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Agent-Based Modeling of Near Miss Incidents by Integrating Construction Site Dynamics with Enriched Worker Behavior

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AGENT-BASED MODELING OF NEAR MISS INCIDENTS BY INTEGRATING CONSTRUCTION SITE DYNAMICS WITH ENRICHED WORKER BEHAVIOR

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To: Dean John Volakis
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This thesis, written by M. Ahmed Rusho and entitled Agent-Based Modeling of Near Miss Incidents by Integrating Construction Site Dynamics with Enriched Worker Behavior, having been approved in respect to style and intellectual content, is referred to you for judgment.

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Florida International University, 2021

DEDICATION

I dedicate this thesis to my beloved family for their endless and unconditional love and support.

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ABSTRACT OF THE THESIS

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by

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Florida International University, 2021

Miami, Florida

Professor Arif Mohaimin Sadri, Major Professor

The construction industry workforce weighs a major percentage of the overall business industry manpower. Due to the unknowns and uncertainties associated with construction activities, the construction industry experiences high frequency of accidents every year. Over the years, researchers have made valiant efforts to address this issue. The existing literature comprises thorough analyses of behavioral, organizational, and infrastructural modules that have reinforced the implementation of better construction safety practices. Recent advancements in construction safety literature imply the application of agent-based models to integrate behavioral attributes into simulated construction environments. Nevertheless, such studies adopted schematic approaches to replicate the hazard scenario in construction sites that varies significantly for different construction activities. Moreover, existing agent-based models have limitations to incorporate minor incidents occurring frequently in construction sites. Hence, a predictive analysis of near-miss events can support the decision-makers to adopt proactive construction safety measures. This study aims to assess the resilience metrics of construction sites in terms of near-miss chances by applying the risk behavior of agents derived from an extensive survey.

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CHAPTER I: INTRODUCTION

1.1 Motivation

The construction industry workforce weighs a large share in the overall industry workforce. Unlike other industries, the injury rate in the construction industry is extremely high. Recent statistics reveal that the industry experiences nearly one-fifth share of the overall workplace fatalities [1]. Hence, ensuring safety in active construction sites is a major concern all over the world [2]. Construction safety is a complex concept that involves the integration of uncertainties and unknowns associated with construction activities. The construction industry requires expertise from multifaceted professionals who differ widely in hazard identification, risk perception, and situation analysis [3]. To address the problem, valiant efforts have been made by researchers over the years. The existing literature shows extensive analyses of infrastructural, behavioral, and organizational modules in construction sites that have contributed to significant changes in construction safety practice. Many researchers have interpreted construction hazards in terms of site layout screening, construction stages, and activities [4]–[6]. The recent paradigm for construction safety relies more on the cognitive models and the behavioral impacts of the construction stakeholders [3], [7], [8]. However, extensive construction safety analyses for active sites call for the integration of construction stakeholder perception along with the site risk screening approach.

1.2 Research Background

Technological advancement has paved the way for predictive analysis of construction hazards. The array of research on modeling of near-miss events has progressed from theoretical analysis to visualization with the help of the Building Information Modeling (BIM) tool [1], [9]. Construction site characteristics vary widely depending on the size and settings. Nevertheless, the components of the site (i.e. workers, materials, equipment, etc.) have similarities in features[10]. Therefore, the concept of site hazard modeling follows the grouping or zoning of the site layout constituents having relevant attributes. Hammad and Zhang have proposed a Discrete Event Simulation (DES) model for improving construction site safety and productivity in real-time for static and dynamic site components [11]. Hegazy used various scheduling intervals to develop cell-based site layout optimization [12]. A cell-based simulation model has also been used to derive the congestion and productivity of an existing site layout using Agent-based Modeling (ABM) [13]. On the other hand, Shen and Marks have utilized equipment footprints to determine hazardous zone boundaries in a construction site [14].

The agent-based modeling (ABM) approach facilitates the inclusion of complex behavior into the model. Since modeling the construction environment involves construction workers' attributes, ABM has been preferred by a wide range of researchers to identify latent contributing variables of construction hazards. For example, it has been explored to determine the influence of safety behavior of the workers in workplace productivity [15], [16]. ABM models have also been used to investigate a comparative analysis of the efficiency of different types of safety investments [17]. On the other hand, some researchers identified the impact of the worker-management relationship on the overall safety behavior of the workers [18]. While these studies provide insights on integrating human behavior into the modeling framework and reveal the potential of ABM, however, in many instances the worker perception is not captured with sufficient details for which such frameworks are difficult to realize in practice. In addition, the empirical literature is inclusive of how extreme weather events further escalate these challenges.

1.3 Research Objectives

The objective of this research is to develop an agent-based modeling framework that integrates worker risk perception on various construction hazards. This research will focus on identifying near-miss events and site layout optimization incorporating construction site dynamics. However, it will also capture their changes during extreme event scenarios.

CHAPTER II: LITERATURE REVIEW

2.1 Studies on Identification of Construction Safety Factors

The construction site operation is highly dependent on the active participation of construction workers. Most of the assigned tasks are laborious and require the high-level engagement of management and workers. Hence, the interdisciplinary nature of the construction activities induces underlying factors which contribute to the construction hazards directly or indirectly. Over the years, researchers have conducted several studies to identify such critical factors that have possibly influenced construction fatalities. Abdel Hamid has developed a model called the Accident Root Causes Tracing Model (ARCTM) where he has investigated three real-life road construction accidents [19]. The ARCTM model hinges on two different domains: (1) Accident Causation Theory, (2) Human Error Theory. Based on the theories and accident investigative report, the model analyzes the source of the construction accidents due to unsafe work conditions, reaction of the workers to the unsafe work conditions, and unsafe work maneuvers. The model also prescribes corrective measures that can help construction practitioners to avoid such unexpected occurrences. ARCTM model is a predictive method of construction hazard analysis whereas Hamid also worked on reactive methods. He conducted an extensive survey study in Malaysia over 140 construction sites to identify the most frequent construction hazard types [20]. The survey covered a wide array of construction projects such as development projects, high-rise constructions, industrial, and institutional construction works. The research methodology was designed with 2 criteria: hazard assessment, and hazard frequency. Based on the scorecards, the study identified 12 types of major construction hazards that cause physical injury hazards and health hazards (long-term side effects). The study covers the primary work categories and the hazards associated with them.

While many researchers focus on discerning the causes of the construction hazards, some studies emphasize on identifying the impact of the construction hazards, i.e. health effects on construction workers. Construction workers suffer from musculoskeletal, respiratory, and cardiovascular diseases due to prolonged exposure to the construction environment [21]. Tunji-Olayeni and Schneider highlighted the required outlines of construction ergonomics to assess and mitigate the aftereffect of construction injuries from a different perspective [5], [21]. Though the spatial and temporal aspects of the studies covered construction practices from two entirely different countries (e.g. Nigeria, United States), however, the band of potential hazards contributing to health issues was somewhat similar. Both studies identified the group of ergonomic hazards related to major construction activities. Schneider's research provides the safety threshold parameters to minimize work fatigue [5]. On the other hand, Tunji-Olayeni's research also contributes to the effect of occupational health hazards in workplace productivity and enlightens on the role of management commitment in such occurrences.

Since construction projects involve multiple activities in the execution phase, most of the studies highlight the construction hazards attributed to overall construction tasks. But, particular tasks require additional attention while being performed by the workers. Similarly, among different construction hazards, a certain group of hazards contributes to the major number of construction accidents (e.g. fatal four hazards). For example, from 1990 to 2005, 22% of construction accidents occur due to struck-by hazards as per OSHA's records [22]. Hence, studies on individual hazards or activities with high casualty frequency have unfolded different dimensions of root cause analysis. Hinze has demonstrated the accident statistics of struck-by hazards from different categories: age, equipment, human factors, and environmental factors [22]. Similarly, Shapira has assessed the influencing factors in construction tower crane operations with the support of statistical and expert knowledge sources [23].

The studies mentioned above provide thorough guidance on the key metrics of construction hazards related to construction activities or workplace layout. Nevertheless, construction site constituents are not the only contributors to construction hazards. Namian and Sawacha identified such latent variables that influence the safety functionality of the construction sites [3], [24]. Namian conducted Job Safety Analysis (JSA) based on historical methods and predictive strategies and identified a set of variables that have direct correlations to the construction hazard impacts. The final set of variables consist of construction individuals' characteristics, socio-demographic aspects, organizational factors, social, and miscellaneous factors, economic, historical, and psychological factors [3], [24]. Jannadi extended the factor identification analysis with the use of Spearman rank correlation efficient for 19 different construction factors which not only identified the variables but also provided their importance index. The index values were developed based on the interviews taken for both: construction safety officers and workers of the top 200 construction contractors in the U.K. Hence, the ranks provided an even picture of the overall construction site scenario. Carter adopted a similar but more extensive hazard rating system where he used the method of statements for pre-analysis of the potential hazards [6]. The hazard identification indices paved the way to recognize unidentified hazards derived from typical behavior-based safety (BBS) techniques.

The enriched literature on the identification of construction hazards has led construction researchers to explore predictive methods and address the potential hazards from the planning stage. Such a study has been proposed by Gambatese who has developed a framework to mitigate the hazard potentiality of construction sites using effective design methods [4]. The details of the progress of such predictive analyses will be discussed later in this chapter.

2.2 Studies on Construction Hazard Perception

Many studies have inferred personal factors to be one of the major contributors to the hazard recognition process [3], [24], [25]. Personal factors such as safety knowledge, safety behavior, management influence, emotional state of the workers influence their decision-making abilities in the construction sites [3]. Hence, a group of researchers has developed risk modeling frameworks using cognitive analysis. Goldenhar developed a multi-predictor stress-injury model where he found multiple key predictors to be directly related to worker behavioral characteristics [9]. In his study, predictors such as safety climate, training, co-worker/ supervisor support also portray that hazard perception is highly influenced by organizational management skills. Fang's research also echoed the effect of safety communication, knowledge, and management-worker relationship to play significant roles in unsafe acts and behaviors [26].

Recent advancements in perception-oriented construction hazard studies underscore building cognitive models to incorporate unrecognized potential hazards due to cognitive failure [7], [8]. Fang and Zhang both adopted staged cognitive models to segregate different levels of cognitive failures [7], [8]. The theory of Surry's model helped Zhang to evaluate cognitive failure steps in terms of attitude, subjective norm, and perceived behavioral control termed as Theory of Planned Behavior (TPB) [8]. The statistical scores of the path analysis of TPB support the validity of the model and explain the causes of worker unsafe behaviors in an innovative fashion. The cognitive analyses on worker risk perception explain the rationale of unsafe behaviors and acts which can be prescribed for improving the risk apprehension in a construction environment. However, the roots of workplace safety norms can be further traced back to long-term safety practices. Some of the studies have explored that the socio-demographic background of workers plays a vital role in shaping their risk perception. For example, Menzel conducted his research on the Latino worker community who constitutes nearly 40% of the construction workforce in the U.S. labor industry [27]. His study shows that disparity in financial security, healthcare insurance, immigration status, etc. varies widely among different communities, hence workers inheriting different race/ethnicity (e.g. Latino, Hispanic) have different risk perceptions.

2.3 Studies on Construction Environment Hazard Mapping

The construction environment is occupied with equipment and machinery, temporary facilities, materials stations, and so on. Depending on the path of worker movement and nature of works, certain areas of the construction site pose a higher hazard potential. So, zoning of hazardous areas in a construction site can alert the construction workers and management to avoid potential injuries. Tarek studied the effect of optimizing site layout plans considering safety parameters [12]. The study proposed a model named "Dynamic Layout Planning" that reallocates the temporary facilities in a construction site leveraging the fastest schedule of construction activities. Geographic Information System (GIS) was used to extract the spatial context of the construction sites in the model. The optimal positions of the temporary facilities were obtained using closeness relationships of the facilities. Nevertheless, the construction safety zones and restricted site perimeters were not compromised in attaining the highest efficiency of the site progress.

Another tool for sorting potential hazards in a construction site is Building Information Modeling (BIM). BIM is traditionally used by construction design professionals for pro-active three-dimensional design and modeling of construction structures. Shen and Marks used the tool to visualize the near-miss reports within the site and take administrative controls over them [1]. "Near-miss" is a common concept used by the Occupational Safety and Health Administration (OSHA). It is defined as an incident where there is no actual damage or casualty within the site but given a slight shift in time or space there could have been damage occurred [1]. The study focuses on safety-leading indicators that are a proactive method of implementing safety programs. In this study, the manual near-miss inspections are plugged into the BIM for visualization and the near-misses are filtered based on the management preferences. Therefore, it gives the safety inspectors a comprehensive picture of the overall site hazard assessment and enables them to take actions well ahead of the timeframe.

Preliminary assessment and flagging risky zones in a construction site provide an initial screening of the risk factors in the existing context. When the site switches to the operational mode, there is significant movement of the workers and machinery, and the initial assessment is no longer valid. This is because hazard proximity zoning is highly dependent on human-equipment interaction [14]. So, to produce a more efficient way of predictive analysis of near-miss events, multiple researchers have produced heatmaps using equipment footprints and defining different hazard zonings for different equipment based on their attributes [10], [14], [28]. Golovina created a hazard index heat map to evaluate the risk potential (i.e. struck-by and caught in between hazards) of the workers on foot [28]. He assigned weights on the proximity conditions. The weights are proximity instance and blind-spot dependent. Golovina's work guided on generating an overall hazard indexing framework but did not explore the shape of the proximity zones around the equipment. Shen and Marks incorporated the method of calibrating the proximity zones of the equipment [14]. The research inspected the equipment footprints to generate individual equipment equations and locate the hazard strips within the site more precisely.

2.4 Studies on Hazard Identification Using Cell-based Information and Agent-based Modeling

Cell-based models are used for both simulation and agent-based modeling frameworks. In the cell-based models, the construction site is divided into multiple grids and the progression of the simulation is dependent on the transition of information through the grid system [29]. Aside from construction safety analysis, cell-based simulations are popular for improving site operation efficiency too. For instance, A cell-based simulation system has been used to identify congestion-index and improving earthmoving operations in construction sites [13], [30]. Hammad used cell-based discrete event systems to simulate the construction environment considering the Spatio-temporal requirements [11]. The study covers both construction safety and productivity by application of conflict rules to control the movement of equipment and other objects.

Agent-Based Modeling (ABM) is a technique used for micro-scale simulation which takes each agent's behavior to reflect on the overall analysis of the system. It is a bottom-up approach where the interaction of the agents and their behavior develops a macro description of the system to provide valuable insight into the mechanisms and behaviors that result in jamming or casualties. ABM helps scale and tune agent complexity and behavior and capable of handling modern data with precision and detailing [31]. The extensive detailing of the ABM frameworks has triggered the widespread use of agent-based modeling. Since evacuation decision-making prominently relies on the behavioral aspects of the evacuee, several agent-based models have been developed by researchers over the years. For example, the help-seeking behavior of communities has been simulated for hurricane scenarios using agent-based modeling [32]. The recent advancements in safety behavior modeling show significant correlation of behavioral attributes of the workforce in construction safety management. Therefore, recent studies have explored agent-based modeling in quantifying safety, productivity, and behavioral parameters. Raoufi integrated fuzzy logic into agent interaction rules [33]. Watkins used agent-based modeling to establish the relationship between labor efficiency (i.e. actual work vs scheduled work) and construction site congestion [34]. Lu underscored using agent-based modeling over equation-based modeling in inspecting the role of safety investment in improving the safety performance of construction sites [17]. The agent-based model outputs were plugged into a safety management tool named Proactive Construction Management System (PCMS) which shows the prospect of agent-based models into real-life construction projects. The model finally measured the comparative efficacy of PCMS, safety supervisor employment, and influence of co-worker safety influences. Similar research objectives have been pursued in other agent-based models where different management decisions (i.e. decision of safety inspection, training, supervisor’s intention, senior management strategy) have been replicated in terms of safety knowledge, awareness, subjective norm, safety attitude, and so on, as well as the effect of safety behavior, has also been quantified as near-miss/

accident events [16], [18]. Binhomaid plotted site obstacles in his agent-based modeling framework to evaluate site productivity including the safety behavior of the construction workers (i.e aggressive or avoided) and measured their impact on the site productivity [15]. The study also examined the effects of changes in construction site policies including safety rewards.

2.5 Knowledge Gap

The advancements in integrating agent-based modeling into the construction arena have unfolded many possibilities. The empirical studies have highlighted different domains of construction challenges to mitigate hazards in the construction sites. On the other hand, it is evident from the studies on worker risk perception that worker behavior is one of the crucial contributing factors in hazard identification. Even though the existing applications of agent-based modeling in construction safety have guided on modeling potential hazards in a construction site, a thorough understanding of a construction site hazard scenario is still missing due to low input of worker risk perception in the modeling framework. Besides, in case of any extreme weather scenario, there are sudden changes in the construction work plans before the site is temporarily shut down. During the lead time of a site closure, there might be changes in the worker's behavior due to the emergency. These changes in the worker’s risk perception due to deviation in the weather scenario need to be explored. Hence, this study aims to develop a behaviorally enriched framework for the identification of hazard hotspots and near-miss events that will also capture the impact of behavioral changes in extreme event scenarios.

CHAPTER III: METHODOLOGY

3.1 Conceptual Framework

The existing literature guides on capturing the risk perception of the construction practitioners through different survey methods. Additionally, existing agent-based modeling frameworks reveal the potential of the approach in replicating real-life construction scenarios. So, the research methodology is designed in two reciprocal approaches: data-driven and agent-based modeling. The proposed framework consists of three sections of the construction site: static (i.e. site layout elements), dynamic (i.e. workers, management officials, equipment, etc.), and virtual components (interaction between different components).

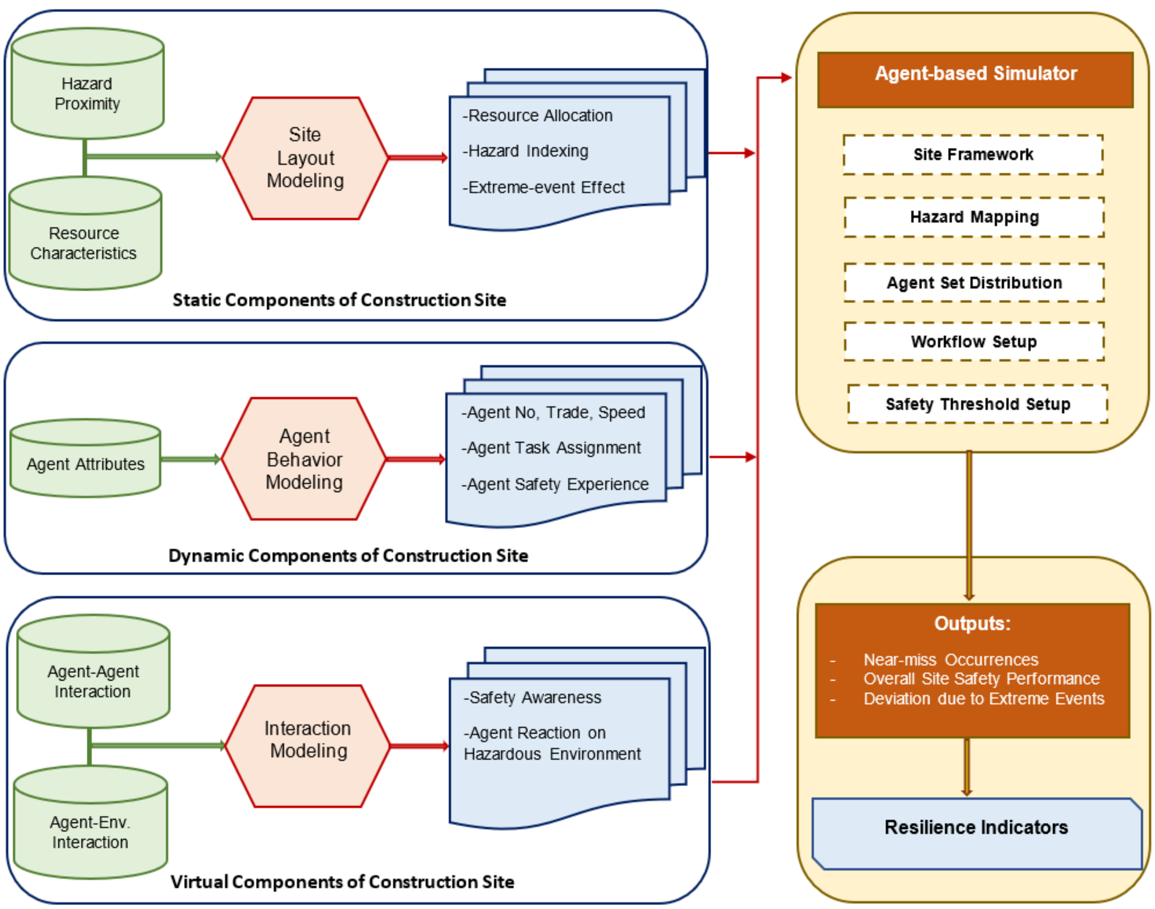


Figure 1: Conceptual Framework

The data for these three components is contingent on the site characteristics and their elements. The scope of controlling the static components (e.g. size, layout, location, etc.) of a construction site is limited. Whereas, the user has more control over the dynamic and virtual components of the framework. For this study, the data-driven approach contributes to the key elements of interaction and behavior modeling whereas the site layout modeling is sourced by empirical guidance from a thorough literature review. The data input of the components is plugged into the agent-based simulator. For this study, NetLogo has been used to develop the agent-based model. The model inherits various parameters which can be utilized to generate the construction site environment into five progressive steps: site framework, hazard mapping, agent set distribution, workflow setup, and safety threshold setup. The output of the model measures the safety metrics of a construction site in three different aspects. Firstly, the proposed model measures the near-miss chances in a construction site after analyzing the human-machine close interactions. Secondly, it weighs the overall site safety functionality based on the given workflow setup. Lastly, it shows the impact of extreme event scenarios on the first two safety metrics and their relative deviation. The conceptual framework is represented in Figure 1 with the steps used in the methodology.

