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DEVELOPING A PROTOCOL FOR ON-SITE MEASUREMENTS OF SITUATIONAL AWARENESS

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ELECTRI INTERNATIONAL
Research and Education for the Electrical Construction Industry

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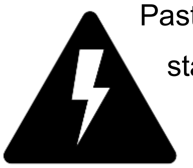
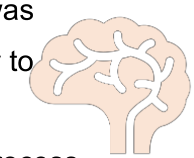
BACKGROUND

Motivation



Past decade, the serious injury and fatality rates on construction sites across U.S. has started to plateau. Although, a number of different trades and workers of varying skill levels need to operate in tandem to deliver the objectives of the project efficiently and safely, the electrical trade has been particularly challenging from a safety perspective. This is due to the nature of work within this sector, which is highly dangerous and leaves the workers with a very small margin for error [1]. Not only is electrocution included in the Occupational Safety and Health Administration's 'fatal four' but the *frequency* of being fatally injured by electrical hazards in construction has continually been orders of magnitude higher than the industry average [2, 3]. Injuries resulting from electrical accidents (e.g., electrical shocks and burns and arc blasts) can cause injuries that can result in severe tissue damage and have a mortality rate of 15%, which is alarmingly high [3]. For the long-term sustainability of the industry, it is critical to develop and deploy resources that allow the management to proactively assess safety performance and identify critical gaps to develop targeted interventions.

What is situational awareness?



Situational awareness, a popular concept in human factors engineering, was pioneered by the aviation industry as a metric to measure an individual's ability to interact with a highly complex environment and process all the relevant information [4]. It is the degree to which we are able to actively extract and process information to guide our decisions and subsequent actions [5]. The importance of situational awareness has been rigorously proven by studies that have shown the lack of situational awareness in a high-risk occupational environment can be a casual factor behind accidents and fatalities [6-8]. Thus, from a construction safety standpoint, to work safely, workers need to have high situational awareness which is the ability to not only accurately detect and classify hazards, assess risk, and project potential outcomes, but also to understand the dynamic nature of their work environment when making safety-related decisions [9-10].

There are a number of studies that show that the construction workers, on average, across all trades are able to identify at most 45% of hazards in their environment [11-14]. There is also preliminary evidence that suggests that workers' perceptions and assessments of risk can be skewed by their psychological status as well [9-10; 15-16]. Unfortunately, academics and practitioners have traditionally investigated these safety metrics in a fragmented manner [9-16] and not as a holistic concept (i.e., situational awareness). Although, these piecemeal assessments of safety performance have been valuable in allowing the industry as a whole to understand some of the shortcomings of the traditional training programs [17] and develop innovative interventions [18], the tools used to make such assessments are often financially prohibitive and impractical (for example: eye-tracking software, virtual reality platform) [19-21]. The sporadic nature of these assessments does not allow safety professionals to have leading information to accurately and consistently *track and benchmark existing* or *predict future* safety performance.

There is a need for a practically applicable assessment tool that collects holistic and predictive information on safety performance that the industry professionals within electrical sector can use as levers to improve future safety performance.

VISION

To address the aforementioned safety need, this project, funded by the ELECTRI International's Early Career Award, developed a new tool to measure situational awareness among construction. This assessment tool addresses the lack a holistic outlook towards safety performance and examines how workers process and interact with all relevant safety information in their work environment. This validated tool can provide impetus to the business units within an organization to strategically develop targeted training interventions that yields highest return on investment.

Create a protocol to measure the situational awareness and human factors performance of construction workers that is practically feasible, accurate, and reliable.

Specifically, the situational awareness assessment tool (SAAT) is designed to be:

- **Actionable**: identifies gaps for targeted interventions to improve safety performance
- **Simple**: easy to use by a broad audience
- **Efficient**: practical feasible and requires minimal resources
- **Reliable**: different people arrive at the same measure

Although, the principle objective of this project was to design a tool to measure situational awareness of workers on construction sites, SAAT also assesses the performance of relevant human factors. This was included to not only identify and describe factors responsible for low situational awareness among construction workers in the electrical sector but also assess the performance of key antecedents to high job satisfaction and positive mental and physical well-being. Over the past decade, the enhancement and management of the wellbeing of workers has come to the forefront as the industry grapples with one of the highest rates of alcohol, opioid, and illicit substance abuse [22], absenteeism [23-24], fatigue [25-26] and depression [27-28]. Considering these trends, it is not surprising that the industry as a whole continues to struggle to recruit and retain skilled labor. *With the current climate of uncertainty and high-stress due to the COVID-19 pandemic, this pressing concern requires even more attention.*

SAAT aims to provide employers with leading information on human factors performance to strategically develop programs when resources are constrained.

