Analytical Investigation on Improving Safety Performance in Construction Sites

Mr Tejas Admane[1], Dr. Sachin Admane[2], Dr. Prashant Sudani[3]
[1]*School of Civil and Environmental Sciences, JSPM University Pune*
[2]*Director, JSPM Group of Institutions, Pune*
[3]*Assistant Professor, JSPM University Pune*

***Abstract*—Construction industries are known to be hazardous due to complex tasks, change of work location, climatic conditions and temporary organizational management. The consequences of these hazards may involve occupational diseases, injuries and fatality. Injuries and accident rates are high in a construction site when compared with other manufacturing industries. Safety is one of the key factors in construction sites to mitigate the severity of the risk. Assessing the performance of the site concerning safety is an important part of the management system as it provides information on the safety of the worker as well as the task. Hence the aim of this research is to investigate the site safety performance and propose a methodology for enhancement. This is done in basically four parts viz., quantification of risk involved in each task, accounting for unsafe supervision, selection of right worker for the right task and usage e.g., PPEs. Safety performance cannot be measured only with the accidents/injuries in the site but the factors which influence the unplanned events have to be highlighted while determining the performance rate. The factors include the task/conditions of the site. Risk involved in each task is quantified using Hazard Identification and Risk Assessment (HIRA) technique. The hazards in the sites are identified through direct observation and previous safety reports and the risk values are determined using likelihood and severity ratings of each hazard. It is known that the construction site has 13.3% of low risk, 37.7 % of medium risk, 44.4 % of high risk and 4.6 % of extreme risk. The relative percentage of risk involved in each task is calculated and it is found that crane operation (10.4%), height work (9.1%) and drilling (8.8%) are the three major tasks with high risk. It is observed that in the particular construction site the relative percentage of low risk is very less. Furthermore, it can be said that by task-based risk quantification the builders/owners may look for suitable or alternate control measures to reduce the risk level to as low as reasonably practicable. This will automatically improve the performance of the site.**

***Index Terms*—Construction Dust, Construction Noise, Personal Protective Equipment.**

I. INTRODUCTION

The construction business is the second largest in India, behind agriculture, because it provides so many jobs to Indians of all educational backgrounds. Because most of the growth is focused on industrialization, smart city construction, housing and urban development, highway Construction/widening, airport, railway, and so on, the construction industries in India account for 9% of the country's GDP. There is a higher percentage of temporary and unskilled workers on construction sites, and the work itself is inherently dangerous due to the presence of heavy equipment, spinning gear, moving vehicles, work at height, work in hot conditions, and a constantly shifting work environment [1,2]. Workers are also subjected to hazardous substances, biological agents, poor ergonomics, vibration, and noise. Consequently, safety in construction sites is an important aspect since it is linked to reducing the likelihood of health problems, injuries, and fatalities among workers. Outdated processes, human mistake, a lack of training programs, an error in safety management, and an unsuitable safety policy are the primary causes of construction risks [3]. Due to the inherently dangerous nature of the work, construction workers suffer three times as many fatalities and twice as many injuries as workers in other industries worldwide [4]. Deaths on construction sites typically result from falls from great heights or from being electrocuted [5]. It is a well-known fact that accidents and injuries related to construction operations are common on construction sites due to a lack of safety measures and worker ignorance [1]. According to Heinrich's Domino Theory, human error accounts for 88% of all accidents, while risky environments account for the remaining 12%. It is estimated that human error accounts for over 80% of all construction accidents [7,8]. This includes mistakes made not just by employees and supervisors but also by personnel at varying levels of the organization, which can have a negative impact on both quality and safety. Possible causes include insufficient training or familiarity with safe operating procedures [9,10], or a mismatch between the worker, supervisor, or engineer and the task. Since most accidents result from human error, it is possible to prevent accidents to a considerable degree if human elements (which include both good and negative characteristics of human nature including ability, age, competence, etc.) are adequately accounted for on a building site. Evaluation of safety performance is a vital aspect of any management system, as it reveals crucial data regarding the security of both employees and the premises [11].

Traditional techniques of measuring safety performance, such as recording rates of fatalities and injuries, have a significant limitation in that they can only be used after the fact [12,13]. Finding the underlying causes of accidents [14] and the behaviors that put people at risk [15] is essential for improving safety results.

The make-up of construction workers in nations like India varies by region, culture, and even personality type. One may also say that employees' actions vary from one another. Therefore, construction sites present unique challenges for safety management. The safety management system is largely influenced by unsafe situations and unsafe behaviors. Safe working conditions are provided when these factors are prioritized and specific safety measures are implemented. While the elimination, substitution, engineering controls, administrative controls, and personal protective equipment (PPE) in the hierarchy of controls can help reduce hazards on the job site, behavior-based safety, the study of how to influence people's actions to prevent accidents, is essential for reducing workplace accidents caused by workers themselves. Constant training and reminders in the form of toolbox discussions can help keep employees safe on the job. Workers can be educated about the dangers they face on the job site and hopefully adopt a more optimistic attitude as a result. Also, the number of accidents and injuries on building sites can be cut down to as little a number as possible. As a result, this paper zeroes in on the most important aspects that can boost construction site safety and proposes some fresh approaches to the problem.

A. Hazards and its Associated Risks

Falls from height, dropped objects, electrocution, cave-ins, and tripped over objects are typical dangers on construction sites. However, the degree to which these risks materialize depends on the precautions taken at the site. Construction presents a wide spectrum of potential dangers due to the wide variety of tasks and their inherent volatility.

1) Construction Dust

Direct sources can be broken down further into two categories: construction dust and demolition dust. Understanding where the dust on a building site comes from Expert interviews and a questionnaire survey were undertaken by Wu et al. [16]. Data collection has been bolstered by both on-site observation and case studies. Participants range from project managers to construction workers and inspectors of all stripes, including those responsible for site safety and environmental protection. Using a Likert scale from 1 (Strongly Disagree) to 5 (Strongly Agree), we can get the RCI (Strongly Agree). Based on data collected by the RCI, we know that excavation, backfilling, and land leveling are the top four activities contributing to dust on construction sites, while blasting and transportation are among the leading contributors of demolition debris.