3.2 Data Collection

The data collection process involves two steps: (i) Designing a comprehensive questionnaire survey to glean the behavioral insights of construction workers, (ii) Conducting the survey.

3.2.1. Designing Questionnaire Survey

The questionnaire includes 47 questions divided into five sections: (1) work information, (2) risk perception, (3) project information, (4) important project execution variables, and (5) background information. Each section is designed to comprehend the different attributes of the survey participants.

Goldenhar mentioned a series of organizational factors which are labeled as “work-stressors” and directly impact the injury and near-miss outcomes such as job control, job certainty, safety climate, training, tenure of job, and so on [9]. The work information section of the survey is designed to reveal organizational insights. The questions focus on organization type, the role of the participant in the organization, job control, and security, work stress, workplace interactions, supervision duties, safety culture of the organization (i.e. in the form of arranging regular safety training for the employees as per OSHA requirement), safety behavior (i.e. regular practice of using PPE in the site), emergency management services (existence of emergency management team in the organization), etc.

The risk perception section of the survey consists of the man-made and natural potential hazards associated with different construction activities. Many studies have delineated the major construction hazards, their relevance to different construction activities (both major and minor activities), and their effects on overall construction site safety [4], [20]. The risk perception section has been outlined based on the literature to cover the broad spectrum of the construction arena. The list of man-made hazards includes tipping hazard, fall hazard, electrocution, struck-by hazard, caught-in-between hazard, pulled-into hazard, equipment positioning hazard, lifting hazard, work stress, miscommunication, excavation hazard, stacking hazard, and noise. The list is inclusive of the "fatal-four" hazards (i.e. fall hazard, electrocution, struck-by, and caught-in-between hazard) which weighs the major portion of the construction injuries. For example, struck-by hazards comprise nearly one-fifth of the overall construction fatalities as per OSHA's records [22]. The list of natural hazards includes heat effect, wind effect, visibility, wildlife, flooding. The list of construction activities comprises substructural activities (e.g. foundation, piling works, etc.), superstructural works (e.g. roof works, column and beam works, etc.), plant and machinery (i.e. works requiring heavy machinery usage such as cranes, excavators, etc.), scaffolding, power access works (i.e. works requiring electrical connections for execution such as drilling, chipping, etc.), ladder works, manual handling (i.e. works requiring the use of manual equipment), curing, Haz-Mat (i.e. works that involve use of hazardous chemicals), and public exposure (i.e. works performed within active public communities or near the areas where there is public movement such as repair works). Based on the experience of the survey respondents in the aforementioned construction activities, the individual is directed to the follow-up questions to rate the risk of each of the listed hazards on a scale of "1" to "5". Since the survey focuses on the deviation of the perception due to weather effect, the rating is captured for both "day-to-day" and "extreme" event scenarios, where "day-to-day" event denotes the execution of construction activities in a regular weather environment and "extreme" event denotes the workflow during the "lead-time" before the construction site is closed due to the extreme weather phenomenon (e.g. flooding, hurricane, etc.). Obviously, the construction sites remain closed when extreme weather events strike the communities. But, before the sites are shut down, there is a "lead-time" provided to the construction site operation team to wrap up the ongoing activities without necessarily changing any major changes in the site layout. The survey aims at apprehending the deviation in workers' risk perception due to sudden change in the weather scenario.

The project information section includes questions on project type, area, scope as well as worker, equipment, and schedule requirement of the project. As the modeling framework requires site layout data input, the information gathered in this section can be used to generate individual datasets for different projects.

The important project execution variables section focuses on the indirect factors that can hamper the productivity and schedule of the project such as quality of material, project location, road connectivity, climate, etc. In this section, the participant is also asked to rank the impact of different extreme weather phenomenon on a scale of "1" to "5" in terms of their impact on the construction schedule.

The background information section focuses on covering the socio-demographic details of the construction workers. Many studies suggest that social and personal factors have latent impacts on workers' safety behaviors [3], [25]. Besides, Menzel has observed that socio-demographic features like race, ethnicity, etc. shape workers' long-term safety knowledge and perception to contribute to their injury probability (e.g. high construction injuries observed among Latino workers) [27]. So, the survey questions of the background information section inquire on the age, gender, race, education, native language, annual income, professional experience, and safety training experience to sort the high impact attributes of the construction workers. The highlights of the survey questionnaire are illustrated in Figure 2.

Work Information

- Organization Type
- Role in Organization
- Job Control
- Job Stress
- Workplace Interactions
- Supervision Role
- Safety Culture
- Safety Practice
- Emergency Management

Risk Perception

- Risk Rating
- Construction Activities
- Construction Hazards
- Weather Impact

Project Information

- Project Type
- Project Area
- Project Scope
- Worker, Equipment Requirement
- Project Duration

Important Project Execution Variables

- Impact of Indirect Factors on Construction Schedule
- Impact of Extreme Events on Construction Schedule

Background Information

- Age
- Gender
- Race
- Education
- Native Language
- Annual Income
- Experience
- Safety Training

Figure 2: Questionnaire Focus on Different Sections of the Survey

3.2.2. Conducting the Survey

The questionnaire survey is designed with the Qualtrics Survey Software. Due to the COVID-19 restrictions, the survey was conducted on construction practitioners through their online participation. The survey was circulated on September 08, 2020, via social media platforms like Linkedin as well as construction professionals, students were invited to participate in the survey by emails. The survey was closed in March 2021, for data analysis.

3.3 Data Analysis

The data analysis methodology includes three steps (i) Data Cleaning, (ii) Statistical Modeling, (iii) Scenario Testing.

3.3.1. Data Cleaning

The survey response was extracted as a CSV file from the Qualtrics server. The unnecessary data columns were cleaned off the resultant CSV file. The survey received 108 responses out of which 85 respondents finished the survey questionnaire. The unfinished responses were trimmed for further analysis. Since

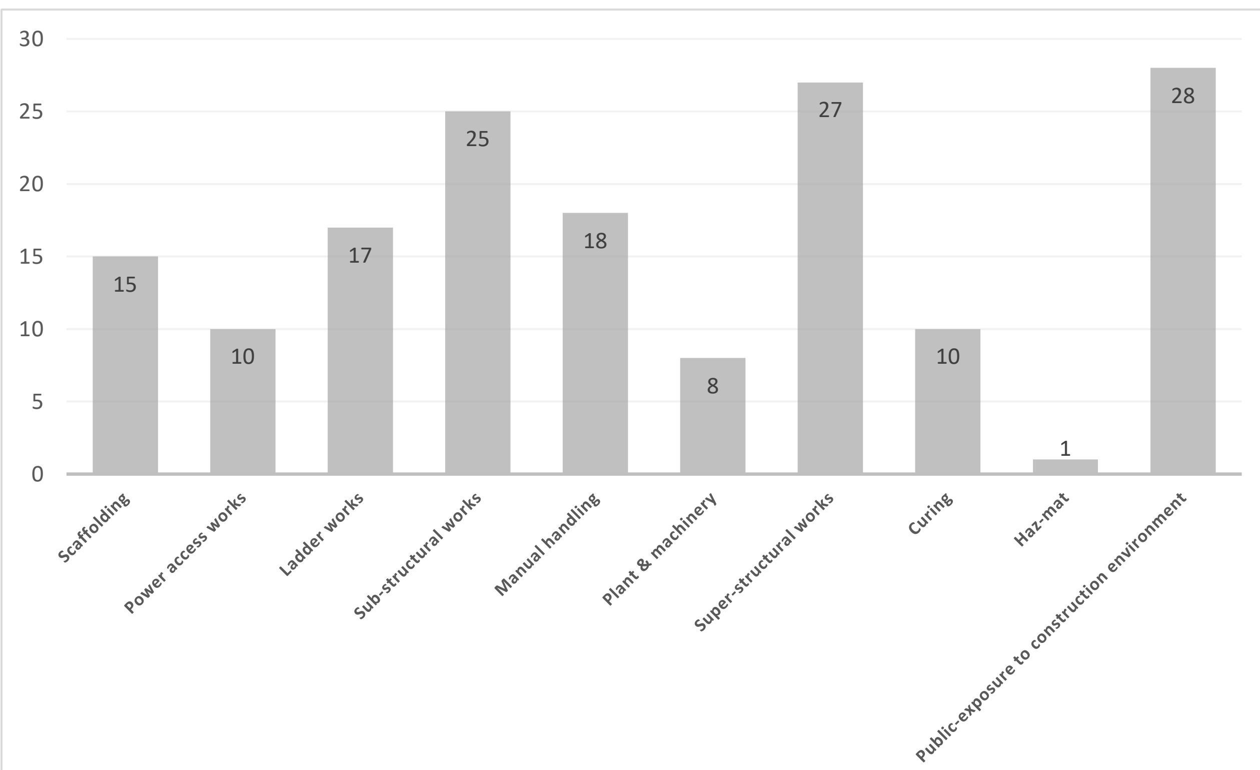


Figure 3: Response of Participant Involvement in Different Construction Activities

several participants had prior experience with multiple construction activities, they had answered follow-up risk rating questions for multiple activities. The construction activities that received the highest number of responses were *public exposure to the construction environment, superstructural works, and substructural works* in descending order. The overview of the responses based on engagement in different construction activities is illustrated in Figure 3. The objective of the study is attributed to capture the risk perception of fatal four hazards (i.e. fall, electrocution, struck-by,caught-in-between hazard) for different construction activities. Hence, the risk ratings for these four types of hazards have been chosen for further analysis using STATA software.

3.3.2. Statistical Modeling

The risk ratings for the fatal four hazards are dependant on a wide array of contributing factors. The risk ratings are received in the ordered format (i.e. 1, 2, 3, 4, 5). Multivariate modeling has been one of the popular approaches to analyze similar datasets. Multivariate modeling can construe the interrelationships between the contributing factors and the risk ratings and can measure the degree of influence of the contributing factors on changing the ratings statistically. For example, Sadri used the ordered probit model to capture the effect of evacuation characteristics, socio-demographic characteristics, and other parameters on evacuation decision-making [35]. For this study, an ordered probit model has been used to comprehend the risk perception analysis in the most explanatory manner. The criteria for selecting the ordered probit model over other models are hinged on a few parameters. For example, the ordered probit model does not consider the response categories to be in the same intervals. Even though the rank orders in this study are labeled as “1”, “2”, “3”, “4”, “5”, it only reflects their ordinality. Secondly, some of the statistical models like the linear regression model consider two respondents to be identical if they have the same response. Since ordered choices account for a range of answers into individual categories, two respondents with the same response may have differences in attributes [36]. Therefore, the ordered probit model has been used here in this study.

The ordered probit model uses the following function with a basic assumption that Y* varies linearly with X, where Y* is the dependent variable (i.e. the risk ratings of the hazards with an ordered ranking from "1" to "5") and X is the vector of variables that contribute to the explanatory aspects of the risk perception:

$$Y^* = \beta X + \varepsilon \tag{1}$$

β is the vector of the parameters and ε is the error term. The error term is assumed to follow a normal distribution with a cumulative distribution labeled as $\Phi(\cdot)$. For a given set of variables, Y* falls within the range of $T_{n-1} < Y^* < T_n$ where T is the threshold or cut point and *n* range from 1 to the number of categorical choices (i.e. 1, 2, 3, 4, 5 for this study). The probability, *P* is as follows:

$$P\,(y = n) = \Phi(T_n - \beta X) - \Phi(T_{n-1} - \beta X) \tag{2}$$

Here, T_0 is equal to zero and T_5 is equal to infinity and $T_4 > T_3 > T_2 > T_1$.

3.3.3. Scenario Testing

The ordered probit model provides the final set of equations with the deciding vector of parameters and explanatory variables. Using equation (2), the probability of the risk perceptions can be achieved. In this study, the probabilities of risk perception for fatal four hazards have been computed. The probabilities have been assessed for substructural works, superstructural works, and public exposure to construction environment works and both the weather scenario ("Day-to-Day" and "Extreme" event) have been considered. This set of calculations has been considered as the "observed" probability. Using Monte-Carlo simulation eight different scenarios have been created with varying parameters. Monte-Carlo simulation is a methodical approach of random sampling which ensures the randomness of the scenario [37]. In this study, 50% of the observed values have been altered to create each of the scenarios, and the probability computed with the altered set of variables has been considered as the "predicted" probability for the comparative analysis. Scenarios 1 and 2 are generated by increasing 50% of less experienced workers and decreasing 50% of less experienced workers in the construction site respectively. In other words, Scenario 1 replaces 50% of the existing experienced workers with inexperienced workers (i.e. experience <= 2 years) in a construction site and vice-versa for scenario 2. Scenario 3 and 4 shuffle the workforce based on their prior safety training. Scenario 3 produces the risk perception probability with 50% more workers having safety training than the observed condition and vice-versa for scenario 4. Scenario 5 is a combination of scenarios 1 and 3. Similarly, scenario 6 is a combination of scenarios 2 and 4. Scenario 7 and 8 weighs on the safety awareness of the employer (i.e. whether safety training sessions are arranged by the employer as per the OSHA requirements). Scenario 7 produces the predicted probability score for a dataset with a 50% improvement in the safety culture and vice-versa for scenario 8. An overview of the eight scenarios is illustrated in Figure 4.

Scenario 1

- Less experienced workers 50% increased

Scenario 2

- Less experienced workers 50% decreased

Scenario 3

- Safety trained workers 50% increased

Scenario 4

- Safety trained workers 50% decreased

Scenario 5

- Less experienced workers 50% increased and Safety trained workers 50% increased

Scenario 6

- Less experienced workers 50% decreased and Safety trained workers 50% decreased

Scenario 7

- Safety culture 50% improved

Scenario 8

- Safety culture 50% deteriorated

Figure 4: Different Scenarios for Predicted Probability

3.4 Agent-based Model

In this study, NetLogo has been used to develop the agent-based modeling framework. NetLogo is used by researchers from different spectrums to model micro-level simulation results. NetLogo allows independent user input for numerous "agents" to operate in the simulation environment [38]. The latest versions of NetLogo include user-friendly interface features (e.g. "input" options, graphical "speed controller", etc.), optimized BehavioralSpace tool, execution of actions in desired orders draw interests of many research enthusiasts to user NetLogo over other agent-based modeling platforms [39]. As shown in Figure 1, the model layout is generated in five consecutive steps: (i) site framework, (ii) hazard mapping, (iii) agent set distribution, (iv) workflow setup, (v) safety threshold setup. Figure 5 demonstrates the interface of the agent-based model with all the action keys, variable inputs, and output plots of the model.

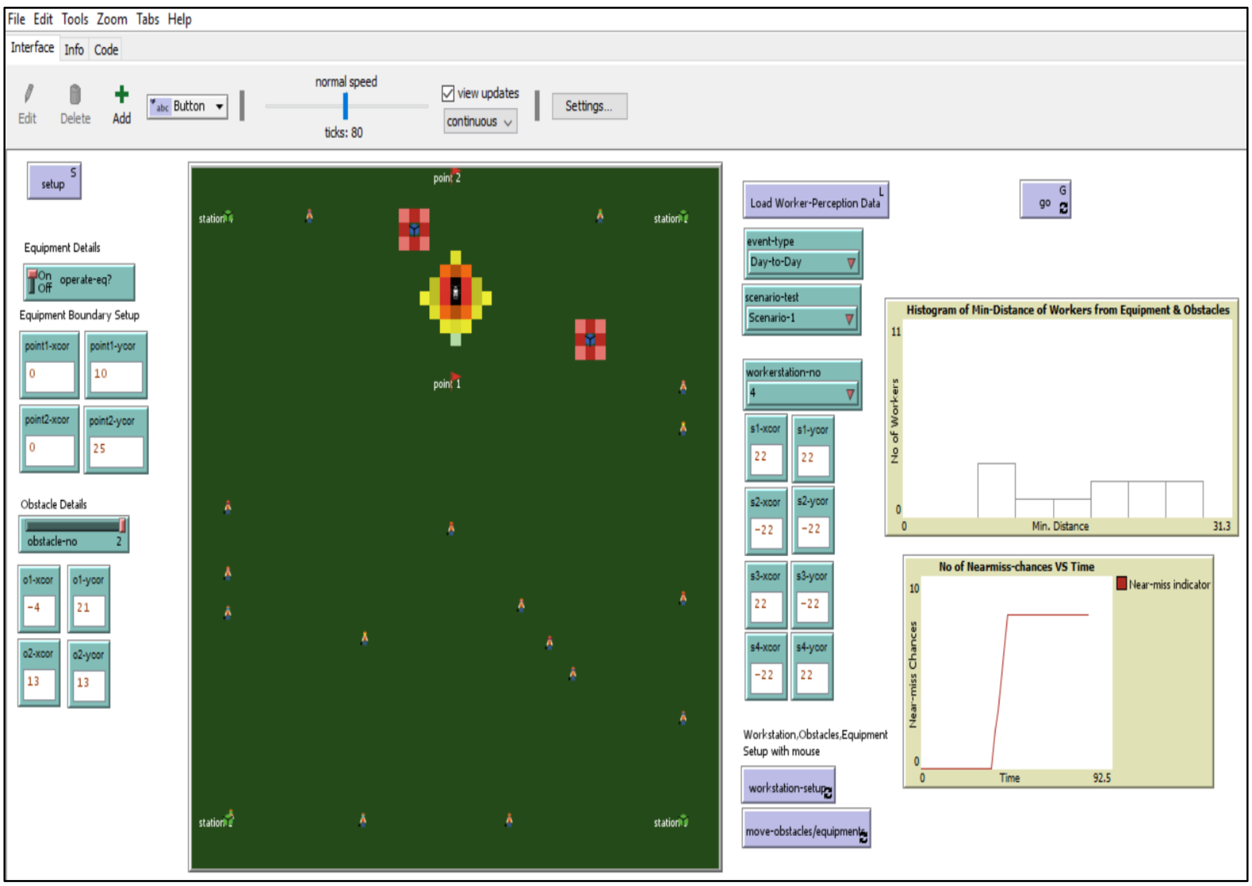


Figure 5: Agent-based Modeling Framework

3.4.1 Site Framework

In this agent-based model, a hypothetical construction site has been designed. For a real-life scenario, the site layout information should conform to the "project information" section of the questionnaire survey and the detailing should adhere to the construction worker responses who are the actual focus group of the survey. In this model, the site is assumed to be 100m*100m and each patch represents 2m*2m. Each tick resembles 1 second in real life. The dimension and speed of the agents have been scaled accordingly. The model has one excavator representing "equipment and machinery". The "operate-eq?" switch allows the user to choose whether the excavator is in operational mode or not. If the excavator is in operational mode, its footprints can be set by the users labeled as "point 1" and "point 2" in the graphical interface. The entry of x-coordinate and y-coordinate of "point1" and "point2" set the equipment operation boundary for the model. Similarly, obstacle numbers (i.e. temporary facilities) and their relative coordinates can be entered from the user interface. If the obstacle number is one, only the first row of the obstacle coordinate is considered. The workstations control the movement of the workers as their relative origin and destination. The workstation coordinates can be entered into the model in the same fashion as described above. The workstations can be set up manually in the construction environment by using the "workstation-setup" button. In a similar way, the position of the equipment or obstacles can be dragged and shifted using the "move-obstacles/equipment" button.

3.4.2 Hazard Mapping

Various researchers have generated heatmaps and designed hazardous proximity zones for heavy construction machinery and obstacles to mitigate injuries causing due to close interaction between the workers and equipment or obstacles [14], [28]. Shen has shown that different construction equipment follows different shapes of equipment footprint and the hazard zoning is governed by that [14]. Since, in this study, excavator represents the use of heavy equipment in the site, the hazard zoning is circular. Golovina has developed hazard heatmaps for excavators assigning weightage to a 12m visibility circle from the center of the excavator [28]. From the assignment of the weights, it is evident that the weights are inversely proportional to the center of the equipment and the closest circle has the highest weightage. The same concept has been used for hazard mapping in this study. From Golovina's study, it is also observed that the zone with a 6m radius from the center of the excavator has the highest hazard indexing when the equipment should be immediately stopped if encountered with any workers in the site. The same hazard zoning and stopping interaction rule have been used as one of the attributes of the equipment. The obstacles in the model represent temporary facilities that contribute to the fall and struck-by near-misses in the construction sites. A distance of 10ft has been considered around the temporary facilities for the hazard zoning around the obstacles as per UBC 1985 guidelines [12]. Hegazy has delineated that the closeness between two temporary components in a construction site can influence the site layout optimization

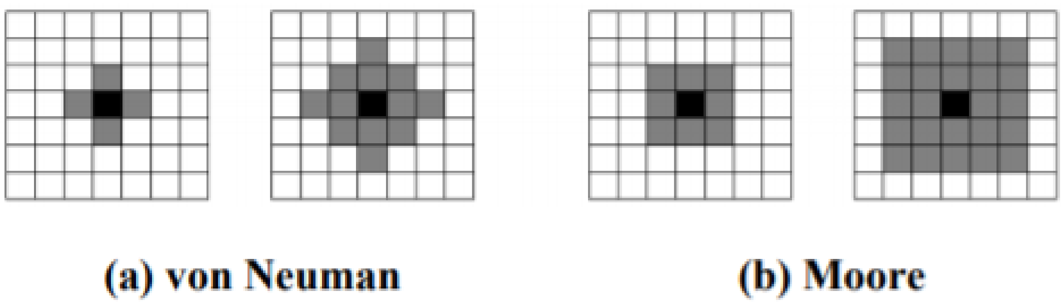


Figure 6: Von-Neumann and Moore Neighborhood [13]

inversely or proportionally based on their closeness relationship weights [12]. Here it is assumed that the equipment and obstacles have an inverse closeness relationship among them and hence overlapping of hazardous zones take the accumulated effect into account. In this model, the Von-Neumann neighborhood has been assigned for the excavator hazard zoning and the Moore neighborhood has been assigned for obstacles. The color indexing of the hazardous zone has been assigned according to their index values where the patch color changes from green to red gradually if the hazard index value rises from low to high.

