 0.55, 0.17	3.92		
CI1	0.35		0.01, 0.01, 0.28, 0.52, 0.19				
CI2	0.33		0.00, 0.02, 0.25, 0.56, 0.17				
CI3	0.33		0.00, 0.01, 0.26, 0.56, 0.16				

FA = Factors; FAC = Factor Construct; MF = membership function; CL = criticality level.

Considering that 91.77 is the total of all FACs' mean values (vFAC1 = 11.92, vFAC2 = 15.87, vFAC3 = 11.95, vFAC4 = 15.85, vFAC5 = 12.10, vFAC6 = 12.05, and vFAC7 = 12.03) (see Table I). Thus, Eqs. (5) and (7) were used to normalize the mean of each FAC i.

$$W_{FAC1} = \frac{11.92}{11.92 + 15.87 + 11.95 + 15.85 + 12.10 + 12.05 + 12.03} = \frac{11.92}{91.77} = 0.13$$

To determine the weighting function of the remaining FACs (W_{FAC2} = 0.17, W_{FAC3} = 0.13, W_{FAC4} = 0.17, W_{FAC5} = 0.13, W_{FAC6} = 0.13, W_{FAC7} = 0.14), the same process was used (see Table I). Furthermore, the total of all normalized weights equals one. For instance, $0.13 + 0.17 + 0.13 + 0.17 + 0.13 + 0.13 + 0.14 = 1$

— **Constructing the multi-criteria and multi-level FSE model**

In order to assess the steps for conducting electrical hazards risk assessment in the construction sector, it is necessary to identify the FACs that are most important. following equation 2, the MFs of the FAs within individual FAC can be describe using Eq. (8), and the components are indicated by Xj_{FAin} :

$$K_i = \begin{vmatrix} MF_{Si1} \\ MF_{Si2} \\ MF_{PP2} \\ \dots\dots\dots \\ MF_{Sin} \end{vmatrix} = \begin{vmatrix} L1_{Si1} & L2_{Si1} & L3_{Si1} & L4_{Si1} & L5_{Si1} \\ L1_{Si2} & L2_{Si2} & L3_{Si2} & L4_{Si2} & L5_{Si2} \\ L1_{Si3} & L2_{Si3} & L3_{Si3} & L4_{Si3} & L5_{Si3} \\ \dots\dots & \dots\dots & \dots\dots & \dots\dots & \dots\dots \\ L1_{Sin} & L2_{Sin} & L3_{Sin} & L4_{Sin} & L5_{Sin} \end{vmatrix} \quad (8)$$

As an example, consider FAC1 in Table I. The elements are denoted in fuzzy matrix form as stated in Eq. (8), so we have:

$$K_i = \begin{vmatrix} MF_{PP1} \\ MF_{PP2} \\ MF_{PP3} \end{vmatrix} = \begin{vmatrix} 0.0 & 0.01 & 0.22 & 0.54 & 0.23 \\ 0.0 & 0.01 & 0.25 & 0.54 & 0.21 \\ 0.0 & 0.02 & 0.22 & 0.56 & 0.20 \end{vmatrix} \quad (9)$$

The FSE consists of three membership function phases that progress from the third to the first. Here, calculations are performed to get to stage 2 of the FSE model. The fuzzy matrix, represented by Ei, is produced through the multiplication of the weighting function set $W_i = \{W_1, W_2 \dots W_n\}$ (refer to Eq. 6) of the FAs inside a FAC by the MFs (derived utilising Eq. 9) of the FAs inside each FAC.

$$\text{So, } E_i = W_i * K_i \quad (10)$$

$$(ei_1, e_{i2}\dots, e_{in}) = (w_{i1}, w_{12}\dots, w_{in}) * \begin{vmatrix} MF_{Si1} \\ MF_{Si2} \\ MF_{Si3} \\ \dots\dots\dots \\ MF_{Sin} \end{vmatrix}$$

Equivalent to:

$$(ei_1, e_{i2}\dots, e_{in}) = (w_{i1}, w_{12}\dots, w_{in}) * \begin{vmatrix} L1_{Si1} & L2_{Si1} & L3_{Si1} & L4_{Si1} & L5_{Si1} \\ L1_{Si2} & L2_{Si2} & L3_{Si2} & L4_{Si2} & L5_{Si2} \\ L1_{Si3} & L2_{Si3} & L3_{Si3} & L4_{Si3} & L5_{Si3} \\ \dots\dots & \dots\dots & \dots\dots & \dots\dots & \dots\dots \\ L1_{Sin} & L2_{Sin} & L3_{Sin} & L4_{Sin} & L5_{Sin} \end{vmatrix}$$

$$= (ei_1, e_{i2}, e_{i3}, e_{i4}\dots, e_{in}) \quad (11)$$

where "*" denotes the fuzzy composition operation, si with respect to a given FAC i, and e_{in} stands for the grade alternative (Ameyaw and Chan, 2016). With reference to FAC1, we have:

$$E_{FAC1} = (0.34, 0.33, 0.33) * \begin{vmatrix} 0.0 & 0.01 & 0.22 & 0.54 & 0.23 \\ 0.0 & 0.01 & 0.25 & 0.54 & 0.21 \\ 0.0 & 0.02 & 0.22 & 0.56 & 0.20 \end{vmatrix}$$

$$= (0.00, 0.01, 0.23, 0.55, 0.21)$$

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The same process was applied to establish the MF of the other FACs at stage 2 (refer to Table II). The subsequent action is to calculate the criticality level (CL) of each FAC. The underlying equation (Eq. 12) is utilized to achieve that:

$$CL_i = \sum_i^5 = 1\ (E_{in} * S) = (ei_1,\ e_{i2}, e_{i3},\ e_{i4},\ e_5) * (1, 2, 3, 4, 5)\ (12).$$

where $1 \leq CL_i \leq 5$

Equation (11); is utilised to estimate the criticality level (CL) for all the FACs (refer to Table II). As an example, the CL of FAC1 to FAC3 is calculated as shown below.

$$CL_{FAC1} = (0.00, 0.01, 0.23, 0.55, 0.21) * (1, 2, 3, 4, 5) = ((0.00*1) + (0.01*2) + (0.23*3) + (0.55*4) + (0.21*5)) = 0.0 + 0.0 + 0.7 + 2.2 + 1.1 = 3.97$$

$$CL_{FAC2} = (0.00, 0.01, 0.24, 0.56, 0.19) * (1, 2, 3, 4, 5) = ((0.00*1) + (0.01*2) + (0.24*3) + (0.56*4) + (0.19*5)) = 0.0 + 0.0 + 0.7 + 2.2 + 1.0 = 3.97$$

$$CL_{FAC3} = (0.00, 0.00, 0.26, 0.55, 0.19) * (1, 2, 3, 4, 5) = ((0.00*1) + (0.00*2) + (0.26*3) + (0.55*4) + (0.19*5)) = 0.0 + 0.00 + 0.8 + 2.2 + 0.9 = 3.92$$

— **Estimating the general significance indices of the factor constructs**

The total criticality level of the FACs was determined using the weighted mean approach for three reasons:

≡ Taking into account that the parameter weightings and their constructs have been standardised, it possesses the highest limit of one.
≡ It also retains the efficacy effect of the factors and their constructs.
≡ Finally, it is commonly utilized in fuzzy multi-criteria choice-making assessment (Oni et al., 2023).

As per Nwaogu et al. (2021), the weighted mean technique is produced by utilizing the formulas given in Eq. 13:

$$e_{in} = \sum_{i=1}^{m} W_{in} X_{psin,}\ n = (1, 2, 3, \ldots\ldots.., p) \qquad (13)$$

From the resulting evaluation matrixes, the fuzzy matrix for $\overline{R_i}$ is built to evaluate the total criticality level of the steps for conducting electrical hazards risk assessment, E_i (i=1, 2, 3)

$$\overline{R_i} = \begin{vmatrix} E_{FAC1} \\ E_{FAC2} \\ E_{FAC3} \\ \ldots\ldots \\ E_{FAC7} \end{vmatrix} = \begin{vmatrix} FAC1_1 & FAC1_2 & FAC1_3 & FAC1_4 & FAC1_5 \\ FAC2_1 & FAC2_2 & FAC2_3 & FAC2_4 & FAC2_5 \\ FAC3_1 & FAC3_2 & FAC3_3 & FAC3_4 & FAC3_5 \\ \ldots\ldots & \ldots\ldots & \ldots\ldots & \ldots\ldots & \ldots\ldots \\ FAC7_1 & FAC7_2 & FAC7_3 & FAC7_4 & FAC7_5 \end{vmatrix} \qquad (14)$$

where, E_{FAC1} to E_{FAC7} denotes the MF of the FACs documented at the level 2 (refer to Table II). Then, $\overline{Ri}$ is standardized by means of Eq. (10,11) with the weighing function set of ($\overline{W}\{w_1, w_2, w_3\}$) for the FACs in order to accomplish the goal.

$$\overline{E} = \overline{W_i} * \overline{R_i}$$

$$(w_1, w_2, w_3, w_4, w_5, w_{6,} w_{7,}) * \begin{vmatrix} FAC1_1 & FAC1_2 & FAC1_3 & FAC1_4 & FAC1_5 \\ FAC2_1 & FAC2_2 & FAC2_3 & FAC2_4 & FAC2_5 \\ FAC3_1 & FAC3_2 & FAC3_3 & FAC3_4 & FAC3_5 \\ FAC4_1 & FAC4_2 & FAC4_3 & FAC4_4 & FAC4_5 \\ FAC5_1 & FAC5_2 & FAC5_3 & FAC5_4 & FAC5_5 \\ FAC6_1 & FAC6_2 & FAC6_3 & FAC6_4 & FAC6_5 \\ FAC7_1 & FAC7_2 & FAC7_3 & FAC7_4 & FAC7_5 \end{vmatrix} \qquad (15)$$

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$$(0.13, 0.17, 0.13, 0.17, 0.13, 0.13, 0.14) * \begin{vmatrix} 0.00 & 0.01 & 0.23 & 0.55 & 0.21 \\ 0.00 & 0.01 & 0.24 & 0.56 & 0.19 \\ 0.00 & 0.00 & 0.26 & 0.55 & 0.19 \\ 0.00 & 0.03 & 0.24 & 0.53 & 0.20 \\ 0.00 & 0.02 & 0.26 & 0.51 & 0.21 \\ 0.00 & 0.01 & 0.27 & 0.52 & 0.20 \\ 0.00 & 0.01 & 0.27 & 0.55 & 0.17 \end{vmatrix}$$

$$\overline{E} = (0.00, 0.01, 0.25, 0.54, 0.20)$$

Finally, Equation (16) below was utilized to ascertain the total criticality level of the steps for conducting electrical hazards risk assessment in the construction sector (refer to Tables II):

$$CL_{overall} = \sum_{i}^{5} = 1\ (E_{in} * S) = (ei_1,\ e_{i2,} e_{i3},\ e_{i4},\ e_5) * (1, 2, 3, 4, 5)” \quad (16).$$

where $1 \leq CL_i \leq 5$

$$CL_{overall} = (0.00, 0.01, 0.25, 0.54, 0.20) * (1, 2, 3, 4, 5)$$
$$CL_{overall} = (0.00*1 + 0.01*2 + 0.25*3 + 0.54*4 + 0.20*5)$$
$$CL_{overall} = 3.92$$

5. DISCUSSION

Preparation and Planning

Having a critical level of 3.97, conducting an electrical hazards risk assessment in construction operations requires careful planning and preparation. Determining the precise places and activities to evaluate, the types of electrical risks to consider, and the general objectives of the assessment, such as reducing the incidence of burns, electrical shock, and electrocution, are the first steps in the procedure. Putting together a capable assessment team is essential; it should consist of people with knowledge of electrical systems, safety procedures, and risk management. According to Oni et al. (2024b), a thorough examination requires professionals with experience who are knowledgeable about both the practicality of construction site operations and the technical aspects of electrical systems.

Another critical stage is to compile pertinent data about electrical systems, work procedures, and the building site. This includes reviewing electrical plans, maintenance logs, past incident reports, and legal requirements. Understanding current circumstances and prospective risks is aided by a comprehensive analysis of the paperwork (Oyetunji et al., 2019).

Hazard Identification

With a critical level of 3.97, hazard identification is a crucial phase in electrical hazards risk assessment for the construction industry. This procedure entails methodically locating potential electrical hazards that construction site personnel might come across. The objective is to identify and record all potential electrical hazards in order to create efficient control strategies and guarantee worker safety. A comprehensive inspection of the construction site is the first step in identifying potential hazards. This entails inspecting electrical systems, apparatus, and installations to find any circumstances that might present an electrical risk. Exposed live wires, overloaded circuits, broken insulation, malfunctioning electrical equipment, and insufficient grounding are common sources of electrical risks (Adedipe et al., 2021).

Engaging the workforce, which consists of workers, supervisors, and electricians, is crucial to this process in order to obtain information about potential hazards. Since workers are frequently the first to identify harmful circumstances or activities, their experiences and observations are invaluable. Interviews and safety meetings can be used to identify risks that inspectors may miss during an inspection (Oni et al., 2022a).

Risk Evaluation

Risk evaluation, with a critical threshold of 3.92, is an essential phase in the construction industry's electrical hazards risk assessment process. In this phase, the electrical dangers that have been detected are analyzed and prioritized according to the gravity of their possible outcomes and the probability that they will occur. The aim is to find the risks that need the most immediate attention and funding for mitigation. Assessing the possible impact of each hazard that has been identified is the first step in the risk appraisal process. This entails calculating how serious the effects might be if the hazard manifests. This could apply to electrical risks and involve possible harm, including burns, electrical shocks, and even fatalities. To help with priority, the severity is frequently divided into stages that range from small injuries to catastrophic occurrences (Oni et al., 2024b).

The possibility or probability of each hazard materializing at the same time needs to be assessed. This entails taking into account variables including how frequently the risk is encountered, how well the electrical equipment is maintained, and how successful the current safety precautions are. To aid in determining the total risk, the probability is usually categorized into levels, ranging from uncommon to frequent occurrences (Adekunle et al., 2018).

Control Measures

Having a 3.92 critical level, Control measures, which concentrate on putting strategies into place to lessen identified risks, are an essential part of completing electrical hazards risk assessment in the construction business. A safer working environment is ensured by effective control mechanisms, which lessen the possibility of electrical accidents and the consequences that go along with them. Engineering controls are one of the primary control strategies.

These are structural modifications to the workplace that reduce or eliminate the risk. Examples include installing ground fault circuit interrupters (GFCIs) and circuit breakers, properly insulating electrical cables, and keeping a safe distance between moist areas and electrical installations (Zhao et al., 2016). Because they can offer a long-term solution to the threats that have been recognized, engineering controls are thought to be very effective. Administrative controls are another crucial element. This entails modifying task execution to improve safety. This includes creating and implementing stringent safety procedures, holding frequent safety training sessions, and making sure there is adequate on-site supervision (Chang et al., 2018). During maintenance and repair work, lockout/tagout (LOTO) procedures are crucial control measures to prevent unintentional energization of electrical equipment.

Documentation and Communication

With a critical threshold of 3.94, documentation and communication are essential components of electrical hazards risk assessment in construction operations. All facets of the risk assessment process, such as recognized hazards, risk assessments, control strategies, and incident reports, must be methodically documented. Good documentation guarantees an exhaustive file for upcoming evaluations, audits, and ongoing development. By ensuring that all pertinent parties are informed about the dangers, safety procedures, and control measures, communication helps to promote a culture of safety. This entails scheduled safety meetings and training sessions, unambiguous directives and signage, channels for reporting and providing feedback, and established procedures for emergency communication.

In the construction sector, communication and documentation work together to promote a strong safety culture. They guarantee that all individuals are aware of the potential hazards and the steps taken to reduce them, which encourages a more proactive approach to safety management. By lowering the risk of accidents and the related downtime and expenses, this all-encompassing strategy not only improves worker safety but also boosts the general efficiency and productivity of construction projects (Oni et al., 2024a).

Implementation and Monitoring

hazard risk assessments in the construction industry require careful implementation and monitoring. By taking these precautions, workers are shielded from electrical threats and ensure that safety measures are correctly implemented and maintained. Putting the identified control measures into action is called implementation. This includes installing safety devices such as ground-fault circuit interrupters (GFCIs) and circuit breakers, as well as ensuring that all electrical installations comply with the necessary standards and laws. It also entails giving employees the appropriate personal protection equipment (PPE), such as boots and gloves with insulation, and making sure they receive training on how to use it properly (Oyetunji et al., 2019).

Monitoring is the continuous process of making sure that the safety precautions put in place are working and are being correctly observed. This entails conducting routine workplace audits and inspections to verify that safety laws and standards are being followed. Regular inspections of electrical systems and equipment should be part of monitoring in order to spot any wear, damage, or malfunction that might be dangerous. Safety management is continuously improved through efficient implementation and monitoring. The construction sector may greatly lower the risk of electrical hazards, protect workers, and enhance overall project safety and productivity by making sure control measures are applied correctly and routinely assessed (Akinlolu et al., 2020).

Continuous Improvement

In the construction sector, continuous improvement in electrical hazards risk assessment is a methodical strategy that aims to improve safety standards over time, with a critical threshold of 3.92. Establishing strong protocols for risk assessment, which include hazard identification, risk evaluation, and control measure implementation, is the first step in this process (Oni et al., 2022b). These procedures are regularly updated based on continuous safety performance metrics monitoring and assessment. Frontline employees, managers, and supervisors must all actively participate in the continuous improvement process for it to be implemented effectively at all organizational levels.

To identify areas for improvement and ensure adherence to safety standards and laws, routine safety audits, inspections, and reviews are required. Additionally, encouraging open lines of communication where employees can voice safety concerns and offer input on safety procedures is another way to cultivate a culture of continuous improvement (Oni et al., 2024b). Because of this feedback loop, safety procedures can be promptly modified in response to on-the-spot observations and practical field experience. Construction organizations may improve their overall safety performance, lower the risk of accidents and injuries, and provide a safer working environment for all workers involved in construction projects by placing a high priority on continual improvement in electrical hazards risk assessment. This proactive strategy not only reduces hazards but also encourages long-term resilience and success in the construction business through sustainable safety procedures.

6. RESEARCH IMPLICATION

This research has meaningful implications for various stakeholders in the construction industry, including practitioners, policymakers, and academia. By systematically analyzing the essential steps for conducting electrical hazards risk assessment in Nigeria, the study provides a robust framework to improve safety practices and reduce risks, with broader impacts on organizational performance and sustainability.

- For Industry Practitioners: The findings highlight critical steps such as preparation, hazard identification, risk evaluation, control measures, and continuous improvement. These steps serve as actionable strategies for construction companies to enhance safety outcomes.
- For Policymakers and Regulators: The study emphasizes the importance of incorporating these findings into regulatory frameworks. Policymakers can use the identified steps to develop or refine safety standards tailored to the Nigerian construction context.
- For Academic Research: The study fills a critical gap in the literature on electrical hazards risk assessment in developing countries, particularly Nigeria. It provides a foundational framework for future research.

7. CONCLUSION

The conclusion highlights a number of important considerations, given the crucial necessity of electrical hazards risk assessment in the construction sector. First and foremost, careful planning and preparation are essential to any successful risk assessment since they guarantee that all possible electrical dangers are recognized and thoroughly assessed. Followed by identifying potential hazards, which necessitates close attention to detail and adherence to safety regulations. The next step is risk evaluation, in which the possibility and seriousness of dangers are determined and used to prioritize control measures.

To effectively reduce hazards, it is imperative to implement strong control mechanisms, with a focus on engineering controls, administrative controls, and personal protective equipment. In order to guarantee that the results of risk assessments, control strategies, and safety procedures are precisely recorded and successfully shared with all parties involved, documentation and communication are essential. This encourages responsibility and raises knowledge of safety within the company. In addition, the implementation and monitoring processes entail putting the chosen control measures into action and regularly assessing their efficacy. This process guarantees continued adherence to safety regulations and permits timely modifications in response to changing circumstances or emerging risks.

A major theme that emerges is continuous improvement, highlighting the necessity of routinely reviewing and improving risk assessment processes and safety standards. Through ongoing improvements to electrical hazard mitigation measures informed by worker feedback and safety audits, this iterative process fosters a proactive safety culture. Overall, a methodical approach to risk assessment of electrical hazards in the construction sector is critical to worker safety and regulatory compliance. Construction companies can improve safety outcomes, effectively mitigate risks, and cultivate a culture of safety excellence by prioritizing the following steps: preparation, hazard identification, risk evaluation, control measures, documentation and communication, implementation and monitoring, and continuous improvement.

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