ABC UTC

ACCELERATED BRIDGE CONSTRUCTION
UNIVERSITY TRANSPORTATION CENTER

ABC-UTC GUIDE FOR:

AN AGENT-BASED DECISION SUPPORT TOOL TO IDENTIFY NEAR-MISS INCIDENTS AND ACCESSIBILITY ISSUES IN ACCELERATED BRIDGE CONSTRUCTION

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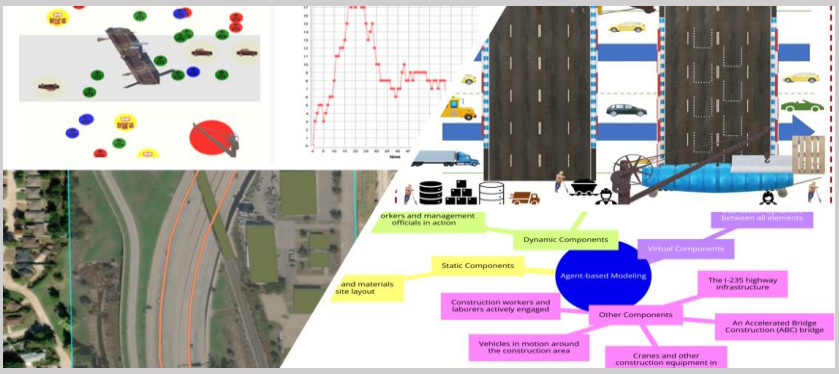

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ABSTRACT

This report summarizes the work activities undertaken in the study and presents the results of those activities toward development of this ABC-UTC Guide for An Agent-based Decision Support Tool to Identify Near-Miss Incidents and Accessibility Issues in Accelerated Bridge Construction. The construction industry has a major problem with safety, as it has very high rates of accidents. About 20% of all work-related incidents happen in construction. This problem is not just in one place but is a concern all over the world. Keeping construction sites safe is complicated because there are many unpredictable risks, and it takes experts from different fields to handle these challenges. In the realm of Accelerated Bridge Construction (ABC), maintaining high safety standards while optimizing construction efficiency is paramount. This study will use a sophisticated computer modeling technique called agent-based modeling to better understand and prevent these near-miss incidents in ABC projects. By closely examining how the different elements of a construction project interact, this research aims to find new ways to enhance safety and accessibility on construction sites. The goal is to create a tool that construction and transportation agencies can use to make sites safer, and more accessible, and reduce the risk of accidents. Preliminary findings indicate that near-miss incidents are not only indicators of potential accidents but also pivotal for developing preventive measures. This study's innovative approach involves categorizing these incidents to tailor safety interventions effectively. The results promise significant contributions to construction safety management, offering a blueprint for integrating ABM into routine safety assessments at ABC sites. This approach will not only help in avoiding potential accidents but also ensure that the benefits of ABC can be fully realized, contributing significantly to the field of construction safety.

ACKNOWLEDGMENTS

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1. INTRODUCTION

This report presents the findings of a comprehensive study focused on improving safety within the realm of Accelerated Bridge Construction (ABC). The construction industry, notorious for its high accident rates, encounters various challenges that jeopardize worker safety and project efficiency. Approximately 20% of all work-related fatalities occur within this sector, prompting an urgent need for innovative solutions to enhance safety and mitigate risks associated with construction activities.

The primary objective of this research is to leverage agent-based modeling (ABM) to simulate the dynamic interactions typical of construction sites that utilize ABC techniques. This sophisticated computational approach allows for a detailed examination of how various elements of a construction project—such as human behavior, equipment use, and material handling—interact and influence overall site safety and accessibility.

By implementing ABC, which involves using pre-manufactured bridge components that are assembled on-site, the construction process becomes not only faster but also potentially safer due to reduced time spent on-site. However, despite these advantages, ABC projects are not devoid of risks, particularly near-miss incidents that can precariously escalate into severe accidents.

The research detailed in this report aims to:

- Analyze and predict near-miss incidents through detailed simulations, enhancing understanding of risk behaviors on-site.
- Develop a decision-support tool to aid construction and transportation agencies in crafting effective safety measures and operational strategies.
- Disseminate findings and recommendations through the ABC University Transportation Center's website, making them accessible for industry and academic use.

