HUMAN PERFORMANCE BEST PRACTICES IN THE ELECTRICAL WORKPLACE

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Abstract – The construction industry is one of the most hazardous industries worldwide, and contact with electricity is a major cause of injury and death among construction workers. It is well known that unsafe acts resulting from human error are the primary cause for up to 80% of accidents across various industries, and some studies show that human performance tools may be functional in mitigating these incidents. Accordingly, this paper provides empirical evidence regarding the effectiveness of human performance tools as used to curb the frequency, probability, and severity of accidents. To achieve its objectives, this study first executed an extensive literature review to identify best practices related to human factors in mitigating the risk of electrical incidents. Then, the authors distributed an online questionnaire among various safety managers to determine the effectiveness of each practice in reducing the frequency, probability and severity of these incidents. The results and analysis show which human performance tools are recognized as most effective in helping safety managers mitigate human errors in electrical jobsites. The results of this study and paper will accelerate and transform current injury-prevention practices as well as overcome some of the barriers in the electrical workplace. An easy-to-use and effective set of human performance best practice solutions will be provided based on standards and industry experience.

Index Terms — Human error, human factors, electrical accidents, human performance.

I. INTRODUCTION

One of the main causes of electrical accidents is human error resulting from an individual's limited capacity for attention and working memory [1]. Even highly skilled workers are naturally at risk of committing blunders. Individuals are also vulnerable to distraction, which is completely independent of expertise with the technical aspects of their jobs. This is because humans have a finite supply of attentional resources which limits performance, especially when these workers are saddled with the responsibility of working on an intricate and dynamic construction site. Distractions may also occur when workers intentionally take shortcuts, or attempt to conduct two or more tasks at once. Refocusing attention on a task once distracted becomes difficult because of the extra cognitive effort needed to channel attention back to the task at hand, which leads to decreased attention overall, and plays a contributing role in accidents and injuries [2]. Such realities manifest what Rasmussen observed [3], wherein the efficiency with which humans process complexity relates to the availability of different mental representations of the environment, and these representations generate rules to control behavior ad hoc.

To overcome human limitations, practitioners have recommended human performance tools to curb the likelihood and impact of accidents resulting from errors in the workplace. Several studies have reviewed the application and benefits of these tools without empirically measuring their effectiveness. Thus, this present study evaluates the effectiveness of major human performance tools in curbing the frequency, probability, and severity of electrical accidents in the construction sector. In an effort to identify tools that will achieve this aim, a comprehensive literature review was carried out to better understand the roles of human factors in the occurrence of electrical incidents. Thereafter, experts in the area of electrical safety identified useful tools to address the recurrence and consequences of human errors. The results of this study will enhance current injury-prevention practices and help overcome human performance challenges in the electrical construction workplace.

II. HUMAN ERRORS AND HUMAN FACTORS IN ACCIDENT CAUSATION

Human errors do not occur in isolation. They are systematically linked to the overall conditions of the working environment, which can include workers' tools and equipment, vaguely-defined tasks, roles and responsibilities, attitudes of managers and supervisors, relevance of work processes and procedures, and the shared value system of employees [4]. Human errors can occur at any stage in the life of a system, from inadequate original designs, installation deficiencies or operation and maintenance anomalies [5]. Safe, careful, experienced, attentive workers remain vulnerable to events beyond their control, and may make decisions and perform actions that unintentionally place them in danger. Workers may also become comfortable with the tasks and safety protocol once procedures are memorized, such that attention is easily captured by stimuli outside of the task at hand, which can result in errors within a task [2]. Therefore, system designs should allow for the detection of mistakes and include prompt intervention strategies that would prevent minor mistakes from metamorphosing into incident-triggering errors or errors that severely affect system performance. Further increasing the

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likelihood of accident in the electrical workplace is non-adherence to the standard for electrical safety (NFPA 70E), especially when working on energized electrical equipment. With safety incorporated into the design of most electrical components, the risk of accidental contact to live electrical components has been significantly reduced, which has brought about disregard for rules and increased risk-taking [6]. In an anonymous survey of over 300 participants carried out by Katzel [7], about 92% of the respondents admitted to violating NFPA rules when working on industrial control panels, more than half (59%) rarely or never wore the required PPE, and nearly all the respondents (94%) believed that the rules were complex to follow, restrictive for everyday use, and had the opposite effect than intended. Thus, most control personnel ignore them, and take risks believed to be reasonable and educated, which they termed 'common sense safety measures'.