3.4.3 Agent Set Distribution

The number of agents is equal to the number of workers who participated in the particular risk perception category questions. By clicking the "Load Worker-Perception Data" button on the interface tab, the workers are generated at the center of the model with the observed risk perception attributes. The workers are assigned a normally distributed walking speed of 1.3 m/s with a standard deviation of 0.25 m/s scaled into the model [40]. The excavator speed is normally distributed and has an average speed of 5 km/h and is assumed to be operating at a 30% speed capacity in the site.

3.4.4 Workflow Setup

The workers are given controlled movement activities within the simulation environment. After the workers are generated, each worker sets one of the workstation points as their targets and forwards towards that direction. Once the worker reaches the initial target, he sets a new target among the other workstations and proceeds towards the new target. Before making any movement, the worker agent checks for two environment-interaction rules. Firstly, the worker checks for avoiding the boundary of the site. Secondly, the worker checks for avoiding collision possibility with any equipment or obstacles on the site.

3.4.5 Safety Threshold Setup

The safety threshold values are fetched from a CSV file and stored as global variables in the model. The threshold values are the resultant average predicted probability values for different scenarios in “Day-to-Day” and “Extreme” event scenario. If a worker agent passes through the hazardous zones, his risk perception is compared with the threshold values. If the risk perception is lower than the threshold value, the near-miss predictor value is updated.

CHAPTER IV: RESULTS AND DISCUSSIONS

4.1 Discussions on the primary analysis of the survey

As mentioned earlier, the survey received 108 total responses where 85 of the respondents finished the survey. As mentioned in Chapter 3, the intended survey focus group is construction workers. However, due to the COVID-19 pandemic lockdown, the survey was conducted online among construction management practitioners. In this section of Chapter 4, the primary findings of the survey based on descriptive statistics and common trends in responses will be explored.

4.1.1 Socio-Demographic Information

As mentioned earlier, the questionnaire survey was circulated online through social media platforms as well as by email invitations. The socio-demographic parameters captured in the survey are age, gender, race, education, native language, experience in the construction industry, income, and previous safety training experience. Since construction enthusiasts from different countries (e.g. U.S.A., Bangladesh, Singapore, Qatar) have participated in the survey and the enlisted countries vary largely in terms of gross annual income, therefore, the income groups do not reflect the actual impacts on the decision making. Hence the income variable has been discarded from further analysis of the study.

Surprisingly, the survey has attracted the tier of young construction professionals which is evident in the descriptive statistics shown in Table 1. 28% of the survey participants are aged below 20 years, and 57% of the participants are aged between 21-30 years which indicates that the major contribution of the survey responses is captured from the young construction affiliates. The “experience in the construction industry” parameter echoes the participation of young professionals where 90% of the participants have less than 5 years of experience in the industry. The construction workforce is comprised of male prevalence [41]. The “gender” attribute of the socio-demographic section also affirms the same concept where 75% of the participants are male.

Table 1: Summary of socio-demographic information of survey participants

Socio-Demographic Variables	% of Survey Participants
Age	
Below 20 years	28%
Between 21-30 years	57%
Above 30 years	15%
Gender	
Male	75%
Female	24%
Other	1%
Race	
Asian	27%
Black or African American	13%
Hispanic or Latino	37%
White	22%
Other	1%
Education	
High School Graduate, Diploma or Equivalent	18%
College Graduate	9%
Trade, Technical, Vocational Training	3%
Associate Degree	36%
Bachelor’s Degree	26%
Master’s Degree	4%
Doctorate Degree	4%
Native Language	
English	62%
Others	38%
Experience in the Construction Industry	
No Experience	24%
Less than 6 Months	9%
6 Months – 1 Year	17%
1 – 2 Years	14%
3 – 5 Years	26%
6 – 10 Years	6%
More than 10 Years	4%
Previous Safety Training Experience	
Yes	48%
No	52%

The majority of the participants are English language speakers (i.e. 62% of the respondents) with a uniform diversity in the racial background (i.e. 27% Asian, 13% Black or African American, 37% Hispanic or Latino, 22% White). The educational background of the participants can be fairly divided into three groups with 30% of the participants having a low educational background (e.g. high school graduate, college graduate, etc.), 36% of the participants having associate degrees, and 34% of the participants having bachelor's or higher degrees. There is an equal distribution on the "previous safety training experience" response where 48% have answered "Yes" and 52% have answered "No". The experience and educational

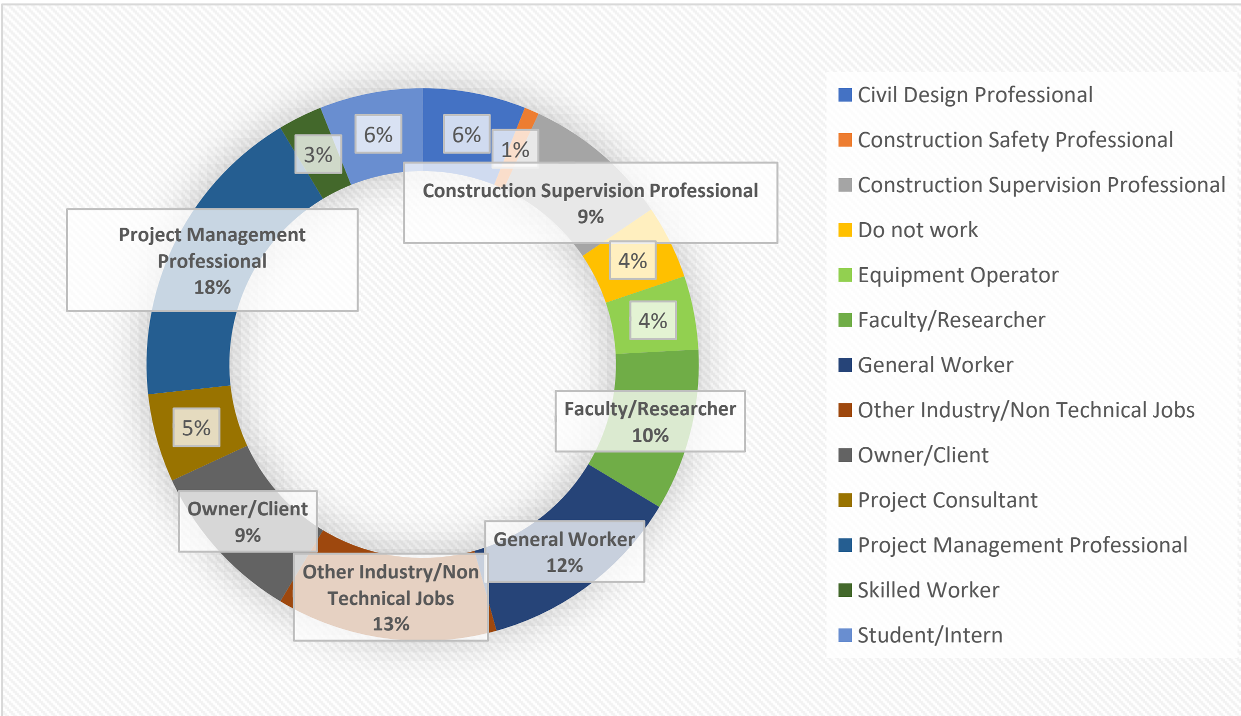


Figure 7: Profession of the Survey Participants

background of the participants show the diversity of the survey response group. Insights on their profession reinforce the diverse reach of the survey. From Figure 7, it can be observed that 18% of the participants are project management professionals, 12% are general workers, 9% are construction supervision professionals. This shows that the survey captured the perception of the construction field affiliates as well as the management professionals. 10% of responses from the faculty/researchers indicate the active contribution of construction professionals with research expertise.

4.1.2 Discussions on Average Resource Requirements

In the "project information" section of the questionnaire survey, the survey participant is asked to provide details about the project that he has been most recently engaged in. The project information includes questions on average worker and equipment requirements for different construction activities followed by the duration required to execute each construction activity. The mean value of the responses reveals that superstructural works require the highest number of resources (i.e. workforce and equipment) and duration

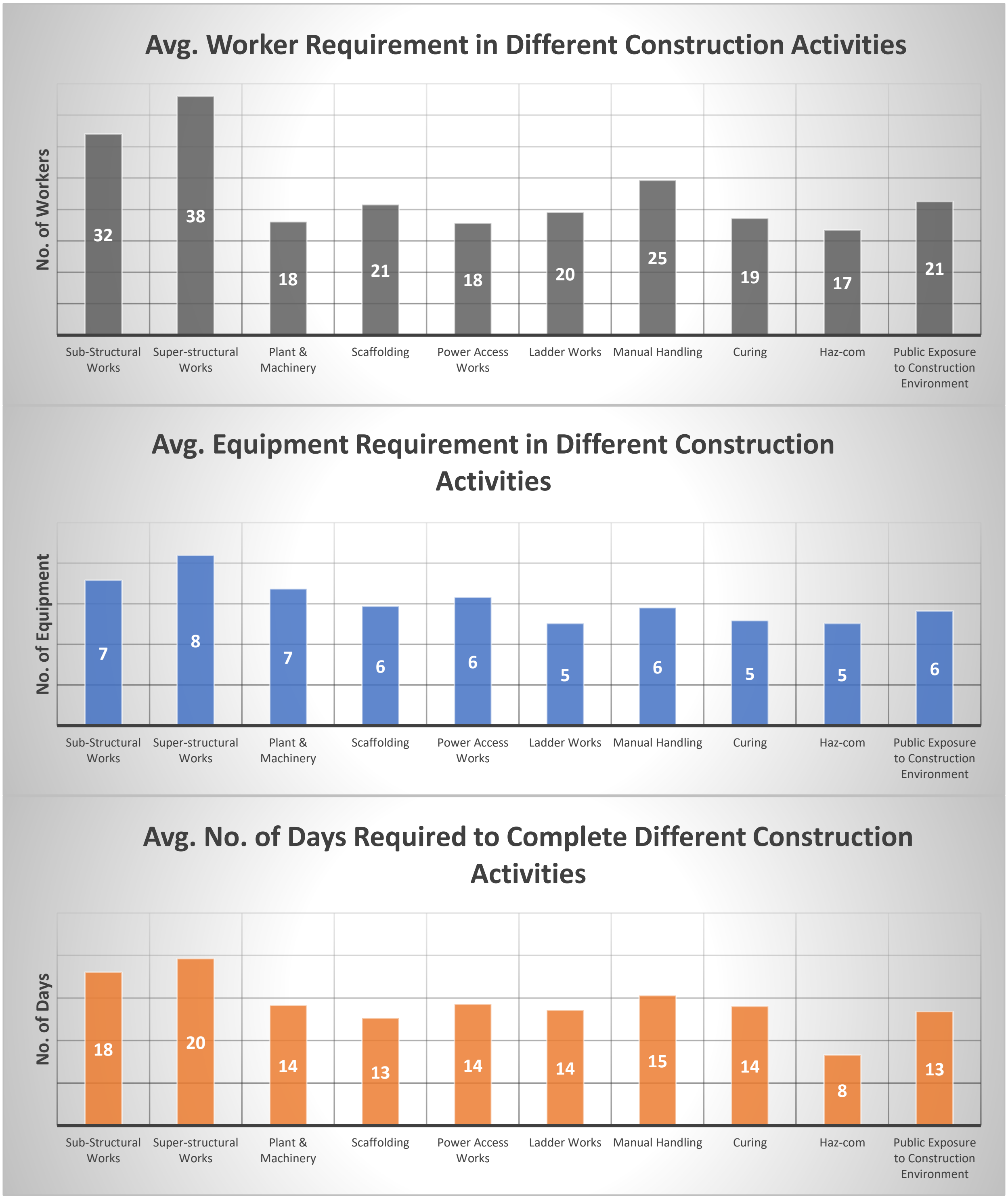


Figure 8: Average Resource Requirement to Complete Different Construction Activities

in a construction project. substructural works have received the second-highest resource and duration requirement. Plant and machinery work, public exposure to construction environment works, and manual handling works require the next largest resource allocations in construction projects. The common pattern among these responses also indicates the critical construction activities in a construction project.

4.1.3 Discussions on Impact Ratings

Natural disasters impact construction sites directly or indirectly. The level of impact depends on the nature of the disaster. The "impact of project execution variables" section of the questionnaire survey captures the impact ratings of different natural disasters to identify the most impactful ones. Figure 9 shows the average

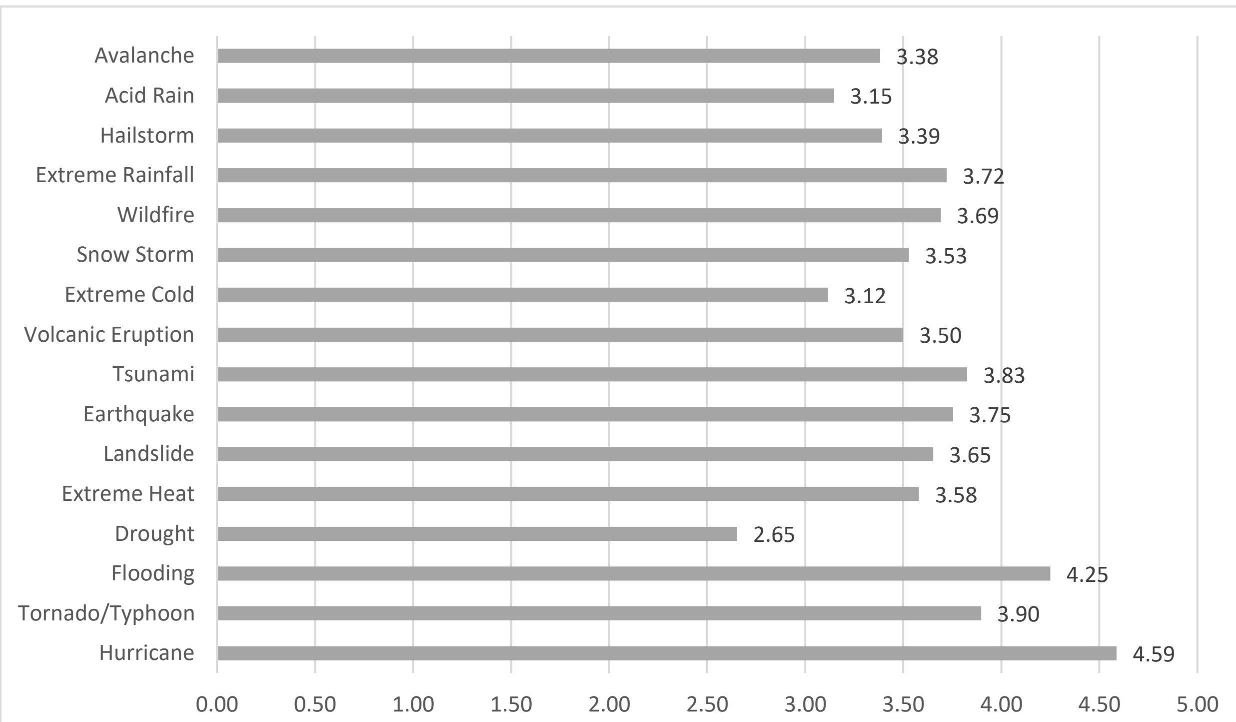


Figure 9: Average Impact Rating of Extreme Events on Construction Activities

impact rating of natural disasters also known as extreme events. The average ratings show that Hurricane and Flooding events have the most impact on construction sites (i.e. average rating 4.59 and 4.25 respectively on a scale of 5). A study on Barbados also shows the massive impact of hurricanes and flooding on construction activities [42]. Besides, Ashraf's study affirms that hurricanes stir up concerns and challenges in the construction industry and hence affect its regular progress to a greater extent [43]. Drought, which is an uncommon natural phenomenon has received the least impact rating of 2.65.

Project execution variables are also important for maintaining project schedules. The survey participants have rated the impact of project execution variables on the construction schedule on a scale of 1 to 5. Among different variables procurement of materials has received the highest impact rating of 4.24 followed by labor availability and equipment and material quality. Ahmadian also delineates the importance of procurement of construction materials in minimizing the risk of any construction delay [44]. Besides, high impact ratings for variables like workforce skills, labor availability support the importance of labor productivity in the construction arena which has been echoed in El-Gohary's research on Egypt's construction labor industry [45]. Equipment and material quality have received the second-highest impact rating of 4.13 from the survey participants. Poon has shown that using good quality materials in construction can reduce building wastes in the Hong Kong construction industry [46] which underpins the necessity of good quality resources in construction.

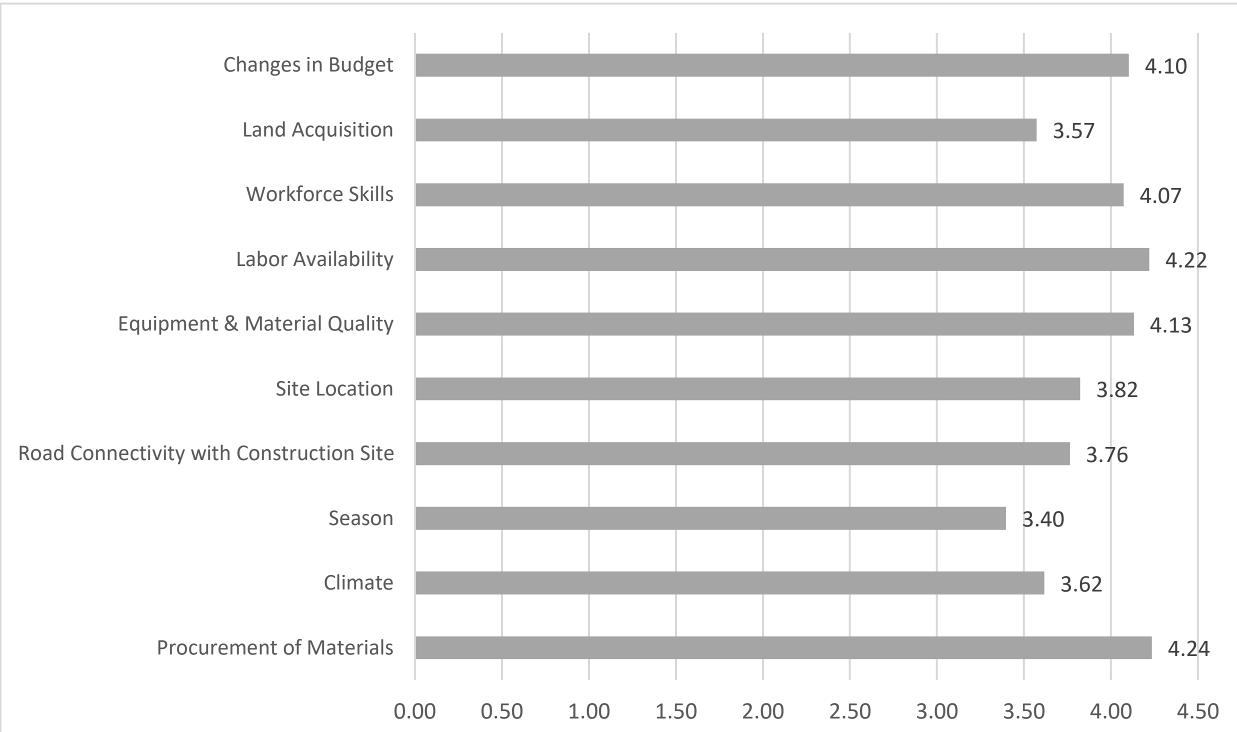


Figure 10: Average Impact Rating of Project Execution Variables on Construction Scheduling

4.1.4 Discussions on Common Trends of Risk Perception Rating

The primary analysis of the survey unfolds some common trends in the risk perception rating of the survey participants. For instance, in substructural activities, the natural hazard (i.e. wind effect, heat effect, visibility, etc.) risk rating tends to decrease when the weather scenario changes from regular to extreme. The trend is opposite for the superstructural and public-exposure construction activities where the average risk rating is likely to rise for the natural hazards whenever the weather scenario shifts from regular to extreme. Table 2 shows the details of the rating trend. In the table, R-Event denotes “Regular Event” and E-Event denotes “Extreme Event”.