Findings from this study are expected to significantly contribute to the body of knowledge in construction safety management, providing actionable insights and practical tools that can be used to reduce accident rates and improve site accessibility. The integration of ABM into routine safety assessments promises to not only advance the effectiveness of current safety practices but also ensure that the benefits of Accelerated Bridge Construction can be fully realized, thereby advancing the industry's commitment to safety and efficiency.

1.1. BACKGROUND

The construction industry often faces accidents due to various uncertainties. To tackle this, researchers have been exploring new methods that consider the behavior of workers, materials, and equipment to improve safety. However, these methods simplify hazard scenarios and overlook near-miss incidents and accessibility problems common at construction sites. Accelerated Bridge Construction (ABC) uses pre-made bridge parts that are installed onsite, which cuts costs, saves time, enhances safety, and ensures better quality. But even ABC projects involve traditional construction work, leading to potential near-miss incidents and accessibility challenges.

This research aims to use agent-based modeling to study and predict near-miss incidents at ABC sites. It will examine how different parts of an ABC project interact and affect safety and accessibility. By analyzing the risk behaviors of these interactions, the study will help identify ways to prevent accidents and improve safety across ABC sites. The findings will be shared on the ABC-UTC website for public and research use. They will help develop a tool for construction and transportation agencies to enhance safety measures, prevent future incidents, improve site safety, increase accessibility, and understand how ABC differs from traditional construction regarding near-miss incidents.

The construction world often sees accidents due to various challenges on sites. To improve safety, researchers are looking at how workers, materials, and machines interact, especially in innovative construction methods like Accelerated Bridge Construction (ABC). ABC uses pre-made bridge pieces, making projects faster, safer, and of higher quality. Yet, ABC still faces challenges like near-miss incidents, where potential accidents nearly happen but are avoided just in time, and issues with accessing parts of the construction site.

The core problem is understanding and preventing near-miss incidents and improving accessibility in ABC projects.

1.2. SCOPE OF THE GUIDE

The construction industry has a major problem with safety, as it has very high rates of accidents. About 20% of all job-related deaths happen in construction. This problem is not just in one place but is a concern all over the world. Keeping construction sites safe is complicated because there are many unpredictable risks, and it takes experts from different fields to handle these challenges.

This study will use a sophisticated computer modeling technique called agent-based modeling to better understand and prevent these near-miss incidents in ABC projects. By closely examining how the different elements of a construction project interact, this research aims to find new ways to enhance safety and accessibility on construction sites. The ultimate goal is to create a tool that construction and transportation agencies can use to make sites safer, and more accessible, and reduce the risk of accidents.

This approach will not only help in avoiding potential accidents but also ensure that the benefits of ABC can be fully realized, contributing significantly to the field of construction safety.

1.3. INTENDED USERS

In the realm of Accelerated Bridge Construction (ABC), maintaining high safety standards while optimizing construction efficiency is paramount. This study will use a sophisticated computer modeling technique called agent-based modeling to better understand and prevent these near-miss incidents in ABC projects. By closely examining how the different elements of a construction project interact, this research aims to find new ways to enhance safety and accessibility on construction sites. The goal is to create a tool that

construction and transportation agencies can use to make sites safer, and more accessible, and reduce the risk of accidents. This study's innovative approach involves categorizing these incidents to tailor safety interventions effectively. The results promise significant contributions to construction safety management, offering a blueprint for integrating ABM into routine safety assessments at ABC sites. The results will be compiled and published on ABC-UTC website and will become available for outside users and researchers. This approach will not only help in avoiding potential accidents but also ensure that the benefits of ABC can be fully realized, contributing significantly to the field of construction safety.

2. DEVELOP A COMPREHENSIVE AGENT-BASED MODELING (ABM) FRAMEWORK

Bringing in construction experts as safety advisors early in a project can make a big difference in keeping the job site safe. It's crucial to think about safety right from the start to cut down on accidents. How people feel about safety impacts how safe a construction site is. When safety is considered in the design and building stages, it not only makes the workplace better but also lessens the need for safety measures [1].