SURVEY DESIGN

There are a number of protocols developed by researchers to measure situational awareness within aviation and medicine domains [29-35]. As effective as these techniques actually are, they are not necessarily transferable to construction safety context. Construction training does take place in simulators nor is the safety training comprehensive education provided over the course of weeks. Therefore, to accurately gauge situational awareness of workers, SAAT was developed for real-time assessments on construction sites. SAAT is a self-report assessment survey tool that examines the ability to identify relevant safety-related information, make risk assessments, project likelihood of accidents, and make a safe decision (Table 1). SAAT would allow safety practitioners and academics to measure situational awareness with high external and ecological validity on construction sites.

Table 1: Situational Awareness Assessment Tool (SAAT)

Situational Awareness Dimension	Description
Hazard Identification	Requires workers to identify all the hazards associated with their task and work environment.
Risk Assessment	Requires workers to rate the level of risk posed by each identified hazard.
Accident Likelihood Projection	Requires workers to rate the likelihood of an accident occurring due to each identified hazard.

Work Environment Knowledge	Requires workers to report their knowledge of workers of work happening around them.
Awareness to Change	Requires workers to report their awareness towards changes in safety information regarding their task and work environment.
Safety Decision	Requires workers to make a decision to stop work to address the safety concerns.

The human factors performance sought here measure the factors that can reduce the cognitive and physical performance of workers on construction sites (Table 2). Furthermore, they can also significantly influence their mental wellness [36-46].

Table 2: Human Performance Factors in SAAT

Human Factors	Description
Familiarity	The amount of familiarity expressed by workers regarding their task and working environment. Familiarity with work can lead to risk normalization among workers.
Attention	The amount of attention required by workers to complete their task. Excess attention or lack thereof towards any task can lead to unchecked hazards and risks.
False Confidence	The degree to which workers believe their experience and skill reduces the risk associated with the work. This false notion of risk normalization can lead to risk-taking decisions.
Fatigue	The amount of fatigue experienced by workers. Fatigue can cause cognitive failures and potentially reduce awareness towards changing work environment.
Personal Stress	The amount of incidental stress being experienced by workers. Incidental or unrelated stress can reduce awareness, increase risk-taking tendencies, and jeopardize decision-making skills.
Work-related Stress	The amount of work-related stress being experienced by workers. Work-related stress (e.g., deadlines, job security, change in management) can cause workers to have differing priorities and safety-related decisions may get compromised.

Cognitive Effort	The amount of cognitive effort being experienced by workers to complete their task. Excessive cognitive effort towards a particular task can cause workers not to pay attention to changes to the hazards and risks in the work environment.
Physical Effort	The perception of the amount of physical effort required by participants to complete their task. Excessive physical effort can lead to fatigue and loss of attention and awareness to changing safety information.
Complexity	The amount of complexity experienced by workers due to task characteristics or work environment. The amount of complexity in the task can make workers over/under-value the risk associated and lead to suboptimal decisions.
Emotional State	The degree to which workers are experiencing positive emotions. Our emotional states have strong and direct relationship with the amount of risk we see in an environment.
Multitasking	The number of tasks that the workers believe they are having to manage and complete at the same time. Multi-tasking can interact with cognitive effort required and reduce hazard recognition performance among workers.
Risk Tolerance	The degree to which workers are willing to accept risks and engage in unsafe behavior is defined as risk tolerance. Safety training programs rarely focus on a worker's inherent desire to accept risks.
Uncertainty Avoidance	The degree to which workers are willing to avoid uncertainty. This unwillingness to engage with uncertainty reflects the level of comfort experienced by workers in a risky situation.
Productivity Prioritization	The degree to which workers prioritize productivity over safety. Not only can this perception and attitude influence safety performance, it is an indicator of safety culture also.
Safety Complacency	The degree of disregard towards safety shown by workers. This could influence risk assessment and risk projection dimensions of situational awareness.