Table 2: Average Risk Rating for Natural Hazards

Activity →	Substructural Activity		Superstructural Activity		Public Exposure to Construction Environment	
Hazard ↓	*R-Event*	*E-Event*	*R-Event*	*E-Event*	*R-Event*	*E-Event*
Wind Effect	4.45	3.87	3.27	4.54	3.51	4.44
Heat Effect	4.26	3.91	2.88	3.81	3	3.69
Visibility	4.57	3.82	2.68	3.88	3.11	3.92
Wildlife	3.95	3.61	1.92	2.69	2.42	3.04
Flooding	3.7	2.77	2.62	3.92	3.07	4.08
Noise	4.3	3.22	2.72	3.42	3.52	4

Effective communication is essential for the transmission of potential hazards in the construction site. Tiezer describes that native language is a prominent factor in the safety education and training of construction workers. Workers who inherit a native language that is different from the country they work in are more vulnerable to workplace hazards [47]. Besides, the discrepancy in workplace communication mechanisms abates the efficiency of safety training. In Table 3, the influence of native language in deciding the risk rating trends among different groups of participants has been explored. The findings are based on fatal-four risk perception for substructural activities. In Table 3 Headings, R denotes regular events and E denotes extreme events.

Table 3: Influence of Native Language in Setting Risk Rating Trends

3.1 Risk Rating Trend for English Speakers (Co-worker VS Supervisor)								
English Speaker	**Fall (R)**	**Fall (E)**	**Electrocution (R)**	**Electrocution (E)**	**Struck -by (R)**	**Struck -by (E)**	**Caught-in/between (R)**	**Caught-in/between (E)**
Co-worker	1..67	3.00	1.67	3.00	2.67	5.00	3.33	5.00
Supervisor	3.00	3.50	3.25	4.13	3.38	4.00	3.88	4.00
3.2 Risk Rating Trend Based on Experience and Native Language (English VS Non-English Speakers)								
Experience (<= 1 year)	**Fall (R)**	**Fall (E)**	**Electrocution (R)**	**Electrocution (E)**	**Struck -by (R)**	**Struck -by (E)**	**Caught-in/between (R)**	**Caught-in/between (E)**
English Speaker	2.00	3.00	2.00	3.00	2.75	5.00	3.50	5.00
Non-English Speaker	5.00	5.00	5.00	5.00	3.00	4.00	3.00	3.00
Experience (> 1 year)	**Fall (R)**	**Fall (E)**	**Electrocution (R)**	**Electrocution (E)**	**Struck -by (R)**	**Struck -by (E)**	**Caught-in/between (R)**	**Caught-in/between (E)**
English Speaker	3.00	3.50	3.29	4.13	3.43	4.00	3.86	4.00
Non-English Speaker	2.91	3.64	2.45	3.27	2.55	3.45	2.91	3.90

The observations from Table 3 are described below:

- In section 3.1 of Table 3, a pattern in risk rating has been observed between the English-speaking co-workers and supervisors. For the English-speaking co-workers, there is a likelihood of abrupt rise in hazard risk ratings whenever the weather scenario changes. For the supervisors, the trend of change in the ratings due to the change in weather scenario is quite low. For example, the change in risk rating for struck-by hazards is 2.33 (i.e. 5.0 for extreme events and 2.67 for regular events) for the co-workers. For the supervisors, the value rises from 3.38 to 4.00 denoting a 0.62 rise in the value. This indicates that construction management professionals with higher job responsibilities tend to perceive the effect of weather change lightly.
- In section 3.2 of Table 3, the risk rating pattern function vertically. For less experienced (<=1 year) professionals, there is a different trend between the English and Non-English speakers in perceiving

the hazard risks. For more experienced professionals the trend of change in hazard rating among different language speaking people is insignificant. For instance, among less experienced professionals, English speakers tend to perceive low risk for fall and electrocution hazard (i.e. Rating “2” on a scale of “5”) whereas Non-English speakers tend to perceive the same hazards with the highest risk threshold (i.e. Rating “5” on a scale of “5”). This suggests that young non-English speaking construction professionals are more likely to be cautious in perceiving construction hazards compared to English-speaking professionals. However, with experience, the barrier in risk rating perishes between English and Non-English speakers.

- Section 3.2 of Table 3 also represents those changes in weather scenarios trigger higher changes in perceptions of the less experienced English-speaking professionals. It also suggests that such changes barely affect the perception of the less experience non-English speaking professionals.
- Finally, from section 3.2 of Table 3, it is evident that less experienced non-English professionals tend to rate hazards higher which is the opposite for experienced professionals.

Menzel studied the risk perception of Latino construction workers [27]. He derived that race-dependent variables like trade skill deficiency, traditional Latino values, health literacy, language/communication skills, etc. can contribute to shaping a worker’s safety awareness and perception.

Table 4: Risk Rating Trends in Terms of Race

4.1 Risk Rating Trend among Non-Hispanic/Latinos (Less Experienced VS More Experienced Professionals)								
Non-Hispanic/ Latinos	**Fall (R)**	**Fall (E)**	**Electrocution (R)**	**Electrocution (E)**	**Struck-by (R)**	**Struck-by (E)**	**Caught-in/between (R)**	**Caught-in/between (E)**
Exp <=1 yr	4.00	5.00	4.00	5.00	3.00	4.00	3.5	3.00
Exp >1 yr	3.08	3.85	2.58	3.54	2.75	3.69	3.08	4.08
4.2 Risk Rating Trend Based on Experience and Race (Hispanic/Latino VS Others)								
Experience (<= 1 year)	**Fall (R)**	**Fall (E)**	**Electrocution (R)**	**Electrocution (E)**	**Struck-by (R)**	**Struck-by (E)**	**Caught-in/between (R)**	**Caught-in/between (E)**
Hispanic or Latino	1.67	3.00	1.67	3.00	2.67	5.00	3.33	5.00
Others	4.00	5.00	4.00	5.00	3.00	4.00	3.50	3.00
Experience (> 1 year)	**Fall (R)**	**Fall (E)**	**Electrocution (R)**	**Electrocution (E)**	**Struck-by (R)**	**Struck-by (E)**	**Caught-in/between (R)**	**Caught-in/between (E)**
Hispanic or Latino	2.67	3.00	3.17	3.83	3.17	3.60	3.67	3.67

Others	3.08	3.85	2.58	3.54	2.75	3.69	3.08	4.08

In Table 4, the trends in risk rating have been observed in terms of racial background. The observations are listed below:

- Section 4.1 in Table 4 shows that Non-Hispanic or Latino professionals with more experience (>1 year) are more likely to rate the fatal-four hazards lower than the less-experienced professionals (<=1 year).
- Section 4.2 in Table 4 suggests that Hispanic or Latinos with less experience tend to recognize the risks to elevate whenever there is a change in the weather scenarios. Less experienced professionals with different racial backgrounds are likely to perceive the changes in hazard due to weather change with little consideration.

4.2 Discussions on the secondary analysis of the survey

The secondary analysis of the survey involves statistical modeling of the survey. As mentioned in Chapter 3, the ordered probit model has been selected to analyze the risk perception of the survey participants. STATA software has been used to apply the ordered probit model on the survey data. Since STATA requires data entry in all the cells for analysis, responses with blank cells (i.e. skipped questions) have been omitted. The final set of observations for the substructural activities, superstructural activities, and public exposure to the construction environment activities consist of 17, 23, and 21 responses respectively. Due to the low sample size, different criteria have been used for the same set of independent variables that can fit the statistical model best. Using different criteria has improved the explanatory power of the model and optimized the score of the statistical parameters. For a single event type (regular or extreme), the same set of criteria has been used to keep uniformity in the analysis. A brief discussion on the group of independent variables and their criteria are stated below:

1. *Age:* Four different criteria have been used for the age variable. In criteria 1, age has been used as a continuous numerical variable. In criteria 2, age has been used as a categorical variable with three

categories: <= 20 years, 21-30 years, and > 30 years. In criteria 3, again three categories have been used: < 25 years, 25-39 years, >=40 years. In criteria 4, age has been used as a binary variable where <=25 years denotes “1” and > 25 years denotes “0”.

2. *Gender:* Single criterion has been used for the gender variable. It is considered as a binary variable where male denotes “1” and female denotes “0”.
3. *Race:* Dual criteria have been used for the race variable. In criteria 1, race has been used as a categorical variable. The categories in criteria 1 are Asian, Black or African American, Hispanic or Latino, White, Others. In criteria 2, race has been used as a binary variable where “1” denotes Asian and “0” denotes Non-Asian/Others.
4. *Safety Training:* Safety training has been used as a binary variable for all the models. “1” denotes the participant has received prior safety training and “0” denotes the participant has no training experience.
5. *Supervision Role:* Same as safety training, supervision role has been used as a binary variable. If the participant has supervision responsibilities in his current job role it is denoted as “1”. No supervision responsibilities are denoted as “0”.
6. *Safety Culture:* Like safety training and supervision role, safety culture has a single binary criterion for analysis. “1” represents that the employer of the participant provides OSHA safety training as per requirements and maintains safe work culture, and “0” means the opposite.
7. *Education:* Education variable has been used as two different criteria for different models. Criteria 1 addresses education as a binary variable where “1” means the participant has attained a bachelor’s or higher degree as the maximum level of education and “0” covers education levels lower than the bachelor’s degree. Criteria 2 considers education as a categorical variable with the enlisted choices (e.g. high school graduate, college graduate, associate degree, bachelor’s degree, etc.)
8. *Language:* The language variable has been utilized in a similar way as the education variable. In criteria 1, language has been treated as a binary variable with “1” meaning English speakers (as the native language) and “0” meaning non-English speakers. In criteria 2, language has been treated as a categorical variable with the enlisted options (e.g. English, Spanish, Creole, Bengali, etc.).

9. *Experience:* The experience variable has also been used in the same manner as the education variable. In criteria 1, experience variable has been used as a binary one where "1" denotes having experience <= 2 years and "0" denotes the opposite. In criteria 2, it has been used as a categorical variable with all the options.

4.2.1 Ordered Probit Model Results for Substructural Activities

Table 5: Results for Substructural Activities (Regular Event)

Variable Description	Fall		Electrocution		Struck-by		Caught-in/between	
	R^2= 0.383		*R^2= 0.205*		*R^2= 0.165*		*R^2= 0.391*	
	Co-eff.	*z*	*Co-eff.*	*z*	*Co-eff.*	*z*	*Co-eff.*	*z*
Age	0.335	2.42	0.045	1.53	0.041	1.4	0.003	0.13
Gender *(1 if male 0 if female)*	0.88	0.65	-	-	0.129	0.09	0.136	0.09
Safety Training *(1 if previous safety training experience = "Yes", 0 if previous safety training experience = "No")*	1.876	2.02	0.561	0.74	1.476	1.95	1.754	1.86
Supervision Role *(1 for supervisors, 0 for co-workers)*	-0.701	-0.77	0.768	0.98	0.495	0.65	-0.23	-0.28
Safety Culture *(1 if the employer provides regular safety training, 0 if otherwise)*	-0.948	-1.2	0.233	0.34	-0.74	-1.02	-1.45	-1.66
Education *(1 if the highest level of education = Bachelor's or higher degree, 0 if otherwise)*	-0.607	-0.39	0.169	0.13	0.617	0.8	-	-
Language *(1 if native language = English, 0 if otherwise)*	-0.322	-0.2	0.577	0.43	-	-	2.32	2.17
Experience *(1 if experience is <= 2 years, 0 if otherwise)*	1.753	1.85	1.902	2.47	0.367	0.48	0.068	0.08

The observations on the results of the statistical model for the substructural activities (regular event) are summarized below:

- Aged people are more likely to rate the risks higher compared to young people. The influence of age is highest on fall hazard and lowest on caught in/between hazard among the fatal-four hazards.
- Gender has a low significance on the overall model and has been excluded in the electrocution hazard analysis. Males are more likely to rate the fatal-four hazards higher compared to females.

- Safety training is statistically significant among different hazards. People with prior safety training are more likely to perceive risk in a higher manner compared to others.
- Supervision role has different trends among the fatal-four hazards. Whereas the co-workers are more likely to rate the fall and caught-in/between hazards higher, the supervisors have a higher probability to rate the electrocution and struck-by hazards higher.
- Surprisingly, if the safety culture of the company is right (i.e. the employer provides regular safety training as per OSHA guidelines) people are less likely to rate fall, struck-by, and caught-in/between hazards higher. The scenario is the opposite for the electrocution hazard.
- Education and language both have low statistical significance on the model and have been omitted partially based on the analysis demand. An individual with higher educational background or English speaking ability as a native language is likely to perceive the fall hazard with low importance. The scenario is opposite for the other hazards and native English speakers tend to rate the caught-in/between hazard higher.
- Experience is statistically significant for fall and electrocution hazards. The results suggest that less experienced professionals are more likely to have a higher risk perception for the fatal four hazards.

Table 6: Results for Substructural Activities (Extreme Event)

Variable Description	Fall		Electrocution		Struck-by		Caught-in/between	
	$R^2 = 0.537$		$R^2 = 0.413$		$R^2 = 0.193$		$R^2 = 0.303$	
	Co-eff.	*z*	*Co-eff.*	*z*	*Co-eff.*	*z*	*Co-eff.*	*z*
Age	0.651	1.55	0.253	1.74	0.001	0.05	-0.106	-0.89
Safety Training *(1 if previous safety training experience = "Yes", 0 if previous safety training experience = "No")*	3.105	1.27	0.18	0.2	0.543	0.69	1.463	1.17
Supervision Role *(1 for supervisors, 0 for co-workers)*	2.114	0.78	0.063	0.07	-0.78	-0.93	-0.175	-0.18
Safety Culture *(1 if the employer provides regular safety training, 0 if otherwise)*	-0.924	-0.95	0.256	0.03	-1.266	-1.52	-0.671	-0.71
Language *(1 if native language = English, 0 if otherwise)*	-	-	2.651	1.93	1.558	1.74	3.598	1.02
Experience *(1 if experience is <= 2 years, 0 if otherwise)*	6.336	1.39	3.464	2.35	0.878	1.2	-0.723	-0.87

Highlights of Table 6 are described below:

- With an increase in age, people are more likely to rate the fall and electrocution hazards higher. For the caught-in/between hazard, the scenario is the opposite. Age is statistically insignificant for struck-by hazards.
- Safety training has high impacts on fall hazards and caught-in/between hazards. Safety training people are more likely to perceive the fatal-four risks in a higher manner compared to people with no prior safety training.
- Supervisors are more likely to perceive the risk of fall hazard higher in an extreme event scenario. For the regular event scenario, the perception was the opposite. Hence, a change in the weather scenario makes a notable impact in this case. Supervision role is statistically insignificant for the electrocution hazard. For struck-by and caught-in/between hazards, co-workers are more likely to rate the risks higher than the supervisors.
- Improvement in safety culture creates a low-risk rating tendency for fall, struck-by, and caught-in/between hazards in an extreme event scenario.
- Language plays an important role in risk perception of electrocution, struck-by, and caught-in/between hazards. The English speakers have a better chance to rate the risk of these hazards higher compared to the non-English speakers.
- Lastly, experience plays an important role in fall and electrocution hazard ratings. Less experienced people have a higher risk rating tendency for fall, electrocution, and struck-by hazards. For the caught-in/between hazard, people with more experience perceive the risk more.

4.2.2 Ordered Probit Model Results for Superstructural Activities

For the superstructural activities, the education variable has been discarded from the ordered probit model analysis for optimizing the statistical parameters of the model. Table 7 and Table 8 show the results of the model for superstructural activities in regular and extreme event scenarios.

Table 7: Results for Superstructural Activities (Regular Event)

Variable Description	Fall		Electrocution		Struck-by		Caught-in/between	
	R^2= 0.288		*R^2= 0.222*		*R^2= 0.331*		*R^2= 0.237*	
	Co-eff.	*z*	*Co-eff.*	*z*	*Co-eff.*	*z*	*Co-eff.*	*z*
Age *(<= 20 years as the base category)*								
21-30 years	0.159	0.14	-1.231	-1.18	-1.324	-1.06	-1.777	-1.69
> 30 years	2.913	1.73	1.235	0.74	1.45	0.81	1.204	0.74
Gender *(1 if male 0 if female)*	-	-	0.363	0.34	1.495	1.1	0.341	0.36
Safety Training *(1 if previous safety training experience = "Yes", 0 if previous safety training experience = "No")*	2.491	2.52	0.792	0.92	1.781	1.91	1.542	1.9
Supervision Role *(1 for supervisors, 0 for co-workers)*	1.374	1.63	0.16	0.21	0.298	0.38	-	-
Safety Culture *(1 if the employer provides regular safety training, 0 if otherwise)*	-1.555	-2.03	0.412	0.46	-1.498	-1.4	-0.909	-1.05
Race *(Asian as the base category)*								
Black or African American	0.883	0.73	-2.508	-1.95	-2.976	-1.97	-2.797	-2.09
Hispanic or Latino	-2.664	-2.49	-2.695	-2.46	-1.442	-1.31	-1.628	-1.66
White	0.847	0.63	-0.625	-0.43	-1.84	-1.01	-0.913	-0.57
Language *(1 if native language = English, 0 if otherwise)*	1.228	1.22	-	-	-0.591	-0.54	-	-
Experience *(6months – 1 year as the base category)*								
1-2 years	2.24	1.94	1.258	1.25	2.367	2.02	1.819	1.86
3-5 years	2.052	2.48	0.586	0.74	1.043	1.19	0.872	1.1
6-10 years	-1.84	-1.03	-0.784	-0.46	-2.391	-1.25	-2.315	-1.34
> 10 years	1.951	0	-2.26	-0.82	5.547	0.02	-0.944	-0.34

The findings of Table 7 are outlined in the following:

- For the age variable, <=20 years has been selected as the base category, and the values for the rest two categories have been analyzed with respect to the base category. The 21-30 years age group is likely to function oppositely compared to the > 30 years age group. The 21-30 years age group is more likely to rate electrocution, struck-by, and caught-in/between hazards in the low thresholds. For the fall hazard, both the age groups are more likely to rate the hazard higher in comparison to the <=20 years age group.

- The gender group is insignificant for the fall hazard. For the rest of the fatal-four hazards, males are more likely to give a higher rating compared to females. Similarly, the language group has minimum influence on the model.
- Safety training is statistically significant for the fall hazard. For all of the fatal-four hazards, people with safety training are expected to perceive the risks in a higher manner.
- For the safety culture variable, apart from the electrocution hazard, the rest three of the fatal-four hazards are less likely to be rated higher by the people working for a better safety cultured employer.
- In the race group, compared to the Asian race, Hispanic or Latinos are likely to perceive the risk of the fatal four hazards oppositely. Black or African Americans and Whites are more likely to rate the fall hazards higher than the Asians. They have a reverse rating tendency for electrocution, struck-by, and caught-in/between hazards compared to the Asians.
- In the experience group, 6 months-1 year experience is the base category. The co-efficient values show that up to 5 years, a construction individual is more likely to perceive the risk higher than his initial risk perception (6months – 1 year). Between 6-10 years the likelihood of a higher risk rating functions adversely. The results for the > 10 years category should be ignored due to the inconsiderable outputs.

Table 8: Results for Superstructural Activities (Extreme Event)

Variable Description	Fall		Electrocution		Struck-by		Caught-in/between	
	$R^2 = 0.44$		$R^2 = 0.264$		$R^2 = 0.168$		$R^2 = 0.396$	
	Co-eff.	*z*	*Co-eff.*	*z*	*Co-eff.*	*z*	*Co-eff.*	*z*
Age	2.052	1.58	0.77	1.41	0.011	0.3	0.103	1.87
Gender *(1 if male 0 if female)*	1.939	1.16	-	-	-0.664	-0.69	-	-
Safety Training *(1 if previous safety training experience = "Yes", 0 if previous safety training experience = "No")*	28.106	1.54	-1.326	-1.79	0.185	0.32	-0.63	-0.84
Supervision Role *(1 for supervisors, 0 for co-workers)*	22.152	1.53	-0.497	-0.73	-1.046	-1.4	-2.247	-2.61

Safety Culture *(1 if the employer provides regular safety training, 0 if otherwise)*	1.22	0.7	0.836	1.24	0.871	1.28	0.371	0.56
Race *(Asian as the base category)*								
Black or African American	-29.189	-1.62	6.418	0.02	-	-	-2.322	-1.83
Hispanic or Latino	-11.828	-1.54	-0.545	-0.65	-	-	8.44	0.01
White	-26.462	-1.59	-0.347	-0.33	-	-	-0.187	-0.19
Language *(1 if native language = English, 0 if otherwise)*	-14.774	-1.82	-2.033	-2.33	-1.276	-1.61	-3.371	-3.35
Experience *(1 if experience is <= 2 years, 0 if otherwise)*	30.385	1.52	-0.681	-1.02	-0.772	-1.2	-	-

Table 8 represents the extreme event scenario for superstructural activities. Brief discussions on the results are stated below:

- The age variable is mostly significant for the fall hazard. In extreme events, more aged people are more likely to rate the hazards highly than young people.
- The gender variable does not carry any statistical importance for the electrocution and caught-in/between hazards. The males are more likely to rate the fall hazards higher. Interestingly, the females are more likely to rate the struck-by hazards higher which has not been observed for any other hazards or activities.
- Safety-trained people are more likely to rate the fall and struck-by hazards higher, whereas they are less likely to do the same for the electrocution and caught-in/between hazards.
- The supervisors are more likely to perceive the fall hazard with a higher risk in extreme event scenarios. Whereas the co-workers (i.e. who do not need to supervise others) are more likely to perceive the tier of other three fatal-four hazards with a higher risk if any extreme event scenario arises.
- In Table 7 we have observed that an improvement in the safety culture lessens the probability of high-risk rating. In extreme event scenarios, improved safety culture increases the chances of higher risk perception.