Research often focuses on human factors as a critical component of construction safety. Work experience plays a crucial role in how well workers notice dangers, while safety training and past injuries don't seem to have a big effect on their alertness to hazards. Eye-tracking technology has shown promise in helping measure and improve how workers spot risks [2]. Studies by Teizer et al. (2008) highlight the need for better handling of construction resources like workers, machines, and materials to ensure projects are completed successfully. It talks about how tough it can be for those on the ground to keep track of where things and people are on a construction site and looks at the pros and cons of current tech used to track these resources. Ultrawideband (UWB) technology is introduced as a new method that can pinpoint the exact location of resources in three dimensions, in real-time. The main aim is to use UWB technology to gather data and help make better decisions in automating the construction of infrastructure [3].

In the construction industry, despite measures to prevent electrical hazards, electrocutions still occur. However, behavior-based controls remain common in trying to prevent electrical incidents. Research shows that the success of these safety measures doesn't significantly vary across different construction settings or jobs. Given this, focusing on preventing electrical accidents in construction is crucial for enhancing workplace safety [4]. While the tracking of near misses offers a valuable avenue for making construction sites safer, the effort faces significant barriers such as insufficient reporting and existing organizational culture that need to be addressed [5]. It suggests that future research should dive deeper into the connection between accidents and the use of tools/equipment, recommending their inclusion in official accident reporting categories. Highlighting the importance of tools and equipment in accident prevention is vital, urging construction managers to consider these aspects seriously to enhance safety across the industry [6].

The study by Choudhry and Fang (2008) investigates why construction workers sometimes act unsafely. They found that not knowing enough about safety, trying to seem tough, feeling rushed by tight schedules, being influenced by peers, and dealing with personal, job, or company issues can lead to risky behavior. This research points out that how a company manages safety, along with the personal feelings, experience, job stress, whether workers feel secure in their jobs, their education, and how much safety training they've had, all affect how safely workers act on the job. These findings suggest ways to make construction sites safer by addressing these factors [7].

Park and Srinivasan (2013) studied how pushing workers to meet high productivity goals might make work sites less safe. They came up with a way to see how safety and getting work done quickly can be balanced, especially looking at how fast workers are moving. This work suggests finding a middle ground where jobs can be done efficiently without putting workers at risk [8].

2.1. STUDIES ON NEAR MISS

Near-miss incidents in construction are events or situations that could have led to an accident, injury, or property damage. In the construction industry, actual accidents are just a tiny part of safety issues; many more near-miss happen that we do not see. These near misses are valuable because they help us guess where future accidents might happen and show us how to make sites safer. Learning from these near-misses and keeping an eye on them as they happen could help stop accidents before they occur. However, there's not much research on collecting near-miss data automatically and tracking these incidents with up-to-date technology onsite [9].

Studies on near-miss incidents have been pivotal in understanding the underlying factors contributing to construction site hazards. Researchers have argued that a near miss, while not causing harm, carries the full potential of a risk-laden mishap. Learning from near-misses is common in high-risk industries, and the construction industry is starting to follow suit. However, the way construction deals with near-misses is not fully figured out yet. While there is some research on managing near-miss reports in construction, there is not much on how to dig into what these reports tell us. For instance, technical failures are tower crane operations' most significant risk factors [10]. Thus, diligent reporting and analysis of these incidents can be an effective proactive tool in mitigating risks.

Recent literature emphasizes creating a safety culture that encourages reporting and discussing near misses. Near-miss learning is cheaper and less harmful than learning from actual accidents. By applying safety principles, we can categorize near-miss incidents based on which safety rules were broken and then target our safety measures effectively [11].

Near-miss reporting is a critical yet often debated aspect of construction safety culture. The term itself, labeled as near-misses, close calls, or near-hits, reflects incidents that could have led to harm but did not. Identifying and investigating near-misses lies in their potential to prevent actual accidents. Research suggests that a robust near-miss reporting system can be an insightful tool for identifying and controlling risks before they

result in injury or damage. For example, if an organization is not recording many near-misses compared to actual injuries, it may indicate underlying issues in the company's safety practices and culture. Effective near-miss reporting processes can offer valuable lessons from incidents without loss, helping organizations learn and implement safety improvements [12].

Near-miss events happen every day in construction and can signal where accidents might occur. They are essential for learning about safety, but we do not know much about them or how to use this info to keep people safe. A study examining near-misses on a construction site classified 110 incidents based on what happened. Half of these were about things falling, either from height or on the same level, hinting that improving formwork processes might help since it was a significant source of debris and heavy lifting [13].