Another study that quantified how much dust people were exposed to was conducted by Tjoe Nij et al. [17]. The laborers who did things like concrete drilling, asphalt cutting, laying natural stone floors, operating heavy machinery, laying terrazzo, and crushing pile tops. To conduct the research, we used a questionnaire survey and a method involving personnel air sampling using portable pumps. The results showed that the maximum concentration of respirable quartz was 0.075 mg/m3, which is 63 times higher than the legal limit. Working with concrete drilling results in significant exposure to silica dust, as documented by Fan et al. [18]. They used dust bubbles as a means of gauging exposure to silica dust and later used this information to lessen it. The dust barrier known as "dust bubbles" is ideal for use while drilling tiny holes. By contrasting how effectively workers drilled with and without dust bubbles, we were able to determine how effective the dust bubbles really were. Respirable dust samples were used to calculate exposure, and it was found that dust bubbles eliminated 63 percent of the dust particles. Long-term exposure to silica dust, as documented by Aggarwal [19], causes silicosis, which in turn can induce tuberculosis and,

eventually, lung cancer.

2) Construction Noise

Koushki et al. [20] conducted a questionnaire survey and measured the noise levels

in different parts of the building site to learn more about the workers' knowledge and perception of noise. The survey has received responses from 500 construction workers at 26 different sites. The decibel levels were measured from 5, 10, and 15 meters away from the noise generators. The impulsive noise reportedly reached up to 100 decibels, and the average noise level at 5 meters was roughly 85. Results from a questionnaire showed that 80% of workers don't use hearing protection, 56% of workers are "extremely upset" by construction noise, and 38% of people accepted that construction noise may cause permanent hearing loss. Negative effects on health in a questionnaire study done by Geetha and Ambika [21], 15% of respondents attributed the noise to heavy machinery, 55% attributed it to other significant equipment, and 30% attributed it to moving vehicles on the site.

B. Fall from Height

The majority of construction site injuries and fatalities can be traced back to falls [22]. Huang and Hinze [23] analyzed ten years' worth of accident data to determine that the majority of fall accidents happened at 30 feet in height. It was determined that there had been an increase in fall accidents by correlating the percentage of falls with the year they occurred. Falls from both higher and lower levels resulted in injuries in 34.6% of cases. According to the research of Kang [24], fall prevention measures may not be effective in preventing worker falls from low-rise rooftops unless they are physically constructed.

1) Electric Lines and Power Cables

The second most common cause of injury on construction sites was determined to be electrical mishaps. The significant number of fatalities can be attributed to the high severity rates of electric dangers [25]. Accidents involving electric contact are four times more common in construction than in any other industry, according to research by Chen and Fosbroke [26]. Roofers, painters, electricians, construction laborers, and carpenters make up 32% of the workforce that suffers electrical accidents, according to study by Cawley and Brenner [27]. Janicak

[28] investigated various case studies of electrocution accidents on construction sites and found key causes, including: 47.2% having contact with an overhead power line; 34.3% having contact with wire & transformers; and 12.4% having contact with electric current of machine & tools.

II. RELATED WORK

This paper goal is to point out the problems with the existing literature and to highlight the importance of the current investigation.

A. *Risk Assessment Techniques*

- In order to improve construction site safety, risk assessment is done to rank every potential danger and set priorities. Large numbers of near-misses and accidents occur because of the difficulty of the job and the employees' inattention to their surroundings. Each company must investigate the origins of each potential threat. As a result, it's important to regularly analyze risks, put preventative measures in place, and see how well they're working [29].
- According to Carter and Smith [30], the first need for assessing risk is the identification of potential threats associated with each task. The potential for accidents and incidents on the building site is increased by the fact that many of the hazards there are still unknown. In light of this, the Danger Identification Index (HII) is used for accurate hazard identification. The formula for determining HII is:

$$\boldsymbol{HII} = \sum_{i=1}^{n} \frac{EL_i}{AL_i} \quad (1)$$

• Where, AL = acceptable level, EL = Exposure Level, n

= number of components.

- Saedi et al. [31] used a technique called Hazard Identification and Risk Assessment to conduct a Risk Assessment (RA) at a hydroelectric power facility (HIRA). The physical, chemical, biological, ergonomic, and electrical are the five classes used to categorize the risks in this study. Ratings of probability and severity were used in the analysis, as described in Equation (2).

- R = L * S (2)
- where R denotes Risk, L indicates Probability, and S indicates Impact.
- Utilizing data from 615 modern incidents, Kraus [32] was able to calculate the risk. In this approach of hazard quantification, the probability ratings for each hazard are determined by the ratio of accident types to total accidents. Probability is calculated using the Equation (3).
- $s = \sum (Si - ni)\ n$ (3)
- The frequency of accidents of a certain kind (n), the frequency of accidents of a given severity (ni), and the frequency of incidents overall (si). Health risks and safety risks were identified by Al-Anbari et al. [33], and Risk Assessment of Safety and Health (RASH) was developed for the construction industry. Risk is measured using the formula given in Equation (4).
- (Ls + Lh) * (Cs + Ch) = R. (4)
- The likelihood of harm to safety and health, denoted by Ls and Lh, and the consequences of harm to safety and health, denoted by Cs and Ch.
- El - Sayegh [34] used a questionnaire survey to assess the dangers of the project. The building site's risks are assessed, and the questionnaire is developed accordingly.

- There are three questions for any risk: how likely it is,
- $RII = \sum WAX$ (5)
- where W is the response's importance, X is its frequency, and A is the greatest importance. CHRA was conducted by Husin et al. [35] in a biochemical and chemical research facility. For this reason, the original RA technique's emphasis on assessing the probability and severity of risks has been replaced with an emphasis on rating the exposure and volume of the chemicals present in these labs. The CHRA was determined using the Equation (6).

- $R = \sqrt{ER * HR}$ (6)
- In this equation, R represents risk, ER represents exposure, and HR represents hazard.

Fine Kinney is a quantitative risk assessment approach that mimics its forebear, the RA method. The technique incorporates the exposure factor and the potential outcome into the risk assessment, as illustrated in Equation (7). Possible outcomes may vary from 1 to 100, whereas probability values are between 0.1 and 10. This means that the risk score may be determined using the formula [1].