- For the race group, Asian is considered as the base category. All the other races are more likely to give a lower ranking to the fall hazards compared to the Asians. For the other types of hazards, the race variable has low statistical significance.
- Language carries a healthy weightage in terms of statistical importance in extreme event scenarios of superstructural activities. It is observed that for all the fatal-four hazards, Non-English speakers are more likely to provide a higher risk rating.
- Less experienced (<=2 years) people are more likely to rate the fall hazard higher and less likely to rate the electrocution and struck-by hazard higher.

4.2.3 Ordered Probit Model Results for Public Exposure to the Construction Environment Activities

For the public exposure to the construction environment activities, the language variable was omitted for optimizing the model. Table 9 and Table 10 show the results for the regular and extreme events.

Table 9: Results for Public Exposure to the Construction Environment Activities (Regular Event)

Variable Description	Fall		Electrocution		Struck-by		Caught-in/between	
	R^2= 0.337		*R^2= 0.506*		*R^2= 0.206*		*R^2= 0.226*	
	Co-eff.	*Z*	*Co-eff.*	*z*	*Co-eff.*	*z*	*Co-eff.*	*z*
Age *(25- 39 years as the base category)*								
< 25 years	2.347	1.24	11.429	2.63	2.805	2.45	1.134	0.66
>= 40 years	3.671	2.13	3.207	1.97	2.076	1.95	0.555	0.37
Gender *(1 if male 0 if female)*	-2.64	-2.31	-	-	-0.593	-0.6	-0.353	-0.31
Safety Training *(1 if previous safety training experience = "Yes", 0 if previous safety training experience = "No")*	0.736	0.97	2.737	2.3	0.517	0.77	0.365	0.51
Supervision Role *(1 for supervisors, 0 for co-workers)*	-2.504	-2.45	0.533	0.44	-0.199	-0.29	-0.339	-0.41
Safety Culture *(1 if the employer provides regular safety training, 0 if otherwise)*	-2.241	-2.11	2.135	1.99	-0.176	-0.27	0.424	0.48
Race *(Asian as the base category)*								
Black or African American	-5.777	-2.06	-	-	-	-	1.73	0.73
Hispanic or Latino	-3.083	-1.58	-	-	-	-	1.638	0.73
White	-3.878	-1.85	-	-	-	-	0.57	0.29
Education *(1 if the highest level of education = Bachelor's or higher degree, 0 if otherwise)*	-2.248	-1.81	4.4	2.02	1.432	1.44	0.816	0.68

Experience *(1 if experience is <= 2 years, 0 if otherwise)*	-1.039	-1.25	-3.967	-2.23	-0.632	-1.03	-0.471	-0.6

Highlights of Table 9 are briefly presented below:

- For the age variable, the 25-39 years age group has been considered as the base group and <25 age group and >=40 age group results have been measured with respect to the base category. The results reveal that both <25 and >=40 age groups are more likely to rate the fatal-four hazards higher than the 25-39 age group.
- The gender variable is applicable for the fall, struck-by, and caught-in/between hazards. The coefficients suggest that females are more likely to perceive higher risks compared to males.
- Like the previous set of results, the safety training variable coefficients suggest that safety trained people are more likely to rate the fatal-four hazards higher.
- Supervision role and safety culture have familiarity in the results. Supervisors and professionals working in good safety culture are less likely to rate the fall, struck-by, and caught-in/between hazards higher and more likely to rate the electrocution hazard higher.
- The race variable has been omitted for the electrocution and struck-by hazard. In comparison to the Asians, other races are more likely to rate the fall hazards lower and the caught-in/between hazards higher.
- More educated people are less likely to rate the fall hazard higher but more likely to rate the rest of the hazards higher.
- The experience coefficients suggest that more experienced people are likely to rate the fatal-four hazards higher in a regular event scenario.

Table 10 shows the final set of statistical models for the dataset for public exposure to the construction environment activities in extreme event scenarios. Similar to the model shown in Table 9, the language variable has been omitted in this case too for producing the optimal set of statistical parameters.

Table 10: Results for Public Exposure to the Construction Environment Activities (Extreme Event)

Variable Description	Fall		Electrocution		Struck-by		Caught-in/between	
	R^2= 0.383		*R^2= 0.35*		*R^2= 0.176*		*R^2= 0.183*	
	Co-eff.	*Z*	*Co-eff.*	*z*	*Co-eff.*	*z*	*Co-eff.*	*z*
Age *(>=40 years as the base category)*								
25-39 years	-3.061	-1.51	-1.5882	-1.66	-2.307	-1.97	-1.799	-1.16
<25 years	-2.119	-1.65	1.125	0.89	0.4	0.32	0.82	0.71
Gender *(1 if male 0 if female)*	-2.037	-1.72	-	-	0.02	0.02	0.156	0.15
Safety Training *(1 if previous safety training experience = "Yes", 0 if previous safety training experience = "No")*	1.413	0.85	1.026	1.35	0.968	1.25	1.329	1.67
Supervision Role *(1 for supervisors, 0 for co-workers)*	-8.475	-0.02	-0.945	-1.12	-0.486	-0.63	-0.558	-0.71
Safety Culture *(1 if the employer provides regular safety training, 0 if otherwise)*	-0.902	-0.61	0.963	1.34	0.139	0.19	0.283	0.35
Race *(1 for Asians, 0 for others)*	1.492	0.62	-	-	-	-	0.979	0.48
Education *(1 if the highest level of education = Bachelor's or higher degree, 0 if otherwise)*	-	-	-	-	1.835	1.57	0.532	0.41
Experience *(1 if experience is <= 2 years, 0 if otherwise)*	-0.614	-0.5	-0.652	-0.81	-0.453	-0.71	-0.409	-0.65

Insights of the results for Table 10 are mentioned below:

- For extreme events, >=40 years age group has been considered as the base category for the age variable. It is observed that compared to the >=40 years age group, 25-39 years age group people are less likely to rate the fatal-four hazards higher. Whereas, a younger group (<25 years) is less likely to rate the fall hazard higher but more likely to rate the other three hazards higher.
- Gender has a very low effect on the model except for the fall hazard. For fall hazards, females are more likely to perceive the risk higher compared to males.
- For the safety training variable, the results indicate that people with prior safety training experience are more likely to perceive the risk of the fatal-four hazards higher.
- In extreme event scenarios, co-workers are more likely to rate the fatal-four hazards higher compared to the supervisors.

- People working in a better safety culture are less likely to rate the fall hazard higher but more likely to rate the rest of the fatal-four hazards higher.
- Race has significance in only fall hazard and caught-in/between hazard results where Asians are more likely to rate the risks higher than the other races.
- People with higher education rate the struck-by and caught-in/between hazard more than the less educated people.
- With growing experience, the likelihood of perceiving the fatal-four risks in a higher manner increases.

4.2.4 Results of Scenario Testing

Section 3.3.3 of chapter 3 describes the methodology of scenario testing where eight different scenarios have been created and the difference in probability between the observed values and scenario values have been evaluated using Equation 2. Table 11, Table 12, Table 13, and Table 14 show highlights of scenario testing for Fatal-four hazards (for both regular and extreme event scenarios) in substructural activities.

Table 11: Scenario Testing Results for Fall Hazard in Substructural Activities

Scenario	***Regular Event***					***Extreme Event***				
	1	2	3	4	5	1	2	3	4	5
Observed	0.057	0.394	0.264	N/A	0.285	N/A	0.291	0.048	0.123	0.538
Scenario 1	0.010	0.269	0.329	N/A	0.392	N/A	0.24	0.038	0.099	0.623
Difference %	**-4.71**	**-12.48**	**6.48**	**N/A**	**10.72**	**N/A**	**-5.09**	**-0.95**	**-2.39**	**8.44**
Scenario 2	0.068	0.451	0.225	N/A	0.257	N/A	0.397	0.053	0.129	0.421
Difference %	**1.12**	**5.67**	**-3.97**	**N/A**	**-2.83**	**N/A**	**10.6**	**0.56**	**0.60**	**-11.75**
Scenario 3	0.038	0.285	0.281	N/A	0.396	N/A	0.254	0.033	0.065	0.648
Difference %	**-1.91**	**-10.89**	**1.71**	**N/A**	**11.09**	**N/A**	**-3.75**	**-1.5**	**-5.77**	**11.03**
Scenario 4	0.097	0.427	0.245	N/A	0.230	N/A	0.36	0.033	0.09	0.516
Difference %	**4.06**	**3.32**	**-1.90**	**N/A**	**-5.48**	**N/A**	**6.88**	**-1.44**	**-3.23**	**-2.21**
Scenario 5	0.045	0.281	0.19	N/A	0.485	N/A	0.115	0.035	0.095	0.755
Difference %	**-1.18**	**-11.33**	**-7.48**	**N/A**	**19.99**	**N/A**	**-17.61**	**-1.27**	**-2.78**	**21.67**
Scenario 6	0.11	0.476	0.215	N/A	0.199	N/A	0.304	0.055	0.144	0.497
Difference %	**5.3**	**8.25**	**-4.96**	**N/A**	**-8.59**	**N/A**	**1.3**	**0.73**	**2.1**	**-4.13**
Scenario 7	0.062	0.425	0.248	N/A	0.266	N/A	0.544	0.039	0.086	0.331
Difference %	**0.49**	**3.07**	**-1.68**	**N/A**	**-1.88**	**N/A**	**25.25**	**-0.88**	**-3.65**	**-20.72**
Scenario 8	0.022	0.367	0.299	N/A	0.312	N/A	0.42	0.046	0.1	0.434
Difference %	**-3.53**	**-2.65**	**3.49**	**N/A**	**2.69**	**N/A**	**12.88**	**-0.2**	**-2.24**	**-10.45**

As shown in Figure 4, scenario 1 shows increased inexperienced workers, scenario 2 shows the opposite of scenario 1. Similarly, scenario 3 shows increased safety trained workers and scenario 4 shows the contrasting scenario. Scenario 5 is a combination of scenarios 1 and 3 and scenario 6 is a combination of scenarios 2 and 4. Scenario 7 shows improved safety culture whereas scenario 8 shows deteriorated safety culture. We can observe in Table 11 that if inexperienced workers are increased, the probability of perceiving low risks decreases but the probability of perceiving risk in the highest form (i.e. 5 on a scale of 5) increases significantly (e.g. 10.72% for regular events and 8.44% for extreme events). On the contrary, if the number of experienced workers is increased, the probability of perceiving lower risks increases but the probability of perceiving the highest threshold of risk (i.e. 5 on a scale of 5) decreases significantly (i.e. decreases by 11.75%). Scenario 3 shows that increasing workers with prior safety training significantly boosts the probability of the highest risk rating (e.g. 11.09% for regular events 11.03% for extreme events). Scenario 5 shows that if inexperienced workers and safety-trained workers both increases, the probability of perceiving level 5 risk improves by nearly 20%. Scenarios 7 and 8 suggest that making changes in the existing safety culture (regardless of positive or negative) improves the lower risk perception probability but highly deteriorates the highest risk perception probability (i.e. decreases by 20.72% for regular events and 10.45% for extreme events).

Table 12: Scenario Testing Results for Struck-by Hazard in Substructural Activities

Scenario	***Regular Event***					***Extreme Event***				
	1	2	3	4	5	1	2	3	4	5
Observed	0.12	0.184	0.515	0.059	0.121	N/A	0.127	0.24	0.326	0.307
Scenario 1	0.088	0.165	0.539	0.066	0.143	N/A	0.09	0.211	0.322	0.377
Difference %	**-3.26**	**-1.86**	**2.36**	**0.64**	**2.12**	**N/A**	**-3.71**	**-2.92**	**-0.36**	**6.98**
Scenario 2	0.128	0.191	0.507	0.057	0.117	N/A	0.16	0.26	0.309	0.272
Difference %	**0.76**	**0.7**	**-0.77**	**-0.25**	**-0.43**	**N/A**	**3.28**	**2**	**-1.74**	**-3.54**
Scenario 3	0.06	0.128	0.539	0.081	0.192	N/A	0.107	0.206	0.328	0.358
Difference %	**-6.04**	**-5.61**	**2.42**	**2.19**	**7.04**	**N/A**	**-1.93**	**-3.39**	**0.19**	**5.12**
Scenario 4	0.167	0.233	0.493	0.039	0.067	N/A	0.138	0.259	0.325	0.277
Difference %	**4.66**	**4.94**	**-2.16**	**-1.99**	**-5.45**	**N/A**	**1.18**	**1.93**	**-0.06**	**-3.05**
Scenario 5	0.081	0.132	0.487	0.081	0.219	N/A	0.083	0.181	0.293	0.443
Difference %	**-3.9**	**-5.17**	**-2.79**	**2.13**	**9.73**	**N/A**	**-4.41**	**-5.91**	**-3.28**	**13.59**

Scenario 6	0.192	0.238	0.49	0.036	0.044	N/A	0.138	0.272	0.336	0.254
Difference %	**7.14**	**5.4**	**-2.47**	**-2.37**	**-7.7**	**N/A**	**1.17**	**3.22**	**0.98**	**-5.37**
Scenario 7	0.135	0.199	0.499	0.054	0.113	N/A	0.207	0.285	0.305	0.203
Difference %	**1.45**	**1.54**	**-1.62**	**-0.53**	**-0.83**	**N/A**	**8.03**	**4.47**	**-2.12**	**-10.38**
Scenario 8	0.084	0.153	0.53	0.068	0.165	N/A	0.114	0.203	0.291	0.392
Difference %	**-3.66**	**-3.08**	**1.5**	**0.87**	**4.37**	**N/A**	**-1.23**	**-3.74**	**-3.47**	**8.44**

Table 12 shows the scenario testing results for struck-by hazards in substructural activities. In extreme event scenarios, none of the respondents have selected rating “1”. So, the rating probability varies from 2 to 5 in extreme events. Scenario 1 test results indicate that even though an increase in inexperienced workers decreases the risk perception probability for the lower risk thresholds, but it improves the probability of perceiving the high-risk threshold. Whereas, an increase in experienced workers decreases the probability of perceiving higher risks in both regular and extreme event scenarios. Scenario 3 and scenario 4 test results also reflect contrasting changes in risk perception. Scenario 3 results imply that increasing safety-trained workers improves the probability of rating high-end risks and vice versa for scenario 4 results. Scenario 5 and scenario 6 test results show that a combination of an increase of inexperienced workers and safety-trained workers decreases the chances of rating the struck-by hazard less and increases the chances of rating it higher in regular and extreme events. Scenario 6 results are reciprocal to scenario 5 result trend. Scenario 7 and scenario 8 test results show an opposite trend meaning if the safety culture is improved, the probability of perceiving low risks is improved but the probability of perceiving high risk deteriorates which is similar to fall hazard test results. If the safety culture is degraded, the changes in risk perception are opposite to scenario 7.

Table 13 illustrates the scenario testing results for electrocution hazards. Scenario 1 shows that increment in inexperienced workers has a major effect on the perception ratings. It drastically reduces the probability of selecting a lower rating (i.e. by a margin of -13.3%) for the electrocution hazard and triggers the probability of selecting the maximum rating (e.g. 17.64% for regular events and 13.68% for extreme events). Similar to Table 12 scenario contrasts, scenario 2 also follows an opposite trend to scenario 1 where an increase in experienced workers decreases the probability of perceiving the electrocution hazard as high risk (e.g. a difference of -9.21% for extreme events). Scenario 3 suggests that an increase in safety training increases the chance of rating the electrocution higher and scenario 4 also echoes the same concept where the likelihood of selecting a higher rating reduces with a decrease in the safety training. Scenario 5 shows that a combinational increase of less experienced-safety trained workers significantly increases the chance of rating the electrocution hazard by a margin of around 15% for the regular and extreme event cases. Scenarios 7 and 8 suggest that any change in the current safety culture brings adverse effects on the highest threshold of risk rating in extreme events. In regular events, the changes in probability are low.

Table 13: Scenario Testing Results for Electrocution Hazard in Substructural Activities

Scenario	***Regular Event***					***Extreme Event***				
	1	2	3	4	5	1	2	3	4	5
Observed	0.184	0.187	0.32	0.131	0.178	0.054	0.15	0.111	0.329	0.356
Scenario 1	0.051	0.098	0.309	0.188	0.354	0.041	0.102	0.073	0.291	0.493
Difference %	**-13.3**	**-8.9**	**-1.13**	**5.69**	**17.64**	**-1.34**	**-4.73**	**-3.85**	**-3.76**	**13.68**
Scenario 2	0.231	0.212	0.307	0.107	0.142	0.099	0.214	0.142	0.281	0.264
Difference %	**4.66**	**2.57**	**-1.29**	**-2.4**	**-3.54**	**4.53**	**6.42**	**3.01**	**-4.74**	**-9.21**
Scenario 3	0.157	0.178	0.314	0.137	0.214	0.047	0.144	0.112	0.334	0.362
Difference %	**-2.75**	**-0.89**	**-0.58**	**0.56**	**3.66**	**-0.65**	**-0.52**	**0.07**	**0.51**	**0.59**
Scenario 4	0.204	0.203	0.322	0.121	0.15	0.056	0.153	0.113	0.324	0.355
Difference %	**1.99**	**1.69**	**0.16**	**-1.02**	**-2.82**	**0.19**	**0.34**	**0.11**	**-0.47**	**-0.17**
Scenario 5	0.127	0.123	0.259	0.153	0.338	0.024	0.089	0.075	0.323	0.488
Difference %	**-5.72**	**-6.34**	**-6.17**	**2.24**	**15.99**	**-2.96**	**-6.06**	**-3.6**	**-0.57**	**13.19**
Scenario 6	0.283	0.197	0.282	0.109	0.128	0.061	0.173	0.126	0.326	0.314
Difference %	**9.88**	**1.07**	**-3.81**	**-2.2**	**-4.94**	**0.7**	**2.3**	**1.49**	**-0.29**	**-4.2**
Scenario 7	0.179	0.185	0.321	0.133	0.183	0.107	0.238	0.158	0.281	0.216
Difference %	**-0.58**	**-0.17**	**0.07**	**0.19**	**0.5**	**5.25**	**8.87**	**4.7**	**-4.78**	**-14.04**
Scenario 8	0.204	0.193	0.311	0.125	0.167	0.101	0.216	0.142	0.282	0.259
Difference %	**1.97**	**0.62**	**-0.91**	**-0.59**	**-1.1**	**4.67**	**6.63**	**3.07**	**-4.66**	**-9.72**

Table 14 shows the scenario test results for caught-in/between hazards. All of the respondents rated the caught-in/between hazards higher for extreme event scenarios. Hence, the probabilities only contain ratings 3,4, and 5 in the extreme event section of the results.

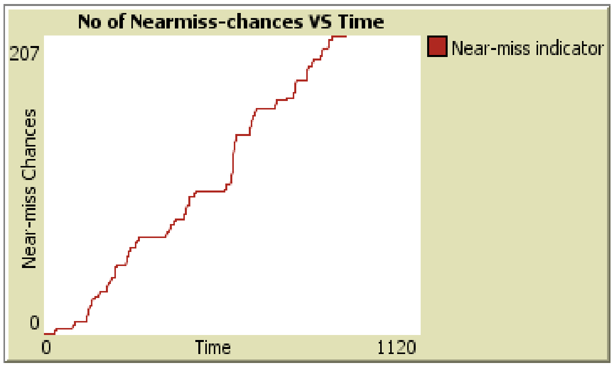
Table 14: Scenario Testing Results for Caught-in/between Hazard in Substructural Activities

Scenario	***Regular Event***					***Extreme Event***				
	1	2	3	4	5	1	2	3	4	5
Observed	0.067	0.121	0.449	0.191	0.171	N/A	N/A	0.304	0.229	0.467
Scenario 1	0.063	0.119	0.45	0.193	0.175	N/A	N/A	0.374	0.225	0.401
Difference %	**-0.37**	**-0.23**	**0.12**	**0.12**	**0.37**	N/A	N/A	**6.94**	**-0.32**	**-6.62**
Scenario 2	0.068	0.122	0.448	0.192	0.171	N/A	N/A	0.256	0.246	0.498
Difference %	**0.12**	**0.04**	**-0.15**	**0.04**	**-0.05**	N/A	N/A	**-4.8**	**1.72**	**3.08**
Scenario 3	0.019	0.052	0.474	0.271	0.184	N/A	N/A	0.22	0.189	0.591
Difference %	**-4.72**	**-6.95**	**2.32**	**7.93**	**1.3**	N/A	N/A	**-8.45**	**-3.94**	**12.39**
Scenario 4	0.08	0.139	0.495	0.196	0.089	N/A	N/A	0.358	0.235	0.407
Difference %	**1.38**	**1.81**	**4.55**	**0.46**	**-8.2**	N/A	N/A	**5.35**	**0.67**	**-6.02**
Scenario 5	0.05	0.091	0.379	0.263	0.216	N/A	N/A	0.27	0.236	0.495
Difference %	**-1.65**	**-2.99**	**-7.01**	**7.19**	**4.46**	N/A	N/A	**-3.47**	**0.7**	**2.77**
Scenario 6	0.092	0.156	0.481	0.187	0.084	N/A	N/A	0.345	0.233	0.422
Difference %	**2.49**	**3.45**	**3.21**	**-0.45**	**-8.69**	N/A	N/A	**4.08**	**0.47**	**-4.55**
Scenario 7	0.08	0.136	0.431	0.205	0.148	N/A	N/A	0.357	0.241	0.402
Difference %	**1.33**	**1.44**	**-1.81**	**1.32**	**-2.28**	N/A	N/A	**5.29**	**1.19**	**-6.49**
Scenario 8	0.04	0.092	0.452	0.148	0.269	N/A	N/A	0.273	0.248	0.479
Difference %	**-2.68**	**-2.96**	**0.24**	**-4.38**	**9.79**	N/A	N/A	**-3.11**	**1.91**	**1.19**

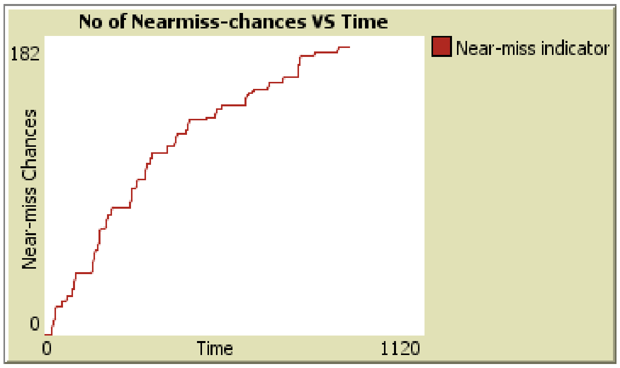
Scenario 1 and scenario 2 regular event test results show that in regular events changing the experience of the workers hardly affects their risk perceptions. In extreme events, increasing inexperienced workers reduce the probability of perceiving caught-in/between hazards with higher ratings. Scenario 2 suggests that with an increase in experience, the probability of perceiving the hazard in extreme events rises. Scenario 3 and 4 reveal that increasing safety-trained workers significantly increase the probability of rating the caught-in/between risk higher. Scenario 6 shows that a combinational change of experience with no training decreases the probability of perceiving higher risk for the hazard by a margin of 8.69%. Scenario 8 suggests that improvement in safety culture can increase the risk perception rating by a positive rise of 9.79% which is also reflected in scenario 7 test results.