Table 1: Categorizing near-miss events in a construction site, showing the types of events, their frequency, and examples

Nature of Near Misses	Number of Events	Examples
Falling materials, tools, and equipment over different levels	31	Scaffolding piece falling from 4th floor to basement
Falling materials, tools, and equipment at the same level	24	Live cables falling on the saw and operator
Impact suffered by worker	10	Temporary panel falling on worker
Worker losing his balance	10	Worker's foot stuck in basement structure frame
Impact of worker against a fixed object	10	Steel bar piercing worker's boot
The imminence of impact involving machines, equipment lifting, moving loads	9	Crane bucket nearly hits worker
Impact of machines, equipment lifting, moving loads	6	The crane's electrical fault caused the piece to fall
Throwing materials and tools	4	Hammer thrown between floors, nearly hitting the worker
The imminence of scaffolding, ladders falling with workers on them	3	Worker nearly falling with an unstable scaffolding tower
Electric shock	2	Worker receiving an electric shock from the power box
Attrition and abrasion	1	Worker's leg marked by boot while pouring concrete

2.2. STUDIES ON AGENT-BASED MODELING (ABM)

Agent-based modeling (ABM) is a powerful tool for simulating complex interactions within construction projects. ABM allows researchers and practitioners to model the behaviors of individual agents, such as workers, equipment, and materials, in a virtual environment, and it provides insights into how changes in individual behaviors can influence overall project outcomes, particularly regarding safety management. Agent-based modeling (ABM) has become increasingly popular in construction research due to its detailed system modeling capabilities and advancements in computing power. An integrated analysis highlights the evolution of ABM research in construction, pointing out gaps and suggesting future research directions [14].

Agent-based modeling and simulation (ABMS) offers a modern method for simulating systems with independent agents interacting with each other. Thanks to computing advancements, ABMS is used across various fields, from finance and logistics to public health and historical analysis. It supports decision-making and theoretical exploration by allowing detailed simulations of agent behaviors within virtual environments [15].

Agent-based modeling and simulation (ABMS) represents an innovative approach for simulating systems with autonomous, interacting agents. Some even consider ABMS a new paradigm in scientific methodology, complementing traditional deductive and inductive approaches[16].

Studies utilizing ABM in construction safety have focused on various aspects, including predicting near-miss incidents, the effectiveness of safety interventions, and the impact of communication patterns among workers on onsite safety. For instance, ABM has been used to simulate the movement of workers and machinery in tight spaces, helping identify potential collision points and suggesting optimal placement and routing to minimize risk.

2.3. STUDIES ON ACCELERATE BRIDGE CONSTRUCTION (ABC)

Accelerated Bridge Construction (ABC) represents a significant advancement in civil engineering, aiming to reduce construction times, minimize onsite risks, and limit disruptions to the public. ABC represents a considerable advancement in bridge engineering, focusing on efficiency without compromising quality[17]. Accelerated Bridge Construction (ABC) refers to the swift replacement or creation of bridges using innovative designs, construction techniques, and high-quality materials. The aim is to build durable, cost-efficient bridges more quickly than traditional methods allow, enhancing safety, reducing traffic disruptions, and shortening the overall construction timeline.

The Federal Highway Administration's "Everyday Counts" initiative champions Accelerated Bridge Construction (ABC) to speed up bridge building, enhance safety, and lessen environmental harm. This initiative supports using innovative technologies and prefabricated bridge elements, particularly in seismic areas, to ensure bridges are built faster without compromising quality or durability. Prefabrication of bridge parts reduces onsite work, enhancing bridges' safety and structural integrity [18].

Accelerated Bridge Construction (ABC) is a crucial strategy for efficiently building and upgrading highway structures. Decision-making tools are recommended during the planning phase to help assess different construction options reliably and avoid costly alternatives, ensuring informed choices for ABC projects [19]. It combines innovative technologies and project management to minimize public inconvenience and lower construction costs. Engineers must evaluate if ABC methods are suitable and cost-effective for a particular site early in project planning.