The frequency of electrical accidents that has emanated from human errors and unsafe practices has been of prime concern in the risky business of construction [8], and given that it is normal human behavior to make mistakes, the human factors involved in the occurrence of these accidents have been studied by various researchers. In one early study, Mellen et al. [9] investigated 155 electrocution cases to determine the role of human factors in electrical accident causation. Carelessness, improper maintenance of equipment, and intoxication were analyzed as primary contributory factors. Williamson and Feyer [10] corroborated the findings of Mellen et al. [9] by analyzing the role of human factors in the immediate and wider circumstances of work-related deaths. They attempted to establish the relative importance of the causes of fatalities due to electrocution and exposure to electricity. The study found that human factors in the form of errors and unsafe work practices were most commonly the major causes of fatalities.

Reinforcing this view, a study by Koval and Floyd [5] on the human-element factors disrupting scheduled system operation showed that the human element is a significant factor that affects the reliability and safety of electrical systems. Koval and Floyd's study emerged out of the realization that many system reliability predictive methods lost sight of the human component of man–machine systems when focusing solely on equipment failures.

Additionally, Leiden et al. [11] conducted a study intended to assess advances in human error modeling and to determine the suitability of existing human performance modeling architectures for human error prediction. They reviewed various task-network, cognitive, and vision models in the National Aeronautics and Space Administration System-Wide Accident Prevention Program to determine their suitability in reducing accidents and human errors in aviation. The study concluded that the tools required further application and refinement to show their viability to the system design process and the associated safety and performance consequences.

Khan et al. [12] developed the Human Error Probability Index (HEPI) tool to understand the mechanisms that cause error, the modes under which human failures occur, and the risks arising from such errors. Their work was prompted by the dearth of developed initiatives to quantify the human error probabilities (HEPs) associated with major actions that take place during offshore emergency situations. HEPI's application is believed to limit opportunities for human error occurrence and to reduce the impact of such errors, consequently leading to more error-tolerant designs and operations.

Einarsson and Brynjarsson [13], in a quest to improve human-factor approaches in hazardous industrial plants, designed a system using scenario-based modified Process Hazard Analysis (PHA) to enhance human interactions and to identify the associated risks within the system to yield more productive accident reporting. They also anticipated that the system would raise the awareness of human operators at hazardous workstations, improve the safety and organizational culture, and enhance the effectiveness of safety management systems.

In research to investigate the nature of operator-system interfaces in nuclear power plant simulators, Carvalho et al. [14] utilized the Human System Interface Laboratory (LABIHS). The study examined how workers applied intellectual skills to interpret the state of the environment and the need for a human-centered approach in the human-system interface (HIS) design to reduce errors and complications that may result in the workplace. Operators working on an advanced control room of a nuclear power plant digital simulator were observed using a cognitive task analysis (CTA) approach. Carvalho proposed that this approach would contribute to operational safety and efficiency through enhanced decision–support system design.

These studies show a multi-industry effort geared towards modifying human behavior and reducing the consequences of human errors. As such, a variety of human performance tools have been developed in a bid to reliably predict the occurrence of mistakes, mitigate their effects, and improve overall safety performance in the workplace. Furthermore, the ongoing quest to maintain an excellent health and safety standard with near-zero electrical incidents has accentuated the need for dependable tools to address human errors that may occur in dynamic environments or during unfamiliar task operations. For this reason, researchers have turned their attention to human performance tools that may be applied to the pursuit of improved safety outcomes on job sites.

III. HUMAN PERFORMANCE TOOLS

Various industries have recognized human-performance theory and tools as best practices that can be applied in any workplace to advance the electrical safety culture and to reduce the human errors that contribute to safety incidents [15]. Human performance tools are used in the workplace to minimize the probability of errors that may translate to incidents when workers are exposed to error-prone conditions [1]. These tools help engage workers to discern and respond to error precursors and to be more aware of their safety, tasks and surroundings [16]. Although there have been tremendous advances in the development of human performance tools and models over the past years, hardly any evidence documents the efficiency of these tools in curbing the impact of electrical accidents in the construction workplace [11]. This study therefore addresses this knowledge gap by empirically measuring the adequacy of these mechanisms. The human performance tools used in this study are:

- *Job planning, pre-job briefing, and post-job review*: Creating a job plan and conducting a pre-job briefing is to help personnel focus on the performance of the tasks and understand their role in the execution of the tasks. A post-job review provides a good opportunity to capture feedback and lessons learned from the job that can be applied to future jobs.