The complete SAAT paper-version is attached in the Appendix. Although, the SAAT was developed as a mobile app[1] and a paper survey, the field-tests confirmed that the contractors and workers unanimously preferred paper over the app version of SAAT for a number of reasons:

1. *Cost*: the cost of hosting fees to maintain the app is prohibitive. This associated cost is the hosting fees (e.g., AWS).
2. *Sampling Constraints*: at any given time, a safety manager or leader will be limited by the number of electronics available to run the app.
3. *Location*: the app sends data from the survey back to servers using the internet, which is a constraint on many jobsites that lack reliable network connection.
4. *Privacy Concerns*: workers on site were more reluctant to download the app on personal devices and participate due to the fear on being easily tracked through IP addresses or time stamps. Thus, surveys provide a better alternative that maintains true anonymity and provides rich data consistently.

FIELD VALIDATION

Location of Data Collection

SAAT was tested and validated by sampling 94 construction workers within the electrical trade sector. The data was collected across Michigan, Indiana, and Ohio on various on-going projects. The survey was deployed by following these steps:

1. *Personalized conversation*: before asking workers to participate in the survey, researcher took time to engage with workers by asking questions, actively listening, and acknowledging their skill and craftsmanship.
2. *Not an audit*: researcher explained that the purpose of this survey was not to audit workers volunteering to participate, rather it is to learn how to improve training programs (i.e., situational awareness) and learning from them how they personally feel about the work they are doing and their work environment (i.e., human factors performance). It is critical for SAAT to be effective that is neither used nor perceived as a job evaluation tool.
3. *Conducting survey*: Workers were reminded the surveys were completely anonymous and could not be traced back to them. Workers were asked to not provide any identifiers on the survey. Once the surveys were distributed, distance was maintained from the workers, so they did not experience any coercion.

[1] Please contact Dr. Sid Bhandari <siddharth.bhandari@colorado.edu> to sign-up and download the app.

Results

These surveys on average took no more than 10 minutes which showcases that SAAT is designed to be consumer facing and is feasible for real-time assessments during work. Each partnering firm received a personalized report for participating in this research where aggregated results on the dimensions of situational awareness was presented. Below are a few highlights that were observed in the pilot test:

1. **Hazard recognition skill:** the hazard recognition skill for this dataset averaged at 33%. Given that the industry average determined over 4,800 worker hours was approximately 45%, the preliminary analysis indicated that the hazard recognition performance of workers within the electrical sector is below the industry average.
2. **Work Environment:** Workers in the same crew across different sites disagreed on the number of tasks happening around them and number of crews working around them suggesting that within crew members there was disagreement on types of hazards and safety concerns facing them. This implies that workers receiving the same training and belonging to same crew may not process safety-related information uniformly.

Combined with poor hazard recognition skills and no alignment on the hazards in the work environment, the crews tested in this pilot investigation report low situational awareness.

On human factors performance front, the dataset showed there was a high level of false confidence, stress, safety complacency, prioritization of productivity over safety, and risk tolerance. The implications of these high level of false confidence, stress, and fatigue have been noted below. Using Pearson's correlational analysis and linear regression models, results showed a number of statistically significant ($p < 0.05$) findings; salient ones are reported below.

1. False confidence can increase productivity prioritization among workers. This suggests that the workers may incorrectly normalize the risks in their environment and partake in risky decisions, given their past experience and self-confidence.
2. Work-related stress was positively correlated with fatigue in workplace and productivity prioritization. In other words, fatigue levels among workers can be exacerbated by their stress levels and encourage them to cut corners when it comes safety. Both personal and work-related stress increases the willingness to accept risks (i.e., risk tolerance) among workers.

3. Positive emotional appraisal for safety can reduce safety complacency, risk tolerance, and productivity prioritization at the cost of safety.
4. Access to information on safety and risk in the environment can reduce false confidence, increase positive emotional appraisal towards safety, and reduce safety complacency.