Table 2: Overview of Research Sections on Construction Safety

Section	Key Focus	Models/Concepts Introduced	Key Findings
Studies on Identification of Construction Safety Factors	Identifying critical factors influencing construction fatalities and hazards.	ARCTM Model, Hazard Assessment and Frequency Survey	Unsafe work conditions, worker reactions to these conditions, and the identification of 12 major hazard types across various construction projects.
Studies on Construction Hazard Perception	Impact of personal and management factors on hazard recognition and decision-making.	Multi-Predictor Stress-Injury Model, Cognitive Analysis, Theory of Planned Behavior (TPB)	Safety knowledge, behavior, management influence, and emotional state of workers are crucial. Organizational management skills strongly influence hazard perception.
Studies on Construction Environment Hazard Mapping	Zoning of hazardous areas and mapping using tools like GIS and BIM.	Dynamic Layout Planning, Near-miss Reports Visualization with BIM	Identifying high-risk zones through site layout optimization and visualizing near-miss incidents to take preemptive safety measures.
Studies on Hazard Identification Using Cell-based Information and Agent-based Modeling	Utilization of cell-based models and ABM for detailed safety and productivity analysis.	Cell-based Discrete Event Systems, Agent-Based Modeling (ABM)	ABM offers a detailed view of individual agent behaviors, contributing to understanding safety, productivity, and behavioral parameters in construction sites.

3. ABC SHORTLISTED SITE

A model is being put together to show exactly how a construction site works when it uses Accelerated Bridges Construction methods, like those used for the I-235 Broadway Extension in Oklahoma City. This project is being looked at closely because it's a recent example of these ABC techniques. Additional information is being sourced from a specialized database provided by ABC-UTC [20] to enrich the model's accuracy and relevance. Initially, over a hundred projects were checked out to find ones similar to the I-235 project, especially those near busy roads. The goal was to pick projects that line up with the I-235 project, focusing on those close to highways, to help make the model better.

3.1. ABC PROJECT AND RESEARCH DATABASES

Location: Interstate 95 over Hermitage Road in the city of Richmond[21]

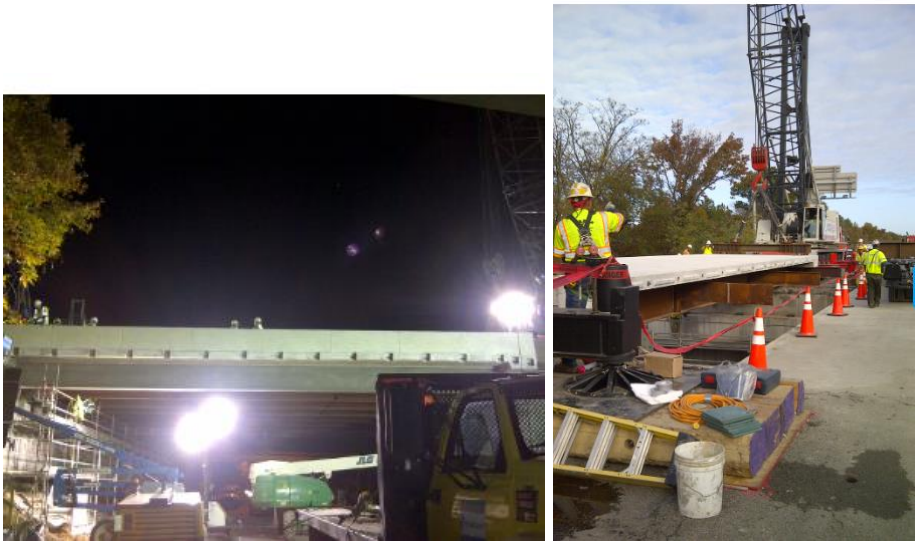


Figure 1: 2012 – I-95 Bridge over Hermitage Road | ABC Project and Research Databases (https://utcdb.fiu.edu/)

Location: Cascade Highway South (OR213) over Washington Street in the city of Oregon City in Clackamas County[22]

Figure 2: 2012 – OR213 Bridge over Washington Street (Jughandle) | ABC Project and Research Databases (https://utcdb.fiu.edu/)

Location: Maryland Avenue over Interstate 35E in the city of Saint Paul in Ramsey County[23]

Figure 3: 2012 – Maryland Avenue Bridge | ABC Project and Research Databases (https://utcdb.fiu.edu/)

Location: Interstate 84 EB and WB over Dingle Ridge Road in Putnam County, 50 miles north of NYC (2.2 MI E JCT RTS I-84+I-684) [24]

Figure 4: 2013 – I-84 Bridges over Dingle Ridge Road | ABC Project and Research Databases (https://utcdb.fiu.edu/)