- *Procedure use and adherence*: A robustly written procedure reduces human variability in the workplace and increases the likelihood of a successful outcome. A worker should proactively read and understand the purpose, scope, and intent of all actions as written, and in the sequence specified. Regardless of a worker's skill or experience, the required step sequence, coordination, technical criteria, diagnostic aids, warnings, and cautionary information cannot be recalled consistently by humans each time tasks are performed [17].
- *Verbalization*: Verbalization involves vocalizing actions and the expected outcome before, during, and after performing each step of the task at hand, to keep the worker mentally alert when a mismatch exists between the eventual outcome and the verbalized expectation.
- *Three-way communication*: Three-way communication facilitates a mutual understanding of the message between a sender and receiver. When the sender conveys a clear and concise message, the receiver should repeat the message back to the sender. There should, in turn, be a confirmation statement from the sender in the affirmative.
- *Flagging and blocking*: When working with similar or multiple components that may increase the chances of mistakes, flagging is used to ensure that the correct equipment is operated at the required time and under the required conditions. Blocking, on the other hand, is a method of preventing access to an area or equipment controls. For instance, when the doors of a panel are opened, and the panel is energized, a physical barrier is to be used and only qualified people should be allowed within that area [6].

IV. RESEARCH METHODS

The present study evaluates the effectiveness of human performance tools in curbing the frequency, probability, and severity of electrical accidents in the construction sector. To achieve this objective, this study performed an extensive literature review to construct a list of human factors that contribute to electrical incidents. In turn, these identified factors supported a survey in which industry respondents assessed 1) human factors at play in incidents and 2) the effectiveness of human performance tools in mitigating incidents.

First, the research team examined existing scholarly research and identified human factors that play a significant role in the immediate and wider circumstances of work-related incidents and accidents. The initial focus of the search was an attempt to understand the concept of human error with respect to the performance of human activities and the overall working environment, as established in existing literature. Consequently, human factors that had a direct effect on the performance of individuals were studied in detail. Search engines used to explore the relevant scholarly materials included Google Scholar, the American Society of Civil Engineering (ASCE) library, and Science Direct. Similarly, human performance tools that reduce the effects of human errors that contribute to electrical workplace incidents were also analyzed. In particular, a broad list of human performance tools employed in the electrical domain were sourced from Annex U – Human Performance and Workplace Electrical Safety, a publication from the Canadian Safety Association (CSA) Z462- 2015 Workplace Electrical Safety Standard. This comprehensive literature review was carried out to lay a solid foundation for this study.

The study then surveyed electrical safety professionals regarding human factors and the effectiveness of certain human performance tools utilized in the electrical workplace to minimize the probability of the types of errors that translate to incidents. To achieve the objectives of the study, a comprehensive list of human factors that play a pivotal role in the occurrence of electrical accidents in the workplace was drawn based upon the results of the literature review. In total, 33 human factors were identified and categorized into four major groups: *task demands, work environment, individual capabilities* and *human nature*. Thereafter, these factors were rated according to their relative importance and frequency in the occurrence of electrical accidents. The respondents were asked to use a five-point Likert scale to rate the relative importance and frequency of a number of identified human factors that contribute to electrical incidents. Also, human performance tools were rated with respect to their effectiveness in reducing the frequency and severity of human error. Thus, respondents selected a numerical value that corresponded to their best choice, based on their experience and judgement.

The questionnaires were sent out to electrical safety practitioners who had an average experience of 28 years. In addition, to increase the number of respondents, the research team sent out the survey to personal electrical safety contacts. A total of 50 surveys were distributed to respondents. Of these, 16 responses were received and analyzed. A detailed analysis of the responses by these electrical safety managers is presented in the section that follows.

V. RESULTS AND ANALYSIS

To accomplish the objectives of the study, 50 electrical safety professionals were contacted. In total, 25 responses were received. Out of these, 9 surveys were incomplete and therefore excluded from the analysis. The remaining 16 respondents returned the completed questionnaire. Their responses were analyzed, and they constituted the sample for the study. These professionals had an average of 22 and 28 years of professional experience in construction safety and the construction industry, respectively. Participants were mainly from Ontario, New York, Alabama and Louisiana. Also, most of the respondents were senior Electrical Engineers and Electrical Health and Safety directors.

A. Human Factors

The values for the relative importance and frequency of the identified human factors as obtained from electrical safety professionals were independently quantified on a five-point Likert scale and the results are shown in Table 1. For clarity, factors have been separated according to groups.