These findings provide guidance on developing targeted training programs that address these concerns specifically. **Another key albeit preliminary finding was the dimensions of situational awareness (i.e., hazard recognition skills, risk assessment, and accident likelihood projection) were not significantly predicted by the human factors.** This suggests that the low situational awareness among workers observed in this study was not a ***direct*** by-product of poor human factors performance, rather it indicates that the training provided to those workers was lacking. Incidentally, this lack of relationship between human factors and situational awareness is a positive finding because human factors are hard to manage consistently due to the fragmented nature of our industry and work. This finding suggests that if the workers are properly trained on identifying and managing safety concerns, the skill will subject to some, but **not significant** variability due to human factors. The personalized findings reported in this study allow management to:

1. Take dedicated training action,
2. Prioritize human resource management strategies, and
3. Improve leadership engagement and communications.

APPLICATIONS AND RECOMMENDATIONS

Deliverables

This project delivers an accurate, reliable, and practically feasible tool to measure situational awareness and human factors performance of construction workers in any trade and any context. It can be deployed on site regularly to acquire leading safety information from workers without investing significant time or any other resources. This ubiquitously applicable tool is consumer facing while providing critical leading information that is predictive of future safety performance. While the app-based version is designed, tested, and ready for use, it is highly recommended to utilize the paper version.

SAAT can complement safety audits and site inspections by providing information on why compliance may be lacking. It promotes a safety culture that is less reliant on blame and more focused on accountability.

As COVID-19 pandemic hits the industry financially, we must consider the impact on the workforce as well. The immediate financial and emotional burdens associated with shuttering the industry or the physical and mental toll of productivity pressures when the work resumes may present unprecedented challenges. These challenges may cripple the industry already struggling with fatalities, substance abuse, suicides, and recruitment and retention concerns. There is a need to develop and use resources that provide proactive information and implement data-driven strategic management interventions.

Future Steps

To wit, for future steps, it is recommended we test new training programs that supplement pre-job safety briefings each morning to improve hazard recognition performance. Preliminary investigations have shown that tools such as energy-based hazard recognition training can improve hazard recognition performance by 30% on average. Furthermore, an academic and industry think tank should be convened to brainstorm and test management strategies for improving mental and physical wellness of workers in this industry. These research investigations are not only highly critical to avoid financial burdens associated with fatalities, injuries, absenteeism, and turnover rates, but also improve the culture of compassion and accountability. For example, there is a need to investigate empirically the key tenets of a deep-rooted and pervasive safety culture. SAAT is the first step that can inform us on what is missing, next step is to develop strategies to address those gaps.

Acknowledgements

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APPENDIX

SITUATIONAL AWARENESS ASSESSMENT TOOL (SAAT)

Consider the work you are doing, all the work happening around you, and your workspace. Please identify **ALL** the hazards present, rate level of danger associated with each hazard and chance of accident due to each hazard.

HAZARDS	RATE DANGER LEVEL on a scale of 1-7 where 1 means no danger and 7 means very high danger.	RATE CHANCE OF ACCIDENT on a scale of 1-7 where 1 means no chance and 7 means very high chance.
Example hazard	*5*	*3*
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		
9.		
10.		
11.		
12.		
13.		
14.		
15.		

2. How many different *unrelated* tasks are happening around you today? ___________

3. How many different *crews* are working around you today? ___________

4. How many instances of non-compliances around you did you see today? ____________________

5. How many safety controls do you have in place around your work environment? ______________

6. Is there a need to stop work? ________________YES ___________________NO

7. There have been several changes today in my task or work environment (example: change in work plans, disruptions, etc.).

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

8. Safety information (example: hazards, lack of proper PPE/tools, etc.) is always readily available around me.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

9. Information about risk (example: work by other crews, weather, etc.) in my work environment is always readily available to me.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

10. The risk and safety concerns (example: lack of resources, training etc.) in the task I am performing constantly change.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

11. I feel sufficiently familiar with the task I am performing today.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

12. I feel completely focused on my task today.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

13. Because I have done this task many times, the risk is now minimal.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

14. I am feeling more tired today than usual.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

15. Recently, I have been experiencing some personal stress in my life.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

16. Recently, I have been experiencing some work-related stress (example: pressure, lack of resources, lack of communication).