Location: Larpenteur Avenue over Interstate 35E in the city of Saint Paul in Ramsey County[25]

Figure 5: 2014 – Larpenteur Avenue Bridge | ABC Project and Research Databases (https://utcdb.fiu.edu/)

Location: PA Turnpike (I-476) Northeast Extension over Crackersport Road (MP A-57.66), South Whitehall Township, Lehigh County[26]

Figure 6: 2017 – Bridge NB-355 at Milepost A-57.66 | ABC Project and Research Databases (https://utcdb.fiu.edu/)

Location: NM-93 over I-40, at the intersection of I-40 and State Road 392[27]

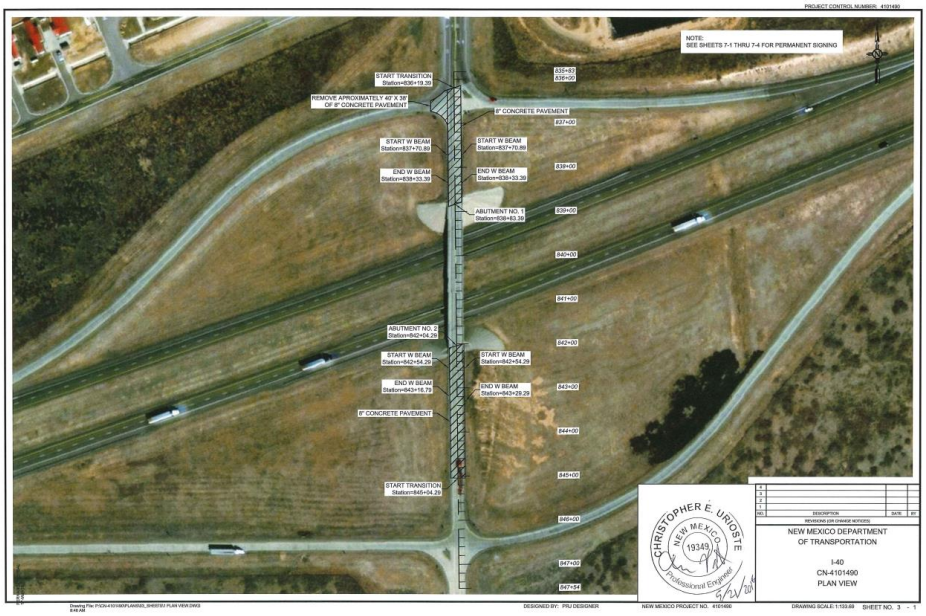


Figure 7: 2019 – Bridge 7345 | ABC Project and Research Databases (https://utcdb.fiu.edu/)

This effort aims to gain a deeper understanding of the complexities involved in Accelerated Bridge Construction (ABC) projects. The objective is to create a model that reflects real-world conditions as closely as possible, thereby facilitating learning about worker safety and ensuring the efficient progress of construction activities.

To aid in this understanding, a summary of key aspects of shortlisted ABC sites has been compiled.

Table 3: Key points about the shortlisted ABC sites

Site	Details	Reason for Selection	Key Findings
I-95 over Hermitage Road[21]	Urban area in Richmond, VA. Utilized overnight work and high-capacity cranes.	High traffic volume, need for reduced impact, and rapid construction.	ABC reduced traffic disruptions and accelerated construction timelines.
OR213 over Washington St[22]	Urban area in Oregon City, OR. Lateral slide construction method used.	Reduced traffic impacts, and improved work-zone safety.	ABC provided significant reductions in traffic disruptions compared to conventional methods.
Maryland Avenue Bridge[23]	Urban area in Saint Paul, MN. Used SPMTs for bridge move.	Reduced onsite construction time, and improved safety.	Effective use of the Design/Build method for

			coordination and communication.
I-84 over Dingle Ridge Rd[24]	Near NYC, NY. The lateral slide method was applied.	Reduced traffic impacts, improved safety, and minimized environmental impacts.	Significant cost savings and safety improvements in work zones.
Larpenteur Ave Bridge[25]	Urban area in Saint Paul, MN. Lateral slide for 2-span bridge.	Minimized traffic disruption and enhanced work-zone safety.	Effective lateral slide technique reducing bridge closure duration.
Bridge NB-355[26]	Urban location in Lehigh County, PA. Lateral slide with specialized equipment.	Reduced traffic impact and rapid construction process.	Reduced traffic impact and utilized innovative equipment for rapid bridge replacement.
Bridge 7345[27]	Rural area in NM over I-40. Conventional equipment for superstructure replacement.	To minimize business impact and improve safety during construction.	Fast-paced construction schedule with effective use of prefabricated elements.