4.2.5 Results of Agent-based Model

Section 3.4 of chapter 3 describes the setup process of the agent-based model. The obstacles and equipment have been placed in close proximity to incorporate their accumulated effect into the site. The second obstacle coordinates are selected in such a way that the workers need to encounter the obstacles in their path between workstation 1 and workstation 2. To summarize, the site layout has been configured in a way that creates the most hazardous conditions for the workers. The output simulation has been generated for 900 ticks representing 15 minutes of high-intensity workload (continuous movement).



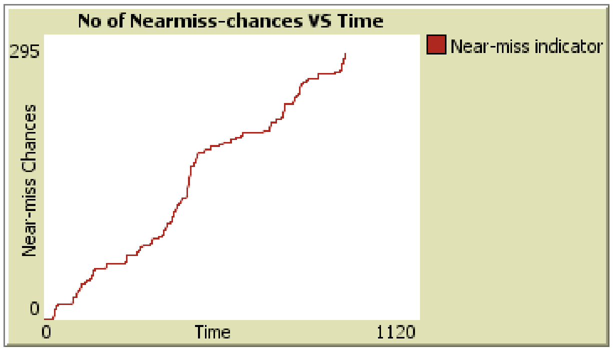
Scenario 1 (Regular Event): Increase in inexperienced workers



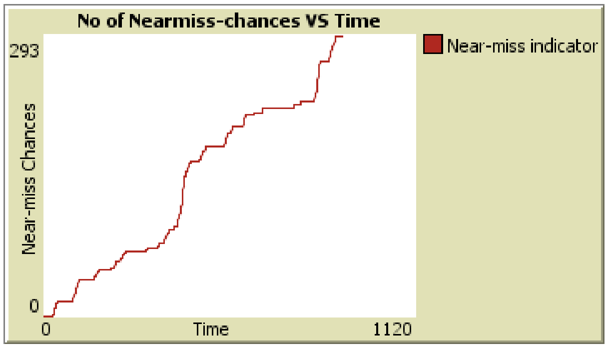
Scenario 2 (Regular Event): Increase in experienced workers

Figure 11: Comparison of Near-miss Indicator Values between Scenario 1 and Scenario 2 (Regular Event)

Figure 11 shows a comparison between scenarios 1 and 2 denoting a negative and positive change in experience respectively. The near-miss indicator which is considered as a safety parameter of the model shows a value of 207 and 175 respectively for scenarios 1 and 2. Therefore, it suggests that including an



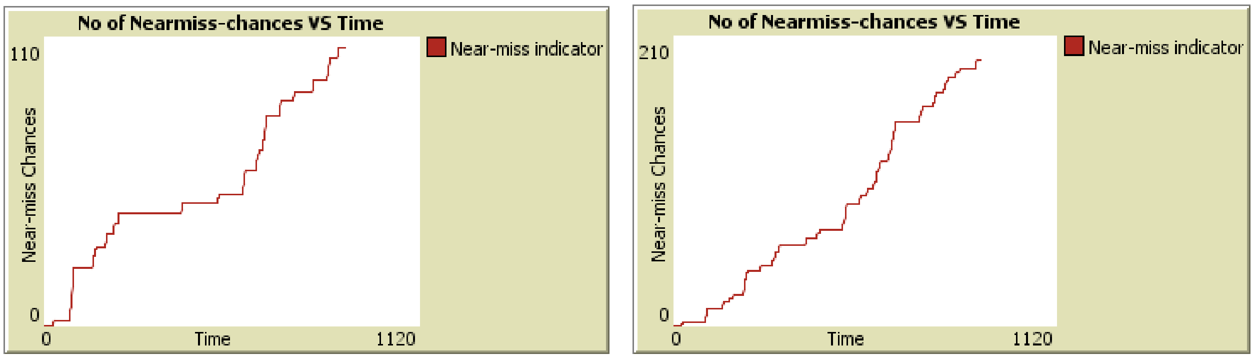
Scenario 1 (Extreme Event): Increase in inexperienced workers



Scenario 2 (Extreme Event): Increase in experienced workers

Figure 12: Comparison of Near-miss Indicator Values between Scenario 1 and Scenario 2 (Extreme Event)

experienced workforce in the environment reduces the near-miss chances of the construction site when it is a regular weather event. Surprisingly, the change in weather events swaps the results for scenarios 1 and 2. Figure 12 suggests that in the case of extreme events, the near-miss indicator value is higher for scenario 2 (i.e. 292 for scenario 2 and 276 for scenario 1). It denotes that in extreme events, inexperienced workers

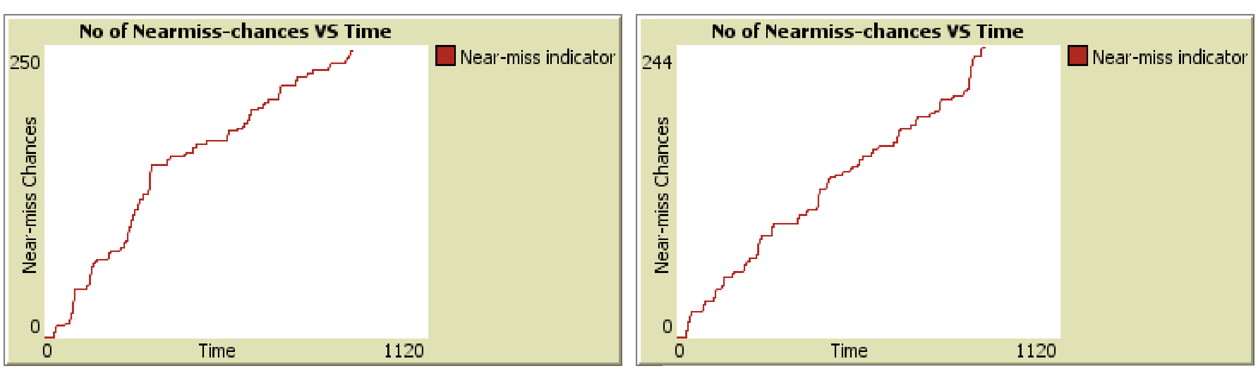


Scenario 3 (Regular Event): Increase in safety training   Scenario 4 (Regular Event): Decrease in safety training

Figure 13: Comparison of Near-miss Indicator Values between Scenario 3 and Scenario 4 (Regular Event)

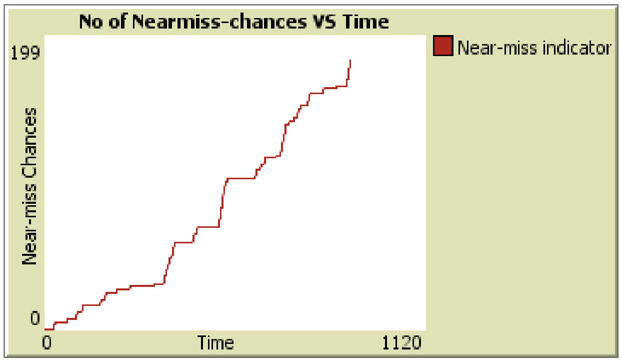
are more likely to work cautiously than experienced workers.

Scenario 3 shows that increasing 50% workforce with safety training can reduce the near-miss indicator value to 106. Moreover, the scenario 3 graph shows that for a substantial period the near-miss chances remain study during the simulation period. Compared to scenarios 1 and 2, the value is significantly lower. On the other hand, if the safety training is decreased, the near-miss value escalates to 193. Figure 14 shows that in extreme events the impact of safety training is quite low. The values for near-miss indicator scenarios 3 and 4 are close regardless of the training experience (i.e. 246 for scenario 3 and 242 for scenario 4).

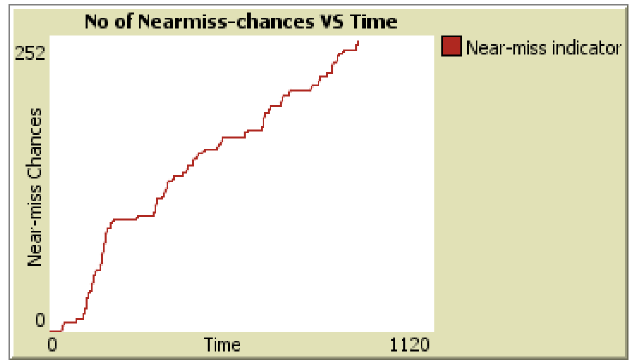


Scenario 3 (Extreme Event): Increase in safety training   Scenario 4 (Extreme Event): Decrease in safety training

Figure 14: Comparison of Near-miss Indicator Values between Scenario 3 and Scenario 4 (Extreme Event)



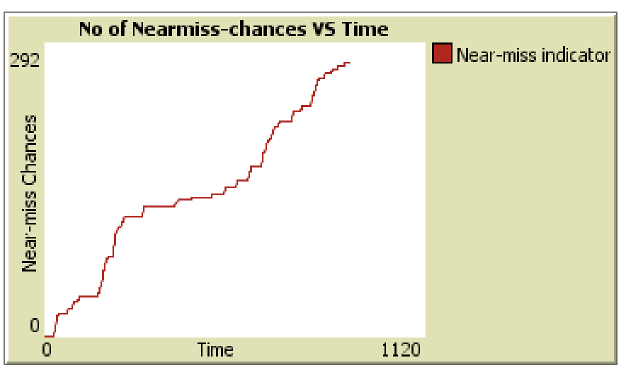
Scenario 5 (Regular Event): Increase in inexperienced workers and safety training



Scenario 6 (Regular Event): Decrease in inexperienced workers and safety training

Figure 16: Comparison of Near-miss Indicator Values between Scenario 5 and Scenario 6 (Regular Event)

Figure 15 shows a comparison of the agent-based modeling output between scenario 5 and scenario 6. Scenario 5 results indicate that providing safety training to inexperienced workers decreases the near-miss indicator value from 207 (scenario 1 value) to 182. Similarly, scenario 6 near-miss indicator value suggests that even after increasing the percentage of experienced workers, a decreasing percentage of safety training causes the rise of the near-miss indicator value to 248.



Scenario 5 (Extreme Event): Increase in inexperienced workers and safety training

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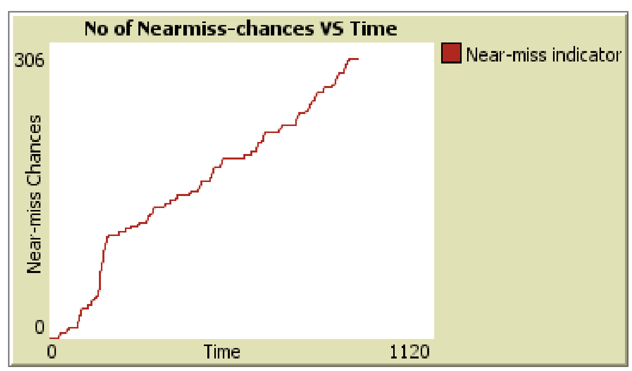
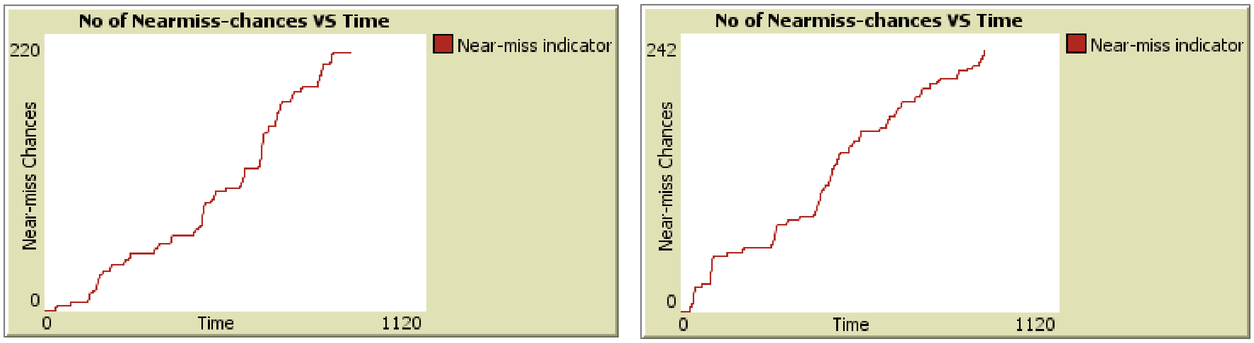


Scenario 6 (Extreme Event): Decrease in inexperienced workers and safety training

Figure 15: Comparison of Near-miss Indicator Values between Scenario 5 and Scenario 6 (Extreme Event)

between that indicates that during extreme weather events, increasing or decreasing experience and training attributes barely affect the environment and have higher risk potential in both cases.

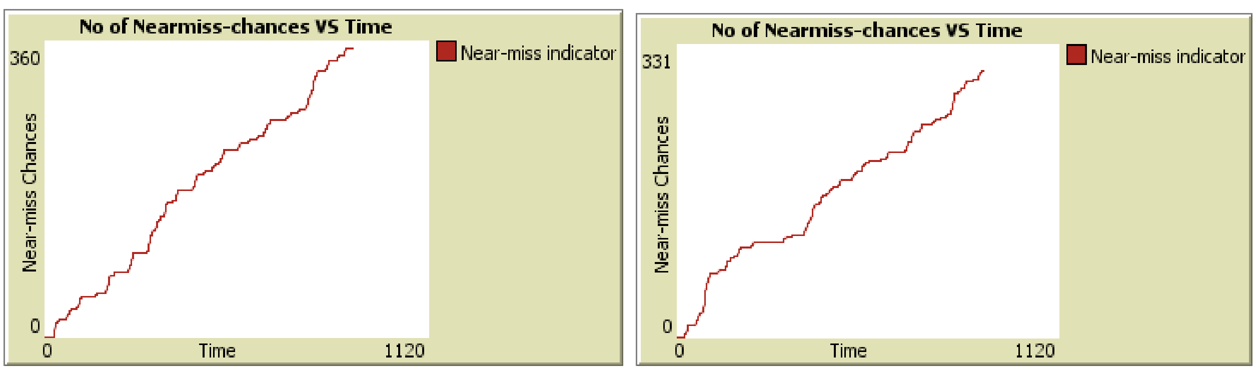


Scenario 7 (Regular Event): Improvement in safety culture

Scenario 8 (Regular Event): Deterioration in safety culture

Figure 18: Comparison of Near-miss Indicator Values between Scenario 7 and Scenario 8 (Regular Event)

Figure 17 suggests that an improved safety culture results in a lower near-miss indicator value of 206 compared to a deteriorated safety culture value of 228. A comparison between the value of scenario 3 (increase in safety training) and scenario 7 (improvement in safety culture) reveals that safety training is more likely to have a higher impact on the construction environment (i.e. scenario 3 imparts a lower near-miss value of 106 compared to scenario 7 value of 206). Figure 18 results imply that even with an improved



Scenario 7 (Extreme Event): Improvement in safety culture

Scenario 8 (Extreme Event): Deterioration in safety culture

Figure 17: Comparison of Near-miss Indicator Values between Scenario 7 and Scenario 8 (Extreme Event)

safety culture, extreme events incur a hike in the near-miss indicator value. The value of 352 surpasses the scenario 8 scores of 302.

The agent-based model also has an output monitor which shows a histogram of workers' minimum distance from obstacles or equipment. The histogram plot updates with each tick during the "go" command. Figure 19 shows a comparison of the average mean distance of workers from obstacles/equipment for three changes in the site layout: (1) if obstacle 2 is moved to center (at 0,0 coordinate), (2) if obstacle 2 is moved near the right corner (at coordinate 22,0), (3) if obstacle 2 is moved near the top corner (at coordinate 4,21).

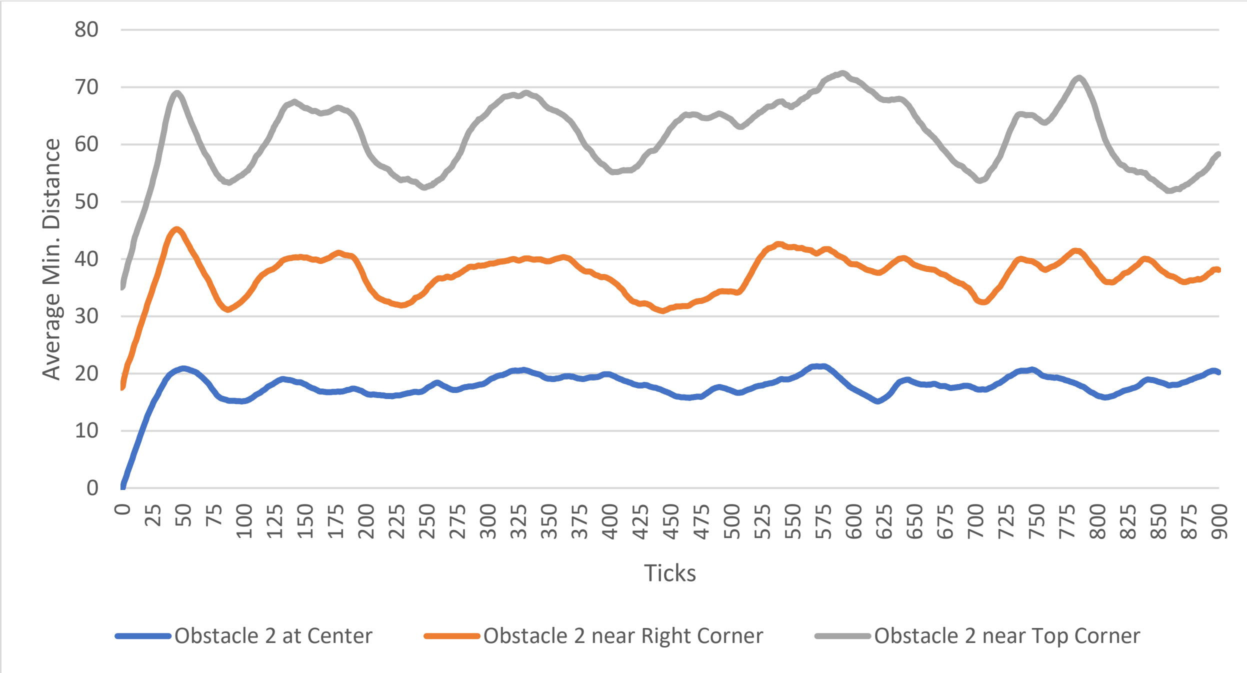


Figure 19: Average Minimum Distance of Workers from Obstacles/Equipment

From Figure 19, if obstacle 2 is set near the top corner, the minimum average distance between the workers and the obstacles/equipment is the maximum. On the contrary, if obstacle 2 is placed at the center, the workers move near the obstacles compared to the other 2 scenarios.

CHAPTER V: CONCLUSION

5.1 Highlights of the Research

The thesis aims to present an exemplary study on developing a tool with high-resolution worker behavior into the agent-based modeling platform that can measure the resilience assessment metrics in active construction sites. The approach to reach the goals of the study included: (1) conducting a well-designed questionnaire survey among the construction practitioners, (2) capturing their risk perception by a thorough analysis of the survey as well as finding the key trends and major contributors of risk perception, and (3) integrating the results into the agent-based modeling framework. The survey received 108 responses from construction affiliates with different backgrounds. The descriptive statistics unfolded that people having the same native language (i.e. English) or race (i.e. Hispanic or Latino) follow certain trends while rating the hazard risks associated with different construction activities. The secondary analysis of the survey involved applying the ordered probit model to the survey results. Using the statistical parameters, the probability of risk ratings in eight different scenarios was computed for both regular and extreme weather events. Finally, the scenario inputs were plugged into the agent-based modeling framework as the risk behaviors of the agents for the struck-by hazard in substructural activities. Some of the key insights from the agent-based model outputs included (i) in regular weather, increasing the percentage of safety-trained workers may improve the construction safety scenario significantly, (ii) extreme weather events are likely to generate more hazardous working conditions regardless of the changes in experience, safety knowledge, or safety culture, (iii) optimizing the site layout components may allow the workers to avoid hazard proximity zones in the construction site while executing the construction activities.