Risk Score = Probability of Dangerous Event x Exposure Factor x Potential Harm (7)

To identify and remove potential points of failure in a given work or endeavor, a Failure Mode and Effects Analysis (FMEA) was conducted. The Risk Priority Number (RPN) is determined by breaking down each task into manageable chunks and considering the likelihood of the risk occurring, its impact, and how easily it can be detected. From best case to worst scenario, these values may be anything from 1 to 10 [7]. The RPN is denoted by the formula: (8). The RPN formula is:

S + O + D (8)

To determine the causes of building delays, expert opinion on construction delays was gauged by a questionnaire survey. Technical consultants, procurement directors, engineers, managers, and directors from various technical departments, as well as site directors and project managers, make up this group of experts. There was a Likert scale employed, with points ranging from 1 (not at all important) to 5 (very important) (very high importance). also reported on the results of a study that used RII to analyze the causes and consequences of construction delays. Respondents in this case were hired help, advisory services, and end users. The values on the chosen 5-point Likert scale go from 1 (not important) to 5 (very important) (extremely important).

Since quality is a key issue in the building sector, used the Relative Importance Index to rank the quality elements in the Indian building sector. Respondents included building owners, design professionals, and construction workers, and the results were compiled using a five-point Likert scale (very high effect). The RII was calculated using Equations (9) and (10), which have been used in all prior research.

$$RII = \frac{\sum W}{AN} \quad (9)$$

how much of an effect it will have, and who will be responsible for dealing with it. The relative importance index (RII) was calculated with the help of Equation (5).

$\sum W = 1n_1 + 1n_2 + 1n_3 + 1n_4 + 1n_5 (10)$

W - Weightage given to each factor ranging from 1 to 5 A

- Highest Weight; N - Total number of samples. Safety concerns in the building industry were evaluated by Gunduz and Ahsan [6] using the Frequency Adjusted Importance Index (FAII). Safety features were broken down into various groups, including training and education, management, health, ownership, staff, the environment, and both internal and external factors. Ratings on the Likert scale may go as high as 5. (Very high). Based on the RII and the FI in the following equation, FAII may be calculated: (11). In order to derive RII and FI, a questionnaire survey is conducted in which respondents rate the significance and frequency of each element used in the equations (12), (13), and (14). (13).

FAII = RII x FI (11)

$$RII = \frac{\sum W}{AN} \ (importance)(12)$$

$$RII = \frac{\sum W}{AN} \ \text{(frequency)}(13)$$

B. Human Error Assessment Techniques

Incorrect safe operating procedures and unwelcome additional information received by the worker outside of the scope of the activity that must be completed within the specified time [9] are examples of human error. It has been discovered by the vast majority of researchers that 90% of accidents can be avoided if proper control measures are implemented by the site administration. In order to keep workers safe, it is necessary to investigate human factors [7], as these causes of accidents are always the result of carelessness on the part of the operator. The underlying idea of Human Error Assessment and Reduction Technique (HEART) is that there is always some chance of making a mistake when performing any given task. Numerous circumstances that lead to errors have an impact on it. For this reason, HEART is built with a variety of general activities and error-producing situations [1] to help pinpoint human mistake and find solutions to industrial issues. Human error probability can be calculated with this method, which has been found to be both a simple and effective approach [3]. Considering human elements is crucial to completing a job successfully. Ability, enthusiasm, rivalry, and loyalty are all part of the human nature that can either be a strength or a weakness [4]. Human error at liquefied petroleum gas filling stations was measured by Human error is measured using the HEART method, while linguistic variables are defined using fuzzy logic. There are four defined tasks, and six experts are polled for their opinions.

Human error at hydrogen fueling stations was evaluated using the HEART technique by Castiglia and Giardina [36]. Human mistake is recognized during maintenance and testing phases of a hydrogen refueling station because of the inherent dangers of doing so. As a complement to HEART, their proposed method makes use of fuzzy theory to increase the accuracy of expert judgments. Next, CREAM is used to evaluate the results. The proposed fuzzy HEART approach has been shown to be more effective.

Human mistake was discovered in a chemical plant's permit to work system by Jahangiri et al. [37]. The Human Risk Standard for Plant Analysis (SPAR-As a means of quantifying the potential for human error, the H) reliability analysis method was chosen. Within the study, two site workers, a shift supervisor, and a safety officer make up the four operators who are polled on a total of eleven different job classifications. There are a total of eight distinct Performance Shaping Factors (PSF) in SPAR-H, each of which is further subdivided into multiple levels. To calculate HEP for each task, we multiply the respondents' ratings of each PSF level by that level's evaluation multiplier.

III. PROPOSED RESEARCH METHODS

The overall research methodology which is adopted in this research is shown in Figure 1.

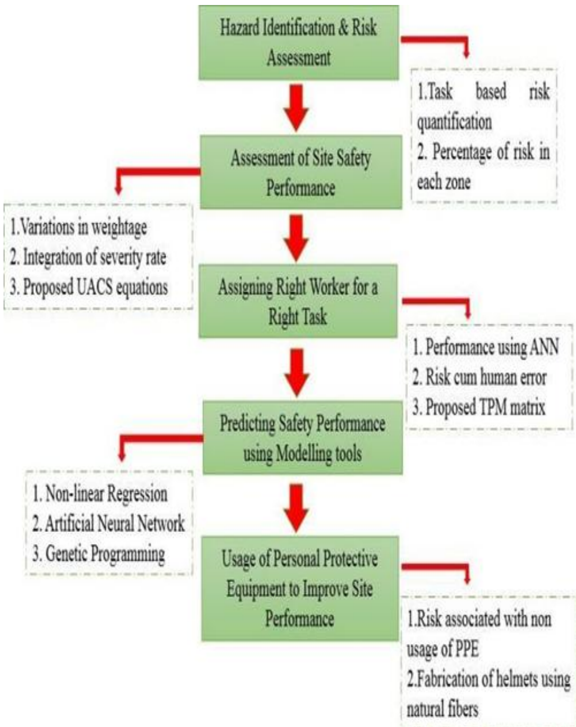

Figure 1: Proposed research methodology

A. Risk Quantification Procedure

Quantitative methods, like HIRA, are used to determine the level of danger associated with any endeavor. The process of risk quantification laid out in Figure 2.