Accelerated Bridge Construction (ABC) refers to the use of innovative planning, design, materials, and construction methods safely and cost-effectively to reduce the onsite construction time and minimize mobility impacts. When exploring near-miss incidents in ABC construction sites, especially those near highways, it's essential to focus on parameters that can accurately represent the complexities and dynamics of such environments in the simulation model.

Traffic and Safety: All these projects are near busy roads, so managing traffic is a big deal. This tells us we need to pay close attention to how cars and people move around the site to avoid close calls. For example, using barriers or signs to keep cars away from work areas. By looking at how different projects manage traffic, like the project on I-95 over Hermitage Road, it's possible to learn what works best for keeping cars and workers safe from each other.

Use of Equipment: Different sites use different gears, like big cranes, or methods like sliding bridges into place. This variation shows the importance of using the right tool for the job to keep things safe and efficient. By looking at what tools were used in projects like the Maryland Avenue Bridge, it's possible to see how using certain equipment can make the job safer and faster, and maybe even cut down on close calls.

Construction Methods/Phases: The methods used to build these bridges, like sliding them into place, can teach us a lot about safety. Some ways might be safer or quicker but require more planning or specific conditions to work right. By examining projects, such as the one at Larpenteur Ave Bridge, it's easier to see which parts of the building process might need extra attention to avoid accidents.

Environmental/Weather/Location Factors: Some bridges are in the city, and some are out in the countryside. This difference means we need to think about what's around the site, like businesses or homes, and how the work might affect them or put people at risk of near misses. For example, looking at a rural project like Bridge 7345, it's clear that each location has its own set of challenges that could lead to safety issues if not handled right.

By taking these lessons into the model, especially for the I-235 project to predict where and why near-misses might happen and figure out ways to stop them before they do. It's about learning from past projects to make new ones safer and smoother for everyone involved.

4. FRAMEWORK & CONCEPTUAL FIGURE

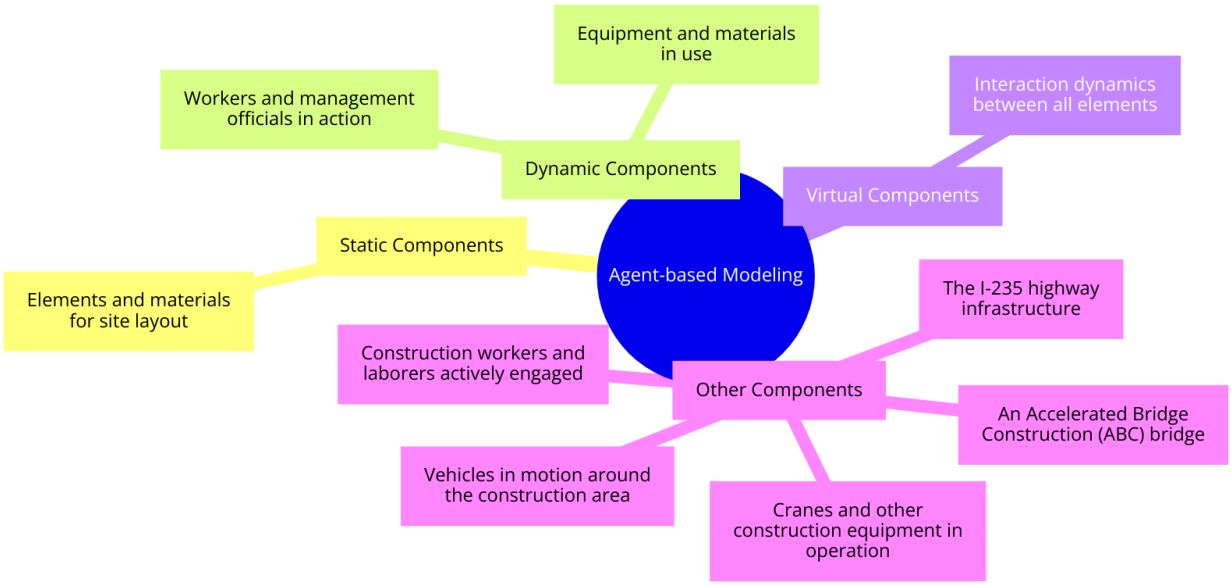
Figure 8 illustrates the various components and entities involved in an agent-based simulation within the GAMA platform, which is designed to model and analyze complex systems. Central to the simulation are the main entities such as the construction site, workers, vehicles, and equipment. These entities interact within the simulation environment, which is categorized into static and dynamic components.