5.2 Key Contributions

The study contributes to enhancing the resilience of active construction sites. It can serve the construction safety professionals in proactive decision-making for the site safety assessment. The agent-based modeling framework integrates enriched behavioral attributes of the agents. Thus, the measures of the analysis reflect the resolutions in actual construction sites. The predictive nature of the model outputs can help policymakers to manage their risk management plans of time. Based on the accuracy of the input, the timeframe with the maximum risk threshold can also be forecasted through the framework. Besides, the study also provides insights about site layout optimization with the details of workers' distances from hazardous substances throughout the operation phase. Moreover, comprehensive hazard assessments for different construction activities can help in prioritizing the tasks based on their risk profiling. Finally, the study incorporates the impact of weather on the risk perception of construction individuals that can assist in better strategizing the overall site safety monitoring.

5.3 Limitations and Future Directions

The research has been accomplished considering some constraints. Firstly, the questionnaire survey has been conducted on construction affiliates from different spectrums which provides a general overview of different risk perceptions in the construction arena. Due to the COVID-19 travel restrictions, the construction sites could not be accessed for in-person interviews. However, in order to apply the model on particular construction sites, site-specific project information is required comprising risk perceptions of the construction workers. Thus, the results may vary significantly from the study. Additionally, as the survey has been participated by construction professionals from different corners of the world (e.g. U.S.A, Bangladesh, Qatar, etc.), the income variable has been excluded from further analysis due to large differences in the economic structure of the countries. In site-specific surveys, the variable can be added for analysis. Similarly, in site-specific surveys, the effect of differences in the native language can influence the risk rating behavior discretely. Furthermore, the effect of safety training has not been explored precisely in the study. For example, an individual with a 10-hour safety training may have a difference in perception than someone with a 300-hour training experience.

In the site layout setup procedure of the model, the hazardous zones are restricted only near the obstacles or equipment. The struck-by near-miss encounters are only activated if the agents step into these hazardous zones. There may be intermittent hindrances causing struck-by incidents due to the geomorphological aspects or elevation of the environment which have been ignored in this model. In considering the weather effect, it has been assumed that the components of the site layout remain constant. In real life scenario, the assumption may not be applicable for all the construction sites.

Future researchers can explore the impact of agent-to-agent interaction (i.e. influence of other co-workers in risk perception) on model outputs. Besides, the model is outlined for single equipment. The inclusion of multiple types of equipment along with their attributes and properly assigned hazardous zones can also be explored to improve the efficiency of the agent-based framework. Lastly, site-specific data and addressing the limitations mentioned in the previous section can help the construction research community in the long run. This study focused on developing a skeletal framework for improving site resilience that can be leveraged for monitoring site safety. The author believes that future advancements in this research can develop a next-generation safety tool and benefit the construction industry.

REFERENCES

[1] X. Shen and E. Marks, "Near-Miss Information Visualization Tool in BIM for Construction Safety," J. Constr. Eng. Manag., vol. 142, no. 4, p. 04015100, 2016, doi: 10.1061/(asce)co.1943-7862.0001100.

[2] N. Khan, A. K. Ali, M. J. Skibniewski, D. Y. Lee, and C. Park, "Excavation Safety Modeling Approach Using BIM and VPL," Adv. Civ. Eng., vol. 2019, 2019, doi: 10.1155/2019/1515808.

[3] D. M. Franco-Duran and G. Mejia A, "Construction Research Congress 2016 2039," Proc. Constr. Res. Congr. 2016, pp. 2039–2049, 2016, doi: 10.1061/9780784479827.203.

[4] J. Gambatese and J. Hinze, "Addressing construction worker safety in the design phase," Organ. Manag. Constr. Shap. Theory Pract. Vol. Two Manag. Constr. Proj. Manag. Risk, pp. 871–880, 2002, doi: 10.4324/9780203477090.

[5] S. Schneider and P. Susi, "Ergonomics and construction: A review of potential hazards in new construction," Am. Ind. Hyg. Assoc. J., vol. 55, no. 7, pp. 635–649, 1994, doi: 10.1080/15428119491018727.

[6] G. Carter and S. D. Smith, "Safety Hazard Identification on Construction Projects," *J. Constr. Eng. Manag.*, vol. 132, no. 2, pp. 197–205, 2006, doi: 10.1061/(asce)0733-9364(2006)132:2(197).

[7] M. Zhang and D. Fang, "Construction Management and Economics A cognitive analysis of why Chinese scaffolders do not use safety harnesses in construction A cognitive analysis of why Chinese scaffolders do not use safety harnesses in construction," no. April 2015, pp. 37–41, 2013, doi: 10.1080/01446193.2013.764000.

[8] D. Fang, C. Zhao, and M. Zhang, "A Cognitive Model of Construction Workers' Unsafe Behaviors," *J. Constr. Eng. Manag.*, vol. 142, no. 9, p. 04016039, 2016, doi: 10.1061/(asce)co.1943-7862.0001118.

[9] L. M. Goldenhar, L. J. Williams, and N. G. Swanson, "Modelling relationships between job stressors and injury and near-miss outcomes for construction labourers," *Work Stress*, vol. 17, no. 3, pp. 218–240, 2003, doi: 10.1080/02678370310001616144.

[10] J. Teizer and T. Cheng, "Proximity hazard indicator for workers-on-foot near miss interactions with construction equipment and geo-referenced hazard areas," *Autom. Constr.*, vol. 60, pp. 58–73, 2015, doi: 10.1016/j.autcon.2015.09.003.

[11] A. Hammad and C. Zhang, "Towards real-time simulation of construction activities considering spatio-temporal resolution requirements for improving safety and productivity," *Proc. - Winter Simul. Conf.*, no. January 2014, pp. 3533–3544, 2011, doi: 10.1109/WSC.2011.6148048.

[12] E. Elbeltagi, T. Hegazy, and A. Eldosouky, "Dynamic Layout of Construction Temporary Facilities Considering Safety," *J. Constr. Eng. Manag.*, vol. 130, no. 4, pp. 534–541, 2004, doi: 10.1061/(asce)0733-9364(2004)130:4(534).

[13] F. Jalaei and A. Jrade, "Construction Research Congress 2014 ©ASCE 2014 140," *Constr. Res. Congr. 2014*, no. 2008, pp. 140–149, 2014.

[14] X. Shen, E. Marks, N. Pradhananga, and T. Cheng, "Hazardous Proximity Zone Design for Heavy Construction Excavation Equipment," *J. Constr. Eng. Manag.*, vol. 142, no. 6, p. 05016001, 2016, doi: 10.1061/(asce)co.1943-7862.0001108.

[15] O. Binhomaid and T. Hegazy, "Agent-based Simulation of Workers ' Behaviors , Productivity ," *Can. J. Civ. Eng.*, pp. 1–30, 2020.

[16] K. D. Walsh and A. Sawhney, "Agent-based modeling of worker safety behavior at the construction workface," *Proceedings of the 12th Annual Conference of the International Group for Lean Construction*. pp. 779–792, 2004.

[17] 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 modeling," *Accid. Anal. Prev.*, vol. 94, pp. 8–17, 2016, doi: 10.1016/j.aap.2016.05.014.

[18] P. Zhang, N. Li, Z. Jiang, D. Fang, and C. J. Anumba, "An agent-based modeling approach for understanding the effect of worker-management interactions on construction workers' safety-related behaviors," *Autom. Constr.*, vol. 97, no. September 2018, pp. 29–43, 2019, doi: 10.1016/j.autcon.2018.10.015.

[19] J. G. Abdelhamid, T.S., Everett, "Identifying Root Causes of Accident," *J. Constr. Eng. Manag. 126 (1), pp. 52-60.*, vol. 25, no. 2, pp. 166–187, 2000.

[20] A. R. A. Hamid and W. Z. W. Y. and B. Singh, "Hazards At Construction Sites," *Proc. 5th Asia-Pacific Struct. Eng. Constr. Conf. (APSEC 2003) 26*, vol. 16, no. 3, pp. 166–172, 2003, doi: 10.1159/000220724.

[21] P. F. Tunji-Olayeni, A. O. Afolabi, and O. I. Okpalamoka, "Survey dataset on occupational hazards on construction sites," *Data Br.*, vol. 18, pp. 1365–1371, 2018, doi: 10.1016/j.dib.2018.04.028.

[22] J. Hinze, X. Huang, and L. Terry, "The Nature of Struck-by Accidents," vol. 131, no. 2, pp. 262–268, 2005.

[23] A. Shapira and M. Simcha, "AHP-Based Weighting of Factors Affecting Safety on Construction Sites with Tower Cranes," *J. Constr. Eng. Manag.*, vol. 135, no. 4, pp. 307–318, 2009, doi: 10.1061/(asce)0733-9364(2009)135:4(307).

[24] E. Sawacha, S. Naoum, and D. Fong, "Factors affecting safety performance on construction sites," *Int. J. Proj. Manag.*, vol. 17, no. 5, pp. 309–315, 1999, doi: 10.1016/S0263-7863(98)00042-8.

[25] M. O. Jannadi, "Factors affecting the safety of the construction industry: A questionnaire including 19 factors that affect construction safety was mailed to the top 200 construction contractors in the UK. Safety officers and workers were asked to indicate how effective ," *Build. Res. Inf.*, vol. 24, no. 2, pp. 108–112, 1996, doi: 10.1080/09613219608727510.

[26] D. P. Fang, F. Xie, X. Y. Huang, and H. Li, "Factor analysis-based studies on construction workplace safety management in China," *Int. J. Proj. Manag.*, vol. 22, no. 1, pp. 43–49, 2004, doi: 10.1016/S0263-7863(02)00115-1.

[27] N. N. Menzel and A. P. Gutierrez, "Latino worker perceptions of construction risks," *Am. J. Ind. Med.*, vol. 53, no. 2, pp. 179–187, 2010, doi: 10.1002/ajim.20735.

[28] O. Golovina, J. Teizer, and N. Pradhananga, "Heat map generation for predictive safety planning: Preventing struck-by and near miss interactions between workers-on-foot and construction equipment," *Autom. Constr.*, vol. 71, pp. 99–115, 2016, doi: 10.1016/j.autcon.2016.03.008.

[29] C. Engineering, "Computing in Civil Engineering 2019 439," pp. 439–446, 2019.

[30] C. I. N. Civil, "Computing in Civil and Building Engineering," *Comput. Civ. Build. Eng.*, pp. 955–1865, 1993.

[31] E. Mas, S. Koshimura, F. Imamura, A. Suppasri, A. Muhari, and B. Adriano, "Recent Advances in Agent-Based Tsunami Evacuation Simulations: Case Studies in Indonesia, Thailand, Japan and Peru," *Pure Appl. Geophys.*, vol. 172, no. 12, pp. 3409–3424, 2015, doi: 10.1007/s00024-015-1105-y.

[32] M. F. DiCarlo and E. Z. Berglund, "Connected communities improve hazard response: An agent-based model of social media behaviors during hurricanes," *Sustain. Cities Soc.*, vol. 69, no. March, p. 102836, 2021, doi: 10.1016/j.scs.2021.102836.

[33] M. Raoufi and A. R. Fayek, "Integrating Fuzzy Logic and agent-based modeling for assessing construction crew behavior," *Annu. Conf. North Am. Fuzzy Inf. Process. Soc. - NAFIPS*, vol. 2015-Septe, 2015, doi: 10.1109/NAFIPS-WConSC.2015.7284151.

[34] M. Watkins, A. Mukherjee, N. Onder, and K. G. Mattila, "Understanding labour productivity as an emergent property of individual and crew interactions on a construction site," *Lean Constr. A New Paradig. Manag. Cap. Proj. - 15th IGLC Conf.*, vol. 135, no. 7, pp. 400–405, 2007.

[35] A. M. Sadri, S. V. Ukkusuri, and P. Murray-Tuite, "A random parameter ordered probit model to understand the mobilization time during hurricane evacuation," *Transp. Res. Part C Emerg. Technol.*, vol. 32, pp. 21–30, 2013, doi: 10.1016/j.trc.2013.03.009.

[36] A. R. Daykin and P. G. Moffatt, "Analyzing Ordered Responses: A Review of the Ordered Probit Model," *Underst. Stat.*, vol. 1, no. 3, pp. 157–166, 2002, doi: 10.1207/s15328031us0103_02.

[37] S. J. Mason, R. R. Hill, L. Mönch, O. Rose, T. Jefferson, and J. W. Fowler, "Proceedings of the 2008 Winter Simulation Conference S. J. Mason, R. R. Hill, L. Mönch, O. Rose, T. Jefferson, J. W. Fowler eds.," pp. 91–100, 2008.

[38] S. Tisue and U. Wilensky, "Netlogo: A simple environment for modeling complexity," *Conf. Complex Syst.*, pp. 1–10, 2004.

[39] S. L. Lytinen and S. F. Railsback, "The evolution of agent-based simulation platforms: a review of NetLogo 5.0 and ReLogo," *Eur. Meet. Cybern. Syst. Res.*, pp. 1–11, 2010.

[40] M. Marzouk and I. Al Daour, "Planning labor evacuation for construction sites using BIM and agent-based simulation," *Saf. Sci.*, vol. 109, no. January 2017, pp. 174–185, 2018, doi: 10.1016/j.ssci.2018.04.023.

[41] S. G. Naoum *et al.*, “Gender in the Construction Industry : Literature Review and Comparative Survey of Men ’ s and Women ’ s Perceptions in UK Construction Consultancies,” vol. 36, no. 2, 2020, doi: 10.1061/(ASCE)ME.1943-5479.0000731.

[42] K. Chmutina and L. Bosher, “Construction in Barbados: Keeping natural hazards in mind?,” *Disaster Prev. Manag. An Int. J.*, vol. 23, no. 2, pp. 175–196, 2014, doi: 10.1108/DPM-07-2013-0111.

[43] M. A. Ahmed, A. M. Sadri, P. Pradhananga, M. Elzomor, and N. Pradhananga, “Social Media Communication Patterns of Construction Industry in Major Disasters.,” in *Construction Research Congress-2020*, 2020.

[44] A. Ahmadian, A. Akbarnezhad, T. H. Rashidi, and S. T. Waller, “Importance of planning for the transport stage in procurement of construction materials,” *31st Int. Symp. Autom. Robot. Constr. Mining, ISARC 2014 - Proc.*, no. Isarc, pp. 466–473, 2014, doi: 10.22260/isarc2014/0062.

[45] K. M. El-Gohary and R. F. Aziz, “Factors Influencing Construction Labor Productivity in Egypt,” *J. Manag. Eng.*, vol. 30, no. 1, pp. 1–9, 2014, doi: 10.1061/(asce)me.1943-5479.0000168.

[46] C. S. Poon, A. T. W. Yu, and L. Jaillon, “Reducing building waste at construction sites in Hong Kong,” *Constr. Manag. Econ.*, vol. 22, no. 5, pp. 461–470, 2004, doi: 10.1080/0144619042000202816.

[47] J. Teizer, “Right-time vs real-time pro-active construction safety and health system architecture,” *Constr. Innov.*, vol. 16, no. 3, pp. 253–280, 2016, doi: 10.1108/CI-10-2015-0049.

APPENDIX

Appendix A Questionnaire Survey

WELCOME

Welcome to the Construction Risk Perception and Resilience Indicators Survey!

The purpose of this study is to capture the risk perception of different construction stakeholders (such as workers, managers, owners, engineers, etc.) involved in construction activities. The study also aims at identifying the underlying factors that impact the construction site resilience (e.g. construction schedule, safety, etc.). Your participation will also contribute towards better understanding of how construction activities and safety practices may differ in regular and extreme weather events.

No one, including the researcher, will be able to associate your responses with your identity. Your participation is voluntary. You may choose not to take the survey, to stop responding at any time, or to skip any questions that you do not want to answer. There will be no more than minimal risk in this study, which means no greater than you would encounter in everyday life. You must be at least 18 years of age to participate in this study. Your completion of the survey serves as your voluntary agreement to participate in this research project and your certification that you are 18 or older.

It may take about 15-20 minutes to complete the survey. If you have concerns or questions about the research, please email M Ahmed Rusho at mrush009@fiu.edu or Dr. Arif Sadri at asadri@fiu.edu. Thank you for taking the time to complete the survey.

By click the button below, I agree that I have read the procedure described above and participate voluntarily in the survey.

WORK INFORMATION

What is the type of your current organization?

- ○ Civil Engineering Company (i.e. design and monitoring)
- ○ Construction Contracting Company/ General Contractors
- ○ Heavy Engineering Construction
- ○ Industrial Infrastructural Companies
- ○ EPC- Engineering, Procurement, and Construction Companies
- ○ PMC- Project Management Consultant
- ○ Real Estate Companies
- ○ MEP Contractors
- ○ Small Renovation Contractors Allied Services
- ○ Others (Specify) ________
- ○ I do not work currently

What is your role in the organization? Please select all that apply.

- ☐ Owner/Client
- ☐ Skilled Worker (e.g. plumber, roofer, mason, carpenter, electrician, etc.)
- ☐ General Worker (i.e. who perform general physical tasks)
- ☐ Equipment Operator
- ☐ Project Management Professional (e.g. Project Manager, Project Scheduler, Project Engineer, etc.)
- ☐ Construction Supervision Professional (e.g. Field Engineer, Construction Superintendent, Construction Surveyor, etc.)
- ☐ Construction Safety Professional
- ☐ Civil Design Professional
- ☐ Project Consultant Construction Inspector
- ☐ Others (Specify) ________

How many years have you been working in this organization? Please mention in years

____

How many hours do you work weekly?

____

How many colleagues/co-workers do you interact daily in the workplace?

Do you need to supervise others in your current role?

- ☐ Yes
- ☐ No

How many workers/colleagues do you need to supervise?

Does your organization provide OSHA safety trainings as per the requirements?

- ☐ Yes
- ☐ No

Do you regularly use PPE in the construction site as per the guidelines?

- ☐ Yes
- ☐ No

Is there any emergency/disaster response team in your site?

- ☐ Yes
- ☐ No
- ☐

RISK PERCEPTION

In this section, you will be asked about your engagement in different construction activities. You need to evaluate the severity of different types of hazards on regular and extreme weather events (i.e. construction works during the lead time before a site is shut down due to extreme weather events such as hurricane, flood alert, etc.) based on these construction activities.

In which of the following construction activities are you involved in the construction site? Please select all that apply.

- ☐ Super-structural works (i.e. major activities performed below the ground level such as piling, excavation, etc.)
- ☐ Sub-structural works (i.e. major activities performed above the ground level such as roofing, flooring, slab and column casting, etc.)
- ☐ Plant and machinery (i.e. major activities performed with machinery such as cranes, excavators, etc.)
- ☐ Scaffolding

- ☐ Power access works (i.e. activities that require electrical power)
- ☐ Ladder works
- ☐ Manual handling (i.e. activities performed with manually run equipment such as concrete chipping, rod bending, carpenter works, etc.)
- ☐ Curing (i.e. curing activity of concrete)
- ☐ Haz-mat (i.e. activities related to handling of hazardous materials)
- ☐ Public exposure to construction environment (i.e. construction activities performed within active public communities or near to the areas where there is public movement such as repair works)

Rank the following construction activities from 1 to 10 according to their importance in maintaining **desired construction schedule**, 1 being the most important and 10 being the least important.

	1	2	3	4	5	6	7	8	9	10
Super-structural works (i.e. major activities performed below the ground level such as piling, excavation, etc.)	○	○	○	○	○	○	○	○	○	○
Sub-structural works (i.e. major activities performed above the ground level such as roofing, flooring, slab and column casting, etc.)	○	○	○	○	○	○	○	○	○	○
Plant and machinery (i.e. major activities performed with machinery such as cranes, excavators, etc.)	○	○	○	○	○	○	○	○	○	○
Scaffolding	○	○	○	○	○	○	○	○	○	○
Power access works (i.e. activities that require electrical power)	○	○	○	○	○	○	○	○	○	○
Ladder works	○	○	○	○	○	○	○	○	○	○
Manual handling (i.e. activities performed with manually run equipment such as concrete chipping, rod bending, carpenter works, etc.)	○	○	○	○	○	○	○	○	○	○
Curing (i.e. curing activity of concrete)	○	○	○	○	○	○	○	○	○	○
Haz-mat (i.e. activities related to handling of hazardous materials)	○	○	○	○	○	○	○	○	○	○
Public exposure to construction environment (i.e. construction activities performed within active public communities or near to the areas where there is public movement such as repair works)	○	○	○	○	○	○	○	○	○	○

Scaffolding:

For scaffolding activity, rate the level of risk for the following types of hazards from 1 to 5. 1 being the least risky and 5 being the most risky.

Rate the risks for both: Regular Weather Events and Extreme Weather Events (i.e. construction works during the lead time before a site is shut down due to extreme events such as hurricane evacuation alert, flood alert, active shooting emergency, etc.)

	Regular Weather Events 1 2 3 4 5	Extreme Weather Events 1 2 3 4 5
Tipping Hazard	○○○○○	○○○○○
Fall Hazard	○○○○○	○○○○○
Electrocution Hazard (i.e. electrical shock)	○○○○○	○○○○○
Struck-by Hazard	○○○○○	○○○○○
Caught-in/between Hazard	○○○○○	○○○○○
Pulled-into Hazard	○○○○○	○○○○○
Equipment Positioning Hazard (i.e. risk of accidents due to the position of the equipment such as crane position)	○○○○○	○○○○○
Lifting Hazard	○○○○○	○○○○○
Work Stress (i.e. hazard resulting from workload)	○○○○○	○○○○○
Communication (i.e. hazard resulting from miscommunication between co-workers or worker-management)	○○○○○	○○○○○
Excavation Hazard	○○○○○	○○○○○
Stacking Hazard (i.e. hazard due to material stacking)	○○○○○	○○○○○
Wind Effect (i.e. wind turbulence)	○○○○○	○○○○○
Heat Effect (i.e. hot temperature)	○○○○○	○○○○○
Visibility (i.e. poor visibility)	○○○○○	○○○○○
Wildlife (i.e. intrusion of wild animals into the construction site)	○○○○○	○○○○○
Flooding	○○○○○	○○○○○
Noise	○○○○○	○○○○○

Power Access Works:

Power access works refer to those activities that require electrical power supply to execute.