TABLE 1
MEDIAN OF RELATIVE IMPORTANCE AND FREQUENCY OF HUMAN FACTORS IN ELECTRICAL CONSTRUCTION INCIDENTS

	Human Factors	Importance (Median)	Frequency (Median)
Task Demands	Time pressure	4	4
	High workload (Memory requirements)	4	4
	Simultaneous or multiple tasks	4	4
	Repetitive actions or monotony	3	3
	Critical steps or irreversible acts	4	3
	Interpretation requirements	3.5	3
	Unclear goals, roles, or responsibilities	3	3
	Lack of or unclear standards	3	3
Work Environment	Distractions/interruptions	4	4
	Changes/departures from routine	3.5	4
	Confusing displays or controls	3	3
	Workarounds/out-of-service instrumentation	3	3
	Obscure electrical supplies or configurations	3	3
	Unexpected equipment conditions	3.5	3
	Lack of alternative indicators	3	3
	Personality conflicts	3	2
Individual Capabilities	Unfamiliar with, or first time performing task	3	3
	Lack of knowledge	3	3
	New technique not used before	3	3
	Imprecise communication habits	4	3
	Lack of proficiency or experience	3.5	3
	Indistinct problem-solving skills	3	3
	Unsafe attitudes for critical task	4	3
	Inappropriate values	3.5	3
	Illness/fatigue	3	3
Human Nature	Stress (limited attention)	4	4
	Habit patterns	4	4
	Assumptions	4	4
	Complacency/ overconfidence	4	4
	Mindset	4	4
	Inaccurate risk perception	4	4
	Mental shortcuts (biases)	4	2
	Limited short-term memory	2	2

1) Task Demands

A task's specific mental, physical, or team requirements may hinder its successful completion and may significantly affect human performance. In total, 8 different task-related factors that may activate errors in the workplace were identified. Based on the assessment of the electrical professionals, *time pressure*, *high workload*, *multiple tasks*, and *critical steps/irreversible acts* were assessed to be the most important factors that could set the tone for errors during the performance of a task. This outcome supports the findings of Tiwari et al. [18], who noted that the increased workload and psychophysical demands of certain tasks impact individuals' focused mental effort and drain information-processing resources. *Time pressure*, *high workload*, and *multiple tasks* were rated the most frequently occurring task-related error precursors.

2) Work Environment

In this category of human factors, *workplace distractions/interruption* was identified as the most important factor that triggers errors and causes incidents in the workplace. This finding was closely followed by *departures from routine* and *unexpected equipment conditions*. This result is in line with the views of Koval and Floyd [5], who observed that distractions may have an impact on electrical safety, as workers and their supervisors are constantly interrupted during their work. This result calls for concerted efforts to minimize all forms of interference that could jeopardize the smooth flow of workplace activities in order to prevent outcomes that could be detrimental to the safety of workers. When asked to rate the relative frequency of the error precursors in this group with respect to workplace accidents, *distractions/interruptions* and *departures from routine* were ranked the highest. *Personality conflicts* was ranked as the lowest-frequency factor in this group.

3) Individual Capabilities

Of the eight identified human factors related to individual capabilities, *imprecise communication habits* and *unsafe* *attitudes for critical tasks* were rated the most important factors in electrical accident causation in the construction workplace. The second-ranked factors in this group were *lack of experience* and *inappropriate values*. On the other hand, *unfamiliarity with a task*, *lack of knowledge*, *use of a new technique*, *indistinct problem-solving*, and *fatigue* were ranked the least important factors in this category.

These outcomes were in keeping with the literature. Specifically, the importance of precise and clear communication vertically and horizontally in the electrical workplace cannot be over-emphasized. Doherty [19] stressed the importance of communication in his study of human performance best practices in electrical safety. In his words, using the phonetic alphabet during efficient communications, providing clear and concise first statements, receiving acknowledgement from the listener, and confirming the acknowledgement are critical human performance tools that reduce the risk of a significant incident. Interestingly, this study's subjects uniformly ranked all eight factors related to individual capabilities. This outcome may point to the fact that while some factors related to human capabilities may seem more important than others, the frequency of their contribution to workplace accidents is not hierarchical. Thus, workers should 1) pay detailed attention to individual elements critical to the successful and safe performance of tasks, and 2) seek to constantly improve task performance with due diligence.

4) Human Nature

Central to the present study is the question of human nature, especially in terms of which elements aid successful task performance and which contribute to the likelihood of workplace accidents. The Human Performance Improvement Handbook 1028-2009 of the U.S. Department of Energy [4] describes an error-likely situation as one wherein the demands of a task exceed the capabilities of the individual, or the work conditions aggravate the limitations of human nature. Eight factors related to human nature were identified and ranked according to their relative importance in electrical incident occurrence. These included *stress*, *habit patterns*, *assumptions*, *complacency*, *mindset*, *inaccurate risk perception*, *mental shortcuts*, and *limited short-term memory*. With the exception of *limited short-term memory*, all the factors were equally ranked with respect to their level of significance. Apart from *mental shortcuts* and *limited working memory*, the safety engineers appraised these human factors uniformly with respect to the frequency of their occurrence in electrical accidents.