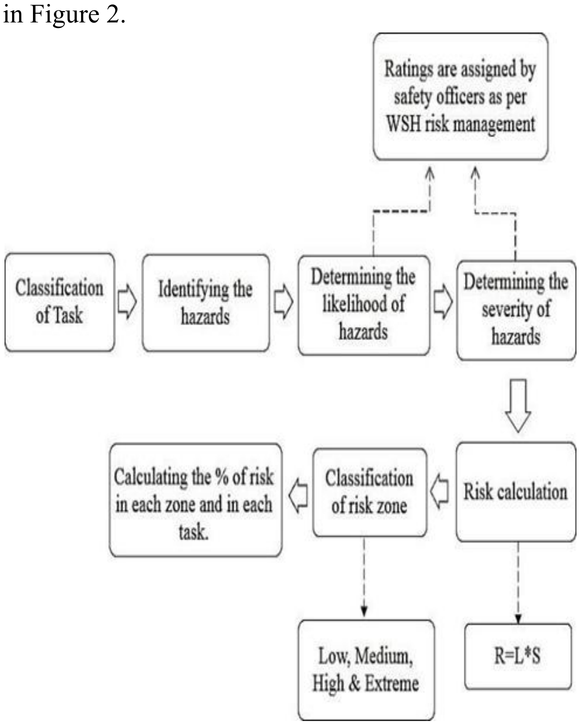

Figure 2: Procedure for risk quantification

Determining Likelihood & Severity Ratings: A site-based project manager verifies the senior safety engineer's comments and gives them more weight due to the engineer's extensive professional experience and educational background. As a result, the final grade is based on the senior safety engineer's evaluation. If there is a discrepancy of two or more stars between the team's ratings, the senior safety engineer should consult with the other members to determine the cause of the discrepancy, as described by Hola and Szóstak [38]. After gaining this new insight, the ratings will need to be reevaluated.

Risk Matrix and Score: By comparing the probability ratings to the severity ratings, a risk matrix may be utilized to represent the risk level. a risk number of 5 indicates a low danger level if the probability rating is 1 and the severity rating is 5. Dangerous tasks at a building site may be pinpointed using the different zones designated for them. Once the danger zone has been identified, it is recommended to implement the appropriate risk response.

B. Models using ANN, GP, and Non-Linear Regression

1) Conditions of the Model

(a) ANN: To predict Safety Performance (SP) using ANN, the inputs are given as, frequency of toolbox talk (I1), safety supervision (I2), safety training (I3), availability of PPE (I4), its usage (I5), type of accidents occurred (I6) and competence of the workers (I7). The functional form of the ANN model is shown in Equation (14).

$$SP = (I1, I2, I3, I4, I5, I6, I7) \quad (14)$$

In order to identify the versatile model, models are analyzed for their performance against four different conditions (C) such as checking the ability of the tool to extrapolate the validation set (C1), to predict the low performance in the validation set (C2), to predict the medium performance (C3) and to predict the performance of the mixed-up data (C4).

To develop an ANN model, the data set is separated into training, testing and validation sets. Model parameters such as the number of hidden neurons, learning rate, momentum rate and initial weights are chosen randomly and are refined on a trial-and-error basis. The effect on model accuracy due to changes in the hidden neurons is shown in Table 1. The performance of the model is measured based on 80%

exact matches with the actual and predicted output. From the results, it is known that the ANN models are not much effective in extrapolating the data but in the case of mixed- up data, it shows satisfactory results by predicting the number of data as fixed in the performance measure.

Table 1: Results of ANN

C	Data Sets	No. of data	No. of matches	%	Hidden neurons
C1	Training	10	9	100	8
	Testing	7	5	71	
	Validation	5	1	20	
C2	Training	10	9	90	7
	Testing	7	6	86	
	Validation	5	3	60	
C3	Training	10	9	90	7
	Testing	7	6	86	
	Validation	5	5	100	
C4	Training	10	9	90	7
	Testing	7	6	86	
	Validation	5	4	80	

2) Conditions of the Genetic Programming

The performance of the model is measured with 80% of the exact matches with the output performance. The data sets which are used for training, testing and validation are as shown in Table 2. GP run with an initial program size of 80 and maximum of 512, crossover rate of 50 and mutation rate of 95. The initial population size is set as 500, where it is increased to 1500 for C1 and 1000 for remaining conditions. The GP models are effective in predicting the output in all conditions as compared to ANN. It can be seen that in extrapolating GP performance beyond the training data set, GP showed 60% of the exact matches for C1 and 80% for all other conditions. It is seen that I5 appears in all equations which indicate the safety performance of the construction site depends on the accident history of the worker.

Table 2: Results of GP

C	Data Sets	No. of data	No. of matches	%	GP evolved equations
C1	Training	10	8	80	$SP = \frac{I5(0.18 - 0.1I4 + I4}{I1}$
	Testing	7	5	71	
	Validation	5	3	60	
C2	Training	10	8	80	$= \frac{I5\ L1(l-1)^{-\frac{1}{2}} + I4}{I6} + 0.66$
	Testing	7	7	100	
	Validation	5	4	80	
C3	Training	10	8	80	$SP = (I_5 I_1^{1/4} * I_4^{1/2})$
	Testing	7	5	71	
	Validation	5	5	100	
C4	Training	10	8	80	$SP=(I_6 I_4 (I_5+I_3) - I_0)^{1/4}$
	Testing	7	6	86	
	Validation	5	4	80	

3) Conditions of the Non-Linear Regression

The best fit NLR model for the data with the least error is identified from the following equations. The regression equation (15) is applicable for C1 whereas equation (16) is applicable for C2, C3 & C4. It can be seen from both the equations that I5, I6 and I7 i.e., PPE usage, type of accidents and competence of the workers have the major impacts and it denotes a vital role in determining the safety performance of the construction sites. However, the input impacts for other variables are merely equal. The overall exact matches for C1 are 60% and 50% for C2, C3 and C4.

$SP=-0.258+(0.027I1+0.004I2+0.123I3+0.085I4+0.283I5+0.238I6+0.297I7)$ (15)

$SP=-0.314+(0.090I1+0.107I2+0.011I3+0.026I4+0.274I5+0.285I6+0.314I7)$ (16)

IV. RESULTS AND DISCUSSIONS

A. Relative %Age of Risk in Each Zone

The risk in the construction site is assessed through HIRA and the risk zones are classified accordingly. The relative percentage of risk involved in the construction site with respect to the risk zone is calculated using Equation (13).

$$\%age\ of\ risk\ in\ each\ zone = \frac{No.of\ hazards\ in\ each\ zone}{Overall\ no.of\ hazards\ in\ each\ zone} \times 100 \quad (17)$$

Therefore, the number of hazards in each zone and the total number of hazards on-site must be determined in order to compute the relative percentage of risk in each zone. According to Figure 4, the proportion of high risk at this construction site is 44.4, which is greater than the percentages anticipated for other risk zones. It's also discovered that over half of all jobs fall into the "high-risk" category, with a relative risk of 49% falling into either the "high" or "extreme" danger zone. Therefore, it is important to calculate the proportion of high- and extreme-risk areas on building sites to alert owners and builders so that they may take the necessary precautions. For the site as a whole to have a lower injury and accident rate, it is essential that employees in high-risk areas be placed there in accordance with their knowledge and experience.