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

17. The work that I'm doing today, and the working conditions are requiring a lot of mental effort from me.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

18. My task today and the working conditions are requiring a lot of physical effort from me

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

19. I find my task procedure and the working conditions today difficult to manage.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

20. Generally speaking, I'm in a positive mood right now.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

21. I prefer to follow the standard operating procedures at all times. No matter the challenges (example: productivity quotas, management pressures, other responsibilities etc.), I make no exception to this rule.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

22. I genuinely feel stressful when I cannot predict the consequences of my actions or the actions of people around me.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

23. I don't usually have time to think or talk about safety when I'm in the middle of my work.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

24. I am constantly having to multitask (example: manage lot of information, do different tasks at the same time).

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

25. Once I take care of PPE and other safety-related rules before starting work, I need to focus on productivity not safety.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

Circle your response.

Age	18-25	26-40	41-50	51-60	60+
Years of Experience in Industry	Less than 12 months	1-3 years	4-6 years	6-10 years	10+ years

Trade and Task: ______________________________________

For more information contact: Dr. Sid Bhandari @ 303-350-7685/siddharth.bhandari@colorado.edu

GUIDELINES FOR THE USING THE SURVEY

This survey has two parts.

Part 1: Situational Awareness: information about the work and surrounding as it relates to safety.

1. **First Question**: Assesses the critical skill level of workers. Here, workers are required to identify all the hazards in their immediate environment, identify the level of risk associated, and provide their estimation of a chance of accident considering the risk.
2. **Second and Fifth Question**: measures the knowledge of workers of work happening around them. The responses to these questions can be used to generate meaningful safety engagement to address any misalignment between crew members.
3. **Sixth Question**: measures the willingness to make decisions to stop work for safety.
4. **Seventh to Tenth Question**: measures the awareness of workers towards any **changes in safety information or perceived level of awareness** pertaining to their task or work environment.

The responses to these questions can be compared against the foreman's responses or safety manager's as a baseline to address any gaps in the knowledge and heighten awareness towards changes. It can also strengthen the safety culture of the organization to have management or leaders on site to participate alongside workers.

Part 2: Leading Indicators that Influence Situational Awareness: these questions seek to measure different human performance factors that has been found to reduce workers cognitive and physical performance in work environment.

1. **Eleventh Question**: the level of **familiarity** reported by the worker for the task on hand.
2. **Twelfth Question**: the level of **attention** reported by the worker for the task on hand.
3. **Thirteenth Question**: the level of **false confidence** experienced by worker.
4. **Fourteenth Question**: the level of **fatigue** experienced by the worker.
5. **Fifteenth Question**: the level of **stress** experienced by the worker due to *personal* events.
6. **Sixteenth Question**: the level of **stress** experienced by the worker due to *work-related* events.

7. **Seventeenth Question**: the level of **cognitive effort** experienced by the worker for the task on hand.
8. **Eighteenth Question**: the level of **physical effort** experienced by the worker for the task on hand
9. **Nineteenth Question**: the level of **complexity** experienced by the worker to manage the task and environment.
10. **Twentieth Question**: the current **emotional state** of the worker.
11. **Twenty First Question**: the level of **willingness** shown by the worker to follow rules and protocols. (*)
12. **Twenty Second Question**: the level of **discomfort** shown by the worker towards uncertainty.
13. **Twenty Third Question**: the level of **complacency** shown by the worker towards safety when focusing on work.
14. **Twenty Fourth Question**: the required level of **multitasking** reported by the worker.
15. **Twenty Fifth Question**: the degree to which worker favors **productivity over safety** towards changing information reported by worker after abiding by the fundamental rules and procedures.

Data Entry: All individual questions assessed by noting: Strongly disagree, disagree, neutral, agree, or strongly agree. For quantitative analysis, a strongly disagree was scored as 1; disagree was scored as 2, neutral was scored as 3; agree was scored as 4; and strongly agree was scored as 5. Question#21 on risk tolerance is stated in negative, therefore was reverse scaled and converted. Once scaled, higher numbers correspond to higher score of risk tolerance.

Because the survey is anonymous, there is guarantee that the responses cannot be traced back to one individual nor can an employer cause a participant any grievance over this project. The participation is purely voluntary. The researcher will be present on site to collect the data and take it back to the lab for analysis, the employer will not be allowed access to individual surveys at any time. Participants will be informed of these facts. Therefore, we believe that these sensitive questions may get close to honest responses from most workers.

Total Anticipated Time: 10-15 minutes.