Similar to the previous question, rate the level of risk of the following types of hazards from 1 to 5 (1 being the least risky and 5 being the most risky) for both regular weather events and extreme weather events.

	Regular Weather Events					Extreme Weather Events				
	1	2	3	4	5	1	2	3	4	5
Tipping Hazard	○	○	○	○	○	○	○	○	○	○
Fall Hazard	○	○	○	○	○	○	○	○	○	○
Electrocution Hazard (i.e. electrical shock)	○	○	○	○	○	○	○	○	○	○
Struck-by Hazard	○	○	○	○	○	○	○	○	○	○
Caught-in/between Hazard	○	○	○	○	○	○	○	○	○	○
Pulled-into Hazard	○	○	○	○	○	○	○	○	○	○
Equipment Positioning Hazard (i.e. risk of accidents due to the position of the equipment such as crane position)	○	○	○	○	○	○	○	○	○	○
Lifting Hazard	○	○	○	○	○	○	○	○	○	○
Work Stress (i.e. hazard resulting from workload)	○	○	○	○	○	○	○	○	○	○
Communication (i.e. hazard resulting from miscommunication between co-workers or worker-management)	○	○	○	○	○	○	○	○	○	○
Excavation Hazard	○	○	○	○	○	○	○	○	○	○
Stacking Hazard (i.e. hazard due to material stacking)	○	○	○	○	○	○	○	○	○	○
Wind Effect (i.e. wind turbulence)	○	○	○	○	○	○	○	○	○	○
Heat Effect (i.e. hot temperature)	○	○	○	○	○	○	○	○	○	○
Visibility (i.e. poor visibility)	○	○	○	○	○	○	○	○	○	○
Wildlife (i.e. intrusion of wild animals into the construction site)	○	○	○	○	○	○	○	○	○	○
Flooding	○	○	○	○	○	○	○	○	○	○
Noise	○	○	○	○	○	○	○	○	○	○

Ladder Works:

Ladders are used to reach higher elevations on a temporary basis.

Similar to the previous question, rate the level of risk of the following types of hazards from 1 to 5 (1 being the least risky and 5 being the most risky) for both regular weather events and extreme weather events.

	Regular Weather Events					Extreme Weather Events				
	1	2	3	4	5	1	2	3	4	5
Tipping Hazard	○	○	○	○	○	○	○	○	○	○
Fall Hazard	○	○	○	○	○	○	○	○	○	○
Electrocution Hazard (i.e. electrical shock)	○	○	○	○	○	○	○	○	○	○
Struck-by Hazard	○	○	○	○	○	○	○	○	○	○
Caught-in/between Hazard	○	○	○	○	○	○	○	○	○	○
Pulled-into Hazard	○	○	○	○	○	○	○	○	○	○
Equipment Positioning Hazard (i.e. risk of accidents due to the position of the equipment such as crane position)	○	○	○	○	○	○	○	○	○	○
Lifting Hazard	○	○	○	○	○	○	○	○	○	○
Work Stress (i.e. hazard resulting from workload)	○	○	○	○	○	○	○	○	○	○
Communication (i.e. hazard resulting from miscommunication between co-workers or worker-management)	○	○	○	○	○	○	○	○	○	○
Excavation Hazard	○	○	○	○	○	○	○	○	○	○
Stacking Hazard (i.e. hazard due to material stacking)	○	○	○	○	○	○	○	○	○	○
Wind Effect (i.e. wind turbulence)	○	○	○	○	○	○	○	○	○	○
Heat Effect (i.e. hot temperature)	○	○	○	○	○	○	○	○	○	○
Visibility (i.e. poor visibility)	○	○	○	○	○	○	○	○	○	○
Wildlife (i.e. intrusion of wild animals into the construction site)	○	○	○	○	○	○	○	○	○	○
Flooding	○	○	○	○	○	○	○	○	○	○
Noise	○	○	○	○	○	○	○	○	○	○

Sub-structural Works:

Sub-structural works include major construction activities below the ground level such as piling, excavation,soil backfilling, foundation wall casting, etc.

Similar to the previous question, rate the level of risk of the following types of hazards from 1 to 5 (1 being the least risky and 5 being the most risky) for both regular weather events and extreme weather events.

	Regular Weather Events					Extreme Weather Events				
	1	2	3	4	5	1	2	3	4	5
Tipping Hazard										
Fall Hazard										
Electrocution Hazard (i.e. electrical shock)										
Struck-by Hazard										
Caught-in/between Hazard										
Pulled-into Hazard										
Equipment Positioning Hazard (i.e. risk of accidents due to the position of the equipment such as crane position)										
Lifting Hazard										
Work Stress (i.e. hazard resulting from workload)										
Communication (i.e. hazard resulting from miscommunication between co-workers or worker-management)										
Excavation Hazard										
Stacking Hazard (i.e. hazard due to material stacking)										
Wind Effect (i.e. wind turbulence)										
Heat Effect (i.e. hot temperature)										
Visibility (i.e. poor visibility)										
Wildlife (i.e. intrusion of wild animals into the construction site)										
Flooding										
Noise										

Manual Handling:

Manual handling activities are performed with manually run equipments. These activites include concrete chipping, rod bending, carpenter works and so on.

Similar to the previous question, rate the level of risk of the following types of hazards from 1 to 5 (1 being the least risky and 5 being the most risky) for both regular weather events and extreme weather events.

	Regular Weather Events					Extreme Weather Events				
	1	2	3	4	5	1	2	3	4	5
Tipping Hazard										
Fall Hazard										
Electrocution Hazard (i.e. electrical shock)										
Struck-by Hazard										
Caught-in/between Hazard										
Pulled-into Hazard										
Equipment Positioning Hazard (i.e. risk of accidents due to the position of the equipment such as crane position)										
Lifting Hazard										
Work Stress (i.e. hazard resulting from workload)										
Communication (i.e. hazard resulting from miscommunication between co-workers or worker-management)										
Excavation Hazard										
Stacking Hazard (i.e. hazard due to material stacking)										
Wind Effect (i.e. wind turbulence)										
Heat Effect (i.e. hot temperature)										
Visibility (i.e. poor visibility)										
Wildlife (i.e. intrusion of wild animals into the construction site)										
Flooding										
Noise										

Plant and Machinery:

Plant and machinery activities are major construction works that require heavy duty machines such as cranes, excavators, etc.

Similar to the previous question, rate the level of risk of the following types of hazards from 1 to 5 (1 being the least risky and 5 being the most risky) for both regular weather events and extreme weather events.

	Regular Weather Events					Extreme Weather Events				
	1	2	3	4	5	1	2	3	4	5
Tipping Hazard										
Fall Hazard										
Electrocution Hazard (i.e. electrical shock)										
Struck-by Hazard										
Caught-in/between Hazard										
Pulled-into Hazard										
Equipment Positioning Hazard (i.e. risk of accidents due to the position of the equipment such as crane position)										
Lifting Hazard										
Work Stress (i.e. hazard resulting from workload)										
Communication (i.e. hazard resulting from miscommunication between co-workers or worker-management)										
Excavation Hazard										
Stacking Hazard (i.e. hazard due to material stacking)										
Wind Effect (i.e. wind turbulence)										
Heat Effect (i.e. hot temperature)										
Visibility (i.e. poor visibility)										
Wildlife (i.e. intrusion of wild animals into the construction site)										
Flooding										
Noise										

Super-structural Works:

Super-structural works are major construction activities performed above the ground level such as roofing, slab and column casting, wood-framing, etc.

Similar to the previous question, rate the level of risk of the following types of hazards from 1 to 5 (1 being the least risky and 5 being the most risky) for both regular weather events and extreme weather events.

	Regular Weather Events					Extreme Weather Events				
	1	2	3	4	5	1	2	3	4	5
Tipping Hazard	○	○	○	○	○	○	○	○	○	○
Fall Hazard	○	○	○	○	○	○	○	○	○	○
Electrocution Hazard (i.e. electrical shock)	○	○	○	○	○	○	○	○	○	○
Struck-by Hazard	○	○	○	○	○	○	○	○	○	○
Caught-in/between Hazard	○	○	○	○	○	○	○	○	○	○
Pulled-into Hazard	○	○	○	○	○	○	○	○	○	○
Equipment Positioning Hazard (i.e. risk of accidents due to the position of the equipment such as crane position)	○	○	○	○	○	○	○	○	○	○
Lifting Hazard	○	○	○	○	○	○	○	○	○	○
Work Stress (i.e. hazard resulting from workload)	○	○	○	○	○	○	○	○	○	○
Communication (i.e. hazard resulting from miscommunication between co-workers or worker-management)	○	○	○	○	○	○	○	○	○	○
Excavation Hazard	○	○	○	○	○	○	○	○	○	○
Stacking Hazard (i.e. hazard due to material stacking)	○	○	○	○	○	○	○	○	○	○
Wind Effect (i.e. wind turbulence)	○	○	○	○	○	○	○	○	○	○
Heat Effect (i.e. hot temperature)	○	○	○	○	○	○	○	○	○	○
Visibility (i.e. poor visibility)	○	○	○	○	○	○	○	○	○	○
Wildlife (i.e. intrusion of wild animals into the construction site)	○	○	○	○	○	○	○	○	○	○
Flooding	○	○	○	○	○	○	○	○	○	○
Noise	○	○	○	○	○	○	○	○	○	○

Curing:

Curing refers to curing of concrete after casting is completed.

Similar to the previous question, rate the level of risk of the following types of hazards from 1 to 5 (1 being the least risky and 5 being the most risky) for both regular weather events and extreme weather events.

	Regular Weather Events					Extreme Weather Events				
	1	2	3	4	5	1	2	3	4	5
Tipping Hazard	○	○	○	○	○	○	○	○	○	○
Fall Hazard	○	○	○	○	○	○	○	○	○	○
Electrocution Hazard (i.e. electrical shock)	○	○	○	○	○	○	○	○	○	○
Struck-by Hazard	○	○	○	○	○	○	○	○	○	○
Caught-in/between Hazard	○	○	○	○	○	○	○	○	○	○
Pulled-into Hazard	○	○	○	○	○	○	○	○	○	○
Equipment Positioning Hazard (i.e. risk of accidents due to the position of the equipment such as crane position)	○	○	○	○	○	○	○	○	○	○
Lifting Hazard	○	○	○	○	○	○	○	○	○	○
Work Stress (i.e. hazard resulting from workload)	○	○	○	○	○	○	○	○	○	○
Communication (i.e. hazard resulting from miscommunication between co-workers or worker-management)	○	○	○	○	○	○	○	○	○	○
Excavation Hazard	○	○	○	○	○	○	○	○	○	○
Stacking Hazard (i.e. hazard due to material stacking)	○	○	○	○	○	○	○	○	○	○
Wind Effect (i.e. wind turbulence)	○	○	○	○	○	○	○	○	○	○
Heat Effect (i.e. hot temperature)	○	○	○	○	○	○	○	○	○	○
Visibility (i.e. poor visibility)	○	○	○	○	○	○	○	○	○	○
Wildlife (i.e. intrusion of wild animals into the construction site)	○	○	○	○	○	○	○	○	○	○
Flooding	○	○	○	○	○	○	○	○	○	○
Noise	○	○	○	○	○	○	○	○	○	○

Haz-Mat Practices:

Haz-mat is the short form of hazardous materials and refers to the handling of hazardous and toxic substances in the workplace.

Similar to the previous question, rate the level of risk of the following types of hazards from 1 to 5 (1 being the least risky and 5 being the most risky) for both regular weather events and extreme weather events.

	Regular Weather Events					Extreme Weather Events				
	1	2	3	4	5	1	2	3	4	5
Tipping Hazard	○	○	○	○	○	○	○	○	○	○
Fall Hazard	○	○	○	○	○	○	○	○	○	○
Electrocution Hazard (i.e. electrical shock)	○	○	○	○	○	○	○	○	○	○
Struck-by Hazard	○	○	○	○	○	○	○	○	○	○
Caught-in/between Hazard	○	○	○	○	○	○	○	○	○	○
Pulled-into Hazard	○	○	○	○	○	○	○	○	○	○
Equipment Positioning Hazard (i.e. risk of accidents due to the position of the equipment such as crane position)	○	○	○	○	○	○	○	○	○	○
Lifting Hazard	○	○	○	○	○	○	○	○	○	○
Work Stress (i.e. hazard resulting from workload)	○	○	○	○	○	○	○	○	○	○
Communication (i.e. hazard resulting from miscommunication between co-workers or worker-management)	○	○	○	○	○	○	○	○	○	○
Excavation Hazard	○	○	○	○	○	○	○	○	○	○
Stacking Hazard (i.e. hazard due to material stacking)	○	○	○	○	○	○	○	○	○	○
Wind Effect (i.e. wind turbulence)	○	○	○	○	○	○	○	○	○	○
Heat Effect (i.e. hot temperature)	○	○	○	○	○	○	○	○	○	○
Visibility (i.e. poor visibility)	○	○	○	○	○	○	○	○	○	○
Wildlife (i.e. intrusion of wild animals into the construction site)	○	○	○	○	○	○	○	○	○	○
Flooding	○	○	○	○	○	○	○	○	○	○
Noise	○	○	○	○	○	○	○	○	○	○

Public Exposure to Construction Environment:

This type of construction activities are performed within active public communities or near to the areas where there is public movements (e.g. repair works)

Similar to the previous question, rate the level of risk of the following types of hazards from 1 to 5 (1 being the least risky and 5 being the most risky) for both regular weather events and extreme weather events.

	Regular Weather Events					Extreme Weather Events				
	1	2	3	4	5	1	2	3	4	5
Tipping Hazard	○	○	○	○	○	○	○	○	○	○
Fall Hazard	○	○	○	○	○	○	○	○	○	○
Electrocution Hazard (i.e. electrical shock)	○	○	○	○	○	○	○	○	○	○
Struck-by Hazard	○	○	○	○	○	○	○	○	○	○
Caught-in/between Hazard	○	○	○	○	○	○	○	○	○	○
Pulled-into Hazard	○	○	○	○	○	○	○	○	○	○
Equipment Positioning Hazard (i.e. risk of accidents due to the position of the equipment such as crane position)	○	○	○	○	○	○	○	○	○	○
Lifting Hazard	○	○	○	○	○	○	○	○	○	○
Work Stress (i.e. hazard resulting from workload)	○	○	○	○	○	○	○	○	○	○
Communication (i.e. hazard resulting from miscommunication between co-workers or worker-management)	○	○	○	○	○	○	○	○	○	○
Excavation Hazard	○	○	○	○	○	○	○	○	○	○
Stacking Hazard (i.e. hazard due to material stacking)	○	○	○	○	○	○	○	○	○	○
Wind Effect (i.e. wind turbulence)	○	○	○	○	○	○	○	○	○	○
Heat Effect (i.e. hot temperature)	○	○	○	○	○	○	○	○	○	○
Visibility (i.e. poor visibility)	○	○	○	○	○	○	○	○	○	○
Wildlife (i.e. intrusion of wild animals into the construction site)	○	○	○	○	○	○	○	○	○	○
Flooding	○	○	○	○	○	○	○	○	○	○
Noise	○	○	○	○	○	○	○	○	○	○

PROJECT INFORMATION

What type of construction project have you been involved most recently? Please select the most suitable one

- ○ Residential Building
- ○ Institutional and Commercial Building (e.g. shopping malls, hospitals, etc.)
- ○ Specialized Industrial Construction
- ○ Infrastructure and Heavy Construction (e.g. highway, railway, etc.)
- ○ Others (Specify) __________

Approximately what is the area size of that construction project? Please specify in square meters

Briefly state the scope of your most recent project.

How many workers are there in that construction site? Please specify in numbers

What is the location of that site? Please specify the city name

What is the duration of the construction project? Please specify in months

How many plants or machineries (e.g. excavators, cranes, concrete mixers, etc.) are there in the site?

How many equipments (e.g. hammer, drilling machine, jig saw, etc.) are there in the construction site?

On average how many **workers** are required to perform the following construction activities for your construction site?

0 10 20 30 40 50 60 70 80 90 100

Super-structural works (i.e. major activities performed below the ground level such as piling, excavation, etc.)

Sub-structural works (i.e. major activities performed above the ground level such as roofing, flooring, slab and column casting, etc.)

Plant and machinery (i.e. major activities performed with machinery such as cranes, excavators, etc.)

Scaffolding

Power access works (i.e. activities that require electrical power)

Ladder works

Manual handling (i.e. activities performed with manually run equipment such as concrete chipping, rod bending, carpenter works, etc.)

Curing (i.e. curing activity of concrete)

Haz-mat (i.e. activities related to handling of hazardous materials)

Public exposure to construction environment (i.e. construction activities performed within active public communities or near to the areas where there is public movement such as repair works)

On average how many **equipment** are required to perform the following construction activities for your construction site?

0 5 10 15 20 25

Super-structural works (i.e. major activities performed below the ground level such as piling, excavation, etc.)

Sub-structural works (i.e. major activities performed above the

ground level such as roofing, flooring, slab and column casting, etc.)

Plant and machinery (i.e. major activities performed with machinery

such as cranes, excavators, etc.)

Scaffolding

Power access works (i.e. activities that require electrical power)

Ladder works

Manual handling (i.e. activities performed with manually run equipment such as concrete chipping, rod bending, carpenter works, etc.)

Curing (i.e. curing activity of concrete)

Haz-mat (i.e. activities related to handling of hazardous materials)

Public exposure to construction environment (i.e. construction activities performed within active public communities or near to the areas where there is public movement such as repair works)

On average how many **days** are required to perform the following construction activities for your construction site?

0 5 10 15 20 25 30

Super-structural works (i.e. major activities performed below the

ground level such as piling, excavation, etc.)

Sub-structural works (i.e. major activities performed above the

ground level such as roofing, flooring, slab and column casting, etc.)

Plant and machinery (i.e. major activities performed with machinery

such as cranes, excavators, etc.)

Scaffolding

Power access works (i.e. activities that require electrical power)

Ladder works

Manual handling (i.e. activities performed with manually run equipment such as concrete chipping, rod bending, carpenter works, etc.)

Curing (i.e. curing activity of concrete)

Haz-mat (i.e. activities related to handling of hazardous materials)

Public exposure to construction environment (i.e. construction activities performed within active public communities or near to the areas where there is public movement such as repair works)

IMPACT OF PROJECT EXECUTION VARIABLES

A list of factors impacting project delivery process is mentioned below. Rate them between 1 to 5 stars, 1 star being the least impactful and 5 stars being the most impactful in construction scheduling.

	1	2	3	4	5
Procurement of Materials					
Climate					
Season					
Road Connectivity with Construction Site					
Site Location					
Equipment and Material Quality					
Labor Quality					
Workforce Skills					
Land Acquisition					
Changes in Budget					

How would you rate the impacts of the following extreme weather events? Rate them between 1 to 5 stars, 1 star for the lowest impact and 5 stars for the highest impact in construction activities.

	1	2	3	4	5
Hurricane	○	○	○	○	○
Tornado/Typhoon	○	○	○	○	○
Flooding	○	○	○	○	○
Drought	○	○	○	○	○
Extreme Heat	○	○	○	○	○
Landslide	○	○	○	○	○
Earthquake	○	○	○	○	○
Tsunami	○	○	○	○	○
Volcanic Eruption	○	○	○	○	○
Extreme Cold	○	○	○	○	○
Snowstorm	○	○	○	○	○
Wildfire	○	○	○	○	○
Extreme Rainfall	○	○	○	○	○
Hailstorm	○	○	○	○	○
Acid Rain	○	○	○	○	○
Avalanche	○	○	○	○	○

BACKGROUND INFORMATION

What is your age in years?

[ ]

What is your gender?

- Male
- Female
- Others

What is your race?

- White
- Black or African American
- American Indian or Alaska Native
- Asian
- Native Hawaiian or Pacific Islander Hispanic or Latino
- Other [ ]
- Don't know

What is your marital status?

- Married
- Widowed
- Divorced
- Separated
- Unmarried

What is the highest degree or level of school you have completed?

- No Schooling
- Incomplete High Schooling
- High School Graduate, Diploma or Equivalent
- College Graduate
- Trade, Technical, Vocational Training
- Associate Degree

- Bachelor's Degree
- Master's Degree
- Doctorate Degree
- Professional Degree
- Others (Specify) ______

What is your native language?

- English
- Spanish
- Portuguese
- Chinese
- Hindi
- Bengali
- Russia
- Others (Specify) ______

Approximately, what is your annual income?

- $10,000 or less
- $10,001 - $25,000
- $25,001 - $40,000
- $40,001 - $60,000
- $60,001-$80,000
- Above $80,000
- Don't Know

What is your professional experience in construction?

- No experience
- Less than 6 months
- 6 months-1 year
- 1-2 years

- 3-5 years
- 6-10 years
- More than 10 years

Have you received any OSHA trainings previously?

- Yes
- No

FINISH

Thank you for your participation!