B. Human Performance Tools

After identifying the human factors that constitute error traps in the course of performing workplace activities, this study then evaluated the effectiveness of the human performance tools in curbing the frequency, probability, and severity of electrical accidents in the construction sector. As such, the frequency and severity values for each human performance tool in the occurrence of electrical incidents were independently quantified on a five-point Likert scale and the results are shown in Table 2. To measure the internal reliability of the collected data, Cronbach alpha was calculated for the frequency (0.981) and severity (0.978) scores of the identified human performance tools, indicating excellent internal reliability.

TABLE 2
MEDIAN OF RELATIVE EFFECTIVENESS OF HUMAN PERFORMANCE TOOLS

Human Performance Tools	Frequency (Median)	Severity (Median)
Job planning and pre-job briefing	4	5
Job-site review	4	5
Post-job review	3	3
Procedure use and adherence	5	5
Self-check with verbalization	4	4
Three-way communication	4	4
Stop when unsure	5	5
Flagging and blocking	5	5

In total, eight different human performance tools were identified and included in the survey (Table 2). Based on the safety managers' judgement and experience, the most effective tools in reducing the frequency of human errors in the occurrence of electrical incidents are:

- Procedure use and adherence
- Stop when unsure
- Flagging and blocking

Likewise, the following tools were rated second in effectiveness:

- Job planning and pre-job briefing
- Job site review
- Self-check with verbalization
- Three-way communication

Bishop and LaRhette [17] captured the importance of consistent use of procedure in the performance of tasks. They emphasized that regardless of a worker's skill or experience, the required step sequence, coordination, technical criteria, diagnostic aids, warnings, and cautionary information may not be recalled consistently by humans each time tasks are performed. Nonetheless, when a worker is unable to follow a procedure or process step, if something unexpected occurs or if the worker has a "gut feeling" that something is not right, the worker should stop and obtain further direction before proceeding with the task [1]. More than half of the identified human performance tools were rated as highly effective in reducing the severity of human errors. These tools are *job planning and pre-job briefing*, *job-site review*, *procedure use and adherence*, *stop when unsure*, and *flagging and blocking*. *Post-job review* was rated the least effective in reducing the severity of human errors.

VI. CONCLUSION

Humans are finite beings whose capacity to perform error-free tasks is limited. Further compounding the fallibility of humans is the existence of error precursors entrenched in the workplace, which cause undesired events and prevent the successful performance of tasks by increasing the likelihood of mistakes. Although extensive research has been carried out over the past decades to understand the influence of human factors in complex and technically challenging work environments, hardly any studies have attempted to assess the relative significance and frequency of these factors in the occurrence of electrical accidents. Furthermore, given that it is normal behavior to make mistakes, experts have recommended the use of certain human performance tools to overcome human limitations in the electrical workplace. Previous studies have performed extensive reviews on the application of certain human performance tools. However, no study has attempted to empirically measure the efficiency of these tools in curbing the impact of electrical accidents in the construction workplace. Therefore, this study addresses this knowledge gap by empirically measuring the effectiveness of these mechanisms.

Practitioners can use the findings of the study to identify the most important and frequently occurring human factors that activate errors and cause incidents in the electrical workplace. Efforts can be applied towards improving aspects of the workplace so as to create favorable and optimum working conditions for workers. Furthermore, management can utilize the outcome of this study to design appropriate training interventions to address unique performance deficiencies in workers. Safety managers will also find the results of the present study highly valuable in identifying the most suitable human performance tools to reduce the likelihood of errors or the severity of errors' consequences when used to address error-likely situations in the electrical workplace.

There are some limitations related to this research that need to be addressed in future studies. First, the significance, frequency, and severity ratings were obtained from electrical practitioners mainly located in Ontario, New York, Alabama, and Louisiana. While these are distinct communities, this condition will limit the external validity of the study. Future studies should be conducted to collect data from larger and more diverse groups of electrical safety experts. Secondly, assessing the frequency and severity of human factors and errors using a Likert scale does not accurately estimate the likelihood of electrical accidents. Further studies should be conducted to measure the effectiveness of a combination of human performance tools in reducing the frequency and severity of human errors when one or more error-likely situations arise. Despite these limitations, the study provides a significant contribution to practice by helping electrical practitioners identify and pay attention to the most important and frequently occurring human factors that activate errors and cause accidents in the electrical workplace. Actions taken after such insight will ensure that workers' performance on the job is maximized and the frequency of accidents is reduced despite inherent human fallibility and imperfections in the work environment.

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VIII. VITA

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