Static components include the site layout and the resources that do not change over time, such as roads, materials, and infrastructure. These elements form the physical and material backdrop against which the simulation unfolds.

Dynamic components encompass the management of the construction process, including planning and supervision, as well as the equipment in use, like cranes and trucks. These aspects of the simulation are subject to change and can influence the outcome of the simulated scenarios.

Virtual components in the simulation represent the interactions between different agents, such as worker to worker, worker to environment, and their impact on the construction phases and traffic flow on the I-235 Highway and ABC Bridge, signifying the flow of vehicles and patterns of movement.

Finally, the simulation includes an emphasis on safety, capturing the procedures and equipment related to maintaining a safe construction environment. This comprehensive framework aims to facilitate a detailed analysis of construction site operations, resource management, and safety protocols.



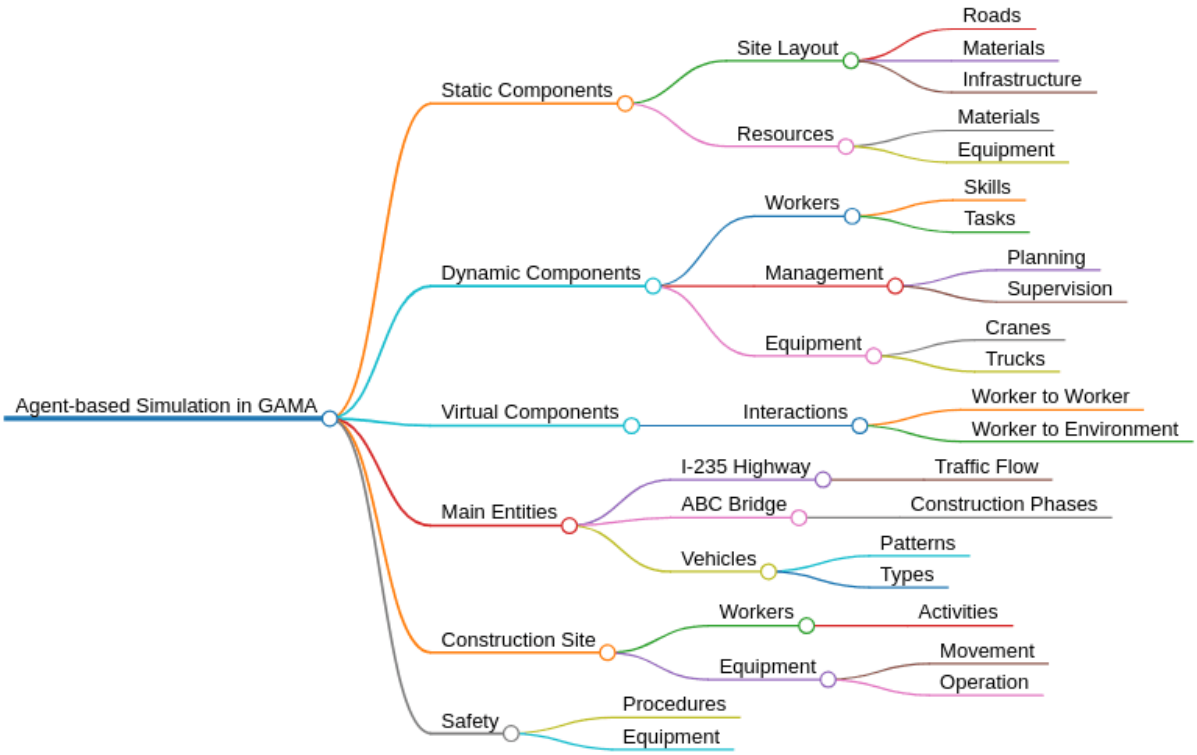


Figure 