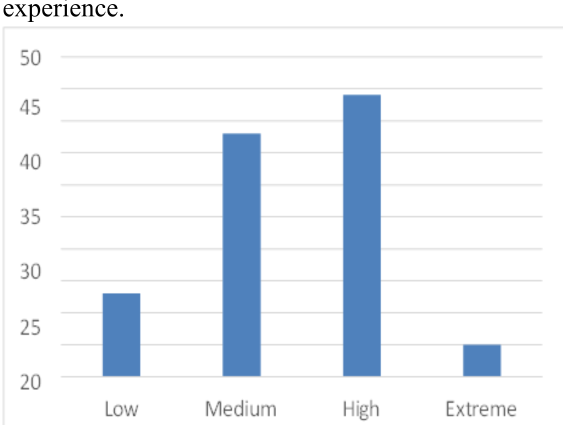

Figure 3: Relative percentage of risk in each zone

B. Relative %Age of Risk in Each Task

In order to determine the relative percentage of risk for each task. The risk value for a particular task is calculated by dividing the sum of the risk value for all the hazards identified in the activity by the overall risk. It is given by Equation 14.

$$\%age\ of\ risk\ in\ each\ task = \frac{\sum H}{R} \times 100 \quad (18)$$

where H is the risk value of each hazard in the task and R is the overall risk.

Ranking the tasks based on their relative risk is how builders identify those with the most potential for harm. Drilling, using scaffolding or ladders, and operating cranes are the three highest-risk activities, as shown in Figure 4. So, if safety inspectors know the amount of risk associated with each job, they may halt that work, take the necessary precautions, and then resume it. As a result, the job at hand will be less hazardous, current employees will have a lower chance of injury, and future incidents will be reduced in severity. Workers in these areas should also utilize appropriate PPE to protect themselves from the dangers, and safety engineers should deliver frequent toolbox talks before the start of these jobs.

C. Risk Assessment on Non-usage of PPE

1) Attitude of the Workers

Workers' attitudes about PPE usage are investigated by categorizing survey results as either favorable, neutral, or

negative. Figure 5 shows that although half of the answers are favorable, almost as many are negative.

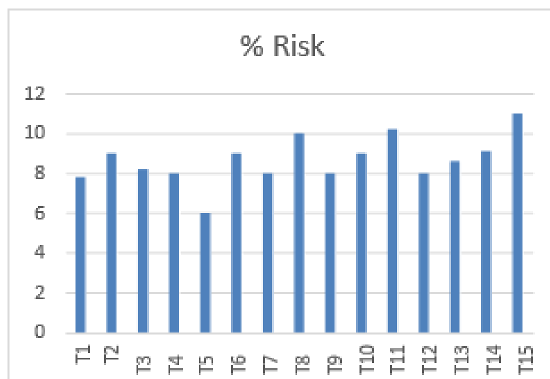

Figure 4: Relative percentage of risk in each task

With practically identical replies, it's easy to assume that this workplace's safety culture is lacking. Educating employees on safety measures has not been a priority, which has contributed to this problem. One important factor that might lead to unsafe behavior is one's attitude on the lack of PPE use. Therefore, frequent safety training may lessen the severity of injuries and accidents when employees' attitudes are at their most optimistic. Workers' attitudes toward safety must be influenced through training in order for them to see dangers, report them to site engineers, and understand the gravity of such threats.

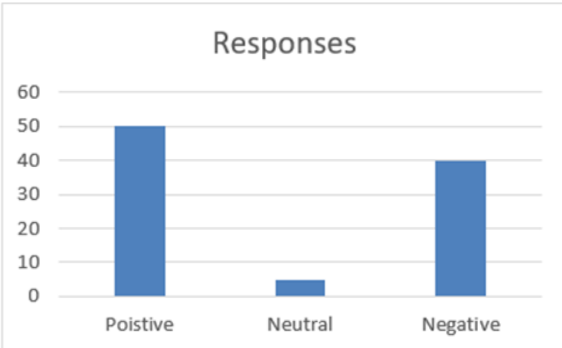

Figure 5: Attitude of the workers

In addition, showing workers footage of past construction site accidents and discussing the difficulties encountered by the worker's family following an accident are two effective ways to alter workers' attitudes. Workers' perceptions of risk will improve if there is a favorable attitude regarding foregoing PPE.

2) Influence of age in Non-Usage of PPE

Because people's ages range from twenty to fifty, we can assess the impact of age on PPE non-use as a measure of good safety culture. Figure 7 reveals that 27% of employees in the 20-25 age range and 35% of workers in the 25-30 age range reacted adversely to using the PPE while on the job. Due to the fact that more than half of the younger workforce has responded negatively, it is clear that this demographic must be properly addressed with the advantages of PPE. Workers in the older age bracket were less likely to disregard PPE owing to their expertise and familiarity with potential dangers. A more significant age gap between employees is not an excuse for a shift in mentality; individuals of all ages must approach their profession with the same dedication.

3) Risk Associated with the Non-Usage of PPE

Each task's potential danger is assigned a risk value if personal protective equipment (PPE) is not used, and an overall risk is established for each PPE. Figure 6 shows that safety helmets have a much higher danger rate than other PPE. When doing activities like excavating, working at height, or moving heavy objects, the incidence of head injuries is high enough to warrant the use of protective headgear. Due of the increased risk of injury associated with working in these settings due to falling items, falls from height, hitting materials, etc. A high prevalence of catastrophic injuries or fatalities among workers as a result. The danger connected with the safety helmets is high since both the severity and the probability ratings are high. Therefore, employees in high-risk environments (where falling items or falls from height are likely) should be cognizant of the need to wear safety helmets.

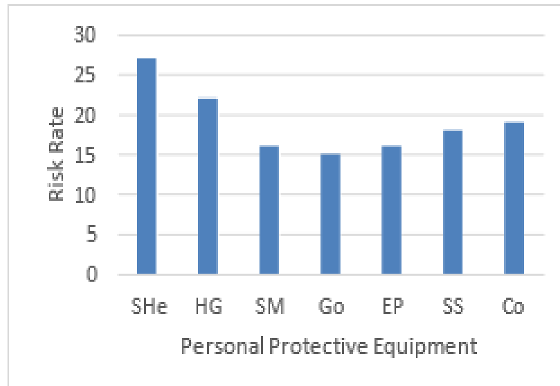

Figure 6: Risk associated with non-usage of PPE

4) Overall Risk in Each Task

To understand the variation in risk levels from task to task, it is necessary to calculate the total risk associated with each activity. Figure 7 reveals that the total risk is greatest for the activities of scaffolding/ladder use, excavation, and concreting, with respective values of 14, 12, and 12. It's common knowledge that jobs like these may expose workers to potentially life-threatening dangers including falls from height or objects, collapses of structures or dirt, damage to subterranean utilities, or even simple slips and trips. The worker should wear appropriate PPE to counteract or lessen the effects of these dangers. In addition, the risk ratings for each activity make clear that they represent the dangers faced by employees doing that duty. Consequently, builders and owners may reduce employees' exposure to hazards by supplying them with and mandating the usage of PPE.

V. EXPERIMENTAL RESULTS

A. Preparation of Composite Materials

- *Selection of Fibers, Resin:* The jute fiber polyester composite yields maximum impact and flexural strength at 44% and it get decreased with the increase in fiber loading [35, 36].

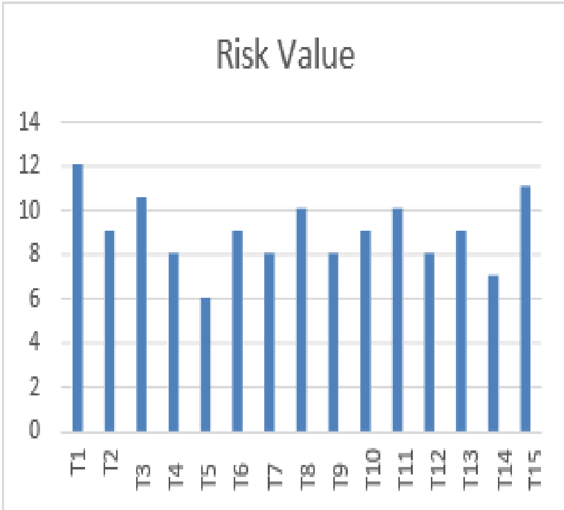

Figure 7: Overall risk in each task

The processing time for jute polyester composite is very less when compared to jute epoxy composite [37, 38]. Hence in this research 44% of jute fiber with the combination of polyester resin is used to fabricate industrial safety helmets.

- *Preparation of Biochar:* Sugarcane bagasse is cut into small pieces, dried for 24 hours, kept in a closed container and heated in a furnace for about one hour at 500^0 Celsius. Slow pyrolysis is adopted to achieve large amount of biochar. As bio-char is rich in carbon content, this can enhance the mechanical property of the material.

B. Composition of Samples and Temperature Conditions

There are three distinct variations in the samples' fiber, reinforcement, and filler compositions. Table 1 provides information on the specific makeup of the samples used in this study. In order to determine the helmet's durability, hot, cold, and damp environments are used. A hot air oven is used, and the temperature is set to 500 degrees Celsius and left to bake for four hours in order to create the desired high temperature. By keeping the temperature at a constant

-100 degrees Celsius for four hours, a freezer may generate a cold temperature. Wet conditions are created by allowing

1 liter of water every hour to accumulate (i.e., the fabricated helmet is placed under flowing water).

Table 1: Sample Composition

S. No	positio n	Fiber Content (%)	lyester (%)	Biochar (%)
1	C1	44	56	-
2	C2	44	51	5
3	C3	44	46	10

C. Shock Absorption Test

The standard unit of measurement for shock resistance is the kilogram-force (kgf), which is calculated by multiplying the impact load by the specific gravity. Figure 8 demonstrates that there is an increase in impact strength from C1 to C3, although closer inspection of C1 reveals evidence of fracture development. There is an increase in impact strength and the absence of cracks in C3 when compared to C2, and the same is true of C2 cracks found in the specimen after examination.

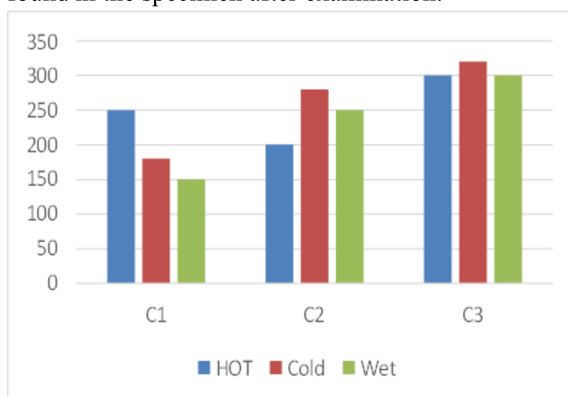

Figure 8: Shock absorption test results

In accordance with (IS 2928:1984), the maximum value of the shock absorption test must be less than 500 kgf, and based on the results of the test, combinations C1, C2, and C3 are within the permissible range. When compared to the other possible permutations, C3 had the highest shock absorption rate under all test settings. Shock absorption is less in the location of impact because fiber cannot form a strong connection with the matrix. By including biochar particles into the matrix, the composites improved their interfacial bonding. Consequently, helmet shells impregnated with biochar have been shown to absorb stress more effectively. While shock absorption was high in the cold and wet settings, it was poor in the hot ones. It's because the polymer's link weakens and it becomes more pliable when heated. However, the composites' increased ductility comes at the expense of their impact strength. Low shock absorption was observed in the unfilled composite when subjected to cold and damp circumstances. This is due to the hydrophilic feature of jute fiber, which allows it to readily absorb water molecules, even in damp and chilly environments. Because of this, the reinforcement becomes brittle and develops poor stress absorption. Because biochar decreases the number of water molecules that come into direct touch with fiber, filled composites exhibit greater shock absorption even when wet and cold.

D. Water Absorption Test

The proportion of water absorption has grown from C1 to C3. The water absorption rate (in percent) for the biochar- filled specimens increases from C2 to C3. C3, a polymer composite, has a high-water absorption rate while yet falling within the allowable range of combinations. Unfilled composites have a greater capacity to absorb water than biochar-filled composites. That's because of the hydrophilic quality of natural fiber and the fact that the fiber is in intimate touch with the water molecules. However, when biochar was included into the composites, the particles prevented water molecules from being trapped, preventing the water from coming into touch with the fiber reinforcement. Additionally, the water absorption rate is shown to rise from 5% to 10% when the biochar weight percentage is raised. Even with only 10% biochar, a substantial number of biochar particles had already adhered to the composite's surface. In addition to being hydrophilic, the biochar particle may absorb a lot of water when left exposed for a long time. That's why composites with biochar added to them improve their water-holding capacity by 10%.

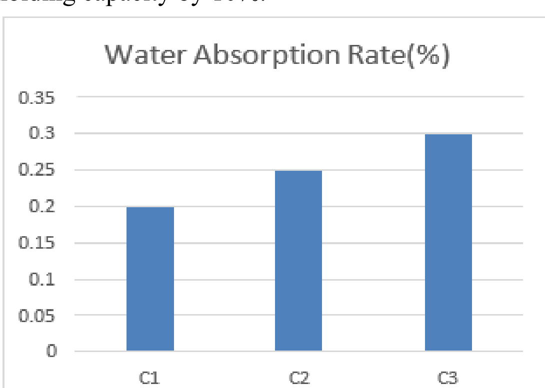

Figure 9: Water absorption test results

E. Flammability and Heat Resistance Test

Neither the jute fiber-based helmet nor the biochar-filled helmet emits any flame when exposed to a flame for less than 10 seconds on the outside surface of the shell. After placing the helmet in an oven, the resulting heat signature is photographed using a thermographic camera for analysis. It has been observed that neither the jute fiber nor the biochar packed shells show signs of separating or softening. Jute has a natural characteristic that makes it difficult to sustain a fire for an extended period of time. Cross-linked polyester resin has a high viscosity, making it resistant to fire and heat up to 80 degrees Celsius. The fillers, which are well mixed with the matrix and distributed throughout the fiber, contribute significantly to the material's fire retardancy.

VI. CONCLUSION

Direct observation identifies the greatest risks associated with each building activity. According to the safety expert, the chance and severity numbers are the best ways to quantify risk. When broken down by risk level, the construction site is found to have 13.3 percent low risk,
37.7 percent medium risk, 44.4 percent high risk, and 4.6 percent severe danger. To determine which endeavor poses the most danger, we first compute the proportion of danger involved in each and then rank them. Crane operating (10.4%), work at height (9.1%), and drilling (8.6%) are often cited as the most hazardous professions. The employees' and the supervisors' perspectives on all site operations were surveyed to establish a new safety performance model for quick and complete evaluation. To determine if the activity is risky or not, a negative Likert scale was used instead of the traditional methods used in earlier studies. The danger level of each task performed on the building site varies. In order to determine how well a company is doing in terms of safety, the employees' and supervisors' assessments are combined with the severity rate, which does not vary regardless of how safe the job becomes. If you use the suggested UACS equation to measure site safety, you'll get a result of 14.47, which means the site is risky. In addition, the supervisors have a safety performance level of 25.11, while the employees have a level of 15.78. Although the supervisors have deemed the location to be safe, it is

important to remember that this is just one opinion measuring and evaluating safety performance. Various building locations may employ this strategy because of its generalizability.

By matching the best worker with the most appropriate assignment, the TPM approach promises a dramatic rise in construction site safety. The recommended approach is not a one-and-done deal, so keep that in mind. In this method, ANN must be taught and the employees' database must be continually updated, making it a recursive strategy. The combination unsupervised and supervised training technique requires careful application and a trial-and-error approach to eventually converge on the best possible settings. It is possible that the training of the algorithm will not be efficient for smaller building sites with a lower amount of data.

ANN, GP, and NLR are the three machine learning techniques used to evaluate building sites for their level of safety. 60 percent of the time, C1 NLR outperformed all other conditions. Overall, GP outperformed ANN in every scenario. The lack of a mathematically expressible link between input and output is an evident weakness of ANN. In this regard, GP models are superior to other types because of their malleability. Despite the subjectivity inherent in the data collected by questionnaire surveys, the absolute validity of these models cannot be disputed. The models, however, can provide some inference that may help engineers and supervisors improve site safety. The risk values for not wearing protective equipment are 27.34 for safety helmets; 22.71 for hand gloves; 20.25 for coveralls; 19.29 for shoes; 18.05 for earplugs; 19.29 for masks; and 18.05 for goggles. Each has an individual value of 17.34 and 16.92. However, safety helmets have the highest larger potential for harm (27.34), which is 4.63 times higher than hand gloves and 10.42 times higher than goggles. Successful testing for shock absorption, penetration, water absorption, flammability, and heat resistance was conducted after the shell of an industrial safety helmet was fabricated utilizing jute fiber as reinforcement and biochar as filling. The greater stress absorption of 333kgf, 338kgf, and 348kgf under hot, cold, and wet environments is attributable to the inclusion of 10%wt of biochar filled composites, while substantial fractures are only seen in the unfilled composites. The composites containing 10%wt of biochar demonstrate maximum resistance in the penetration test of 2.8mm, 3mm, and 2.7mm in hot, cold, and wet circumstances, respectively. This is more than both the empty composites and the composites containing 5%wt of biochar. Both the filled and unfilled composites passed the flammability and heat resistance tests with flying colors, maintaining their integrity after being exposed to flame for 10 seconds and withstanding temperatures of up to 80 degrees Celsius.

REFERENCES

[1] M. Gunduz, M.T. Birgonul and M. Ozdemir, Development of a safety performance index assessment tool by using a fuzzy structural equation model for construction sites, Automation in Construction, 85 (2018), 124-134.

[2] O. Rozenfeld, R. Sacks, Y. Rosenfeld and H. Baum, Construction job safety analysis, Safety science, 48 (4) (2010), 491-498.

[3] IWH. Fung, VWY. Vivian, TY. Lo, and LLH. Lu, Developing a risk assessment model for construction safety, International Journal of Project Management, 28 (6) (2010),593-600.

[4] C.F. Chi, C.C. Yang and Z.L Chen. In-depth accident analysis of electrical fatalities in the construction industry, International Journal of Industrial Ergonomics, 39 (4) (2009), 635-644.

[5] T. Aksorn and B.H.W. Hadikusumo, Critical success factors influencing safety program performance in Thai construction projects, Safety Science, 46 (4) (2008), 709-727.

[6] M. Gunduz and B Ahsan, Construction safety factors assessment through frequency adjusted importance index, International Journal of Industrial Ergonomics, 64 (2018), 155-162.

[7] A. Pinto, I.L. Nunes and R.A. Ribeiro, Occupational risk assessment in construction industry–Overview and reflection, Safety Science, 49 (5) (2011), 616-624.

[8] J.W. Garrett and J. Teizer, Human factors analysis classification system relating to human error awareness taxonomy in construction safety, Journal of Construction Engineering and Management, 135 (8) (2009), 754-763.

[9] T. Vondráčková, V. Voštová, and V. Nývlt, The human factor as a cause of failures in building

structures, MATEC Web of Conferences, 93 (2017), Article no. 03005.
[10] A. Atkinson, Human error in the management of building projects, Construction Management and Economics, 16 (3) (1998), 339-349.
[11] G. S. Beriha, B. Patnaik, S. S. Mahapatra and S. Padhee, Assessment of safety performance in Indian industries using fuzzy approach, Expert Systems with Applications, 39 (3) (2012), 3311-3323.
[12] B. H. Guo, T. W. Yiu and V. A. González, Predicting safety behavior in the construction industry: Development and test of an integrative model, Safety Science, 84 (2016), 1-11.
[13] M. Lu, C. M. Cheung, H. Li and S. C. Hsu, Understanding the relationship between safety investment and safety performance of construction projects through agent-based modelling, Accident Analysis and Prevention, 94 (2016), 8-17.
[14] A. Charehzehi and A. Ahankoob, Enhancement of safety performance at construction site, International Journal of Advances in Engineering & Technology, 5 (1) (2012), 303-312.
[15] Y. Khosravi, H. Asilian Mahabadi, E. Hajizadeh, N. Hassanzadeh Rangi, H. Bastani, A. Khavanin and S.B. Mortazavi, Modeling the factors affecting unsafe behavior in the construction industry from safety supervisors' perspective, Journal of Research in Health Sciences, 14 (1) (2013), 29-35.
[16] Z. Wu, X. Zhang and M. Wu, Mitigating construction dust pollution: State of the art and the way forward, Journal of Cleaner Production, 112 (2016) 1658-1666.
[17] E. Tjoe Nij, S. Hilhorst, T. Spee, J. Spierings, F. Steffens, Dust control measures in the construction industry." Annals of Occupational Hygiene, 47 (3) (2003), 211-218.
[18] S. Fan, Y.W. Wong, L. Shen, W. Lu, T. Wang and A. Yu, The effectiveness of Dust bubbles on dust control in the process of concrete drilling, Safety Science, 50 (5) (2012),1284-1289.
[19] B.D. Aggarwal, Worker Education Level is a Factor in Self- compliance with Dust-preventive Methods among Small- scale Agate Industrial Workers, Journal of Occupational Health, 55 (4) (2013), 312-317.
[20] P.A. Koushki, N. Kartam and N. Al-Mutairi, Workers' perceptions and awareness of noise pollution at construction sites in Kuwait, Civil Engineering and Environmental Systems, 21 (2) (2004), 127-136.
[21] M. Geetha and D. Ambika, Study on noise pollution at construction site, International Journal of Research in Engineering and Technology, 4 (2) (2015), 420–421.
[22] H. Guo, Y. Yu and M. Skitmore, Visualization technology- based construction safety management: A review. Automation in Construction, 73 (2017), 135-144.
[23] X. Huang and J. Hinze, Analysis of construction worker fall accidents." Journal of Construction Engineering and Management, 129 (3) (2003), 262-271.
[24] Y. Kang, Use of fall protection in the US construction industry, Journal of Management in Engineering, 34 (6) (2018), Article no. 04018045.
[25] M. Suárez Cebador, J.C. Rubio-Romero and A. López- Arquillos, A. Severity of electrical accidents in the construction industry in Spain, Journal of Safety Research, 48 (2014), 63-70.
[26] G.X. Chen and D.E. Fosbroke, Work-related fatal-injury risk of construction workers by occupation and cause of death, Human and Ecological Risk Assessment, 4 (6) (1998),1371-1390.
[27] J.C. Cawley and B.C. Brenner, Occupational electrical injuries in the US, 2003–2009, IEEE IAS Electrical Safety Workshop, (2012), 1-5.
[28] C.A. Janicak, Occupational fatalities due to electrocutions in the construction industry, Journal of Safety Research, 39 (6) (2008), 617-621.
[29] Z.Z. Wang and C. Chen, Fuzzy comprehensive Bayesian network-based safety risk assessment for metro construction projects. Tunnelling and Underground Space Technology, 70 (2017), 330-342.
[30] G. Carter and S. D. Smith, Safety hazard identification on construction projects, Journal of Construction Engineering and Management, 132 (2) (2006), 197-205.
[31] A. M. Saedi, J. J. Thambirajah and A. Pariatamby, A HIRARC model for safety and risk evaluation at a hydroelectric power generation plant, Safety Science, 70 (2014), 308-

315.

[32] M. Kraus, Risk assessments of contemporary accidents in construction industry, MATEC Web of Conferences, EDP Sciences, 146 (2018), Article no. 03004.

[33] S. Al-Anbari, A. Khalina, A. Alnuaimi, A. Normariah and A. Yahya, Risk assessment of safety and health (RASH) for building construction, Process Safety and Environmental Protection, 94 (2015), 149-158.

[34] S.M. El-Sayegh, Risk assessment and allocation in the UAE construction industry, International Journal of Project Management, 26 (4) (2008), 431- 438.

[35] S.N.H. Husin, A.B. Mohamad, S.R.S. Abdullah and N. Anuar, Chemical health risk assessment at the chemical and biochemical engineering laboratory, Procedia-Social and Behavioral Sciences, 60 (2012), 300-307.

[36] Castiglia, F., and M. Giardina. Analysis of operator human errors in hydrogen refuelling stations: Comparison between human rate assessment techniques. International Journal of Hydrogen Energy 38, no. 2 (2013): 1166-1176.

[37] Jahangiri, Mehdi, Reza Jafari Nodoushan, Farzan Madadizadeh, and Hossein Fallah. "Assessment of the probability of human error occurring in the process of appendectomy operation using SPAR-H method." Occupational Medicine Quarterly Journal 12, no. 2 (2020): 17-28.

[38] M. Suárez Cebador, J.C. Rubio-Romero and A. López- Arquillos, A. Severity of electrical accidents in the construction industry in Spain, Journal of Safety Research, 48 (2014), 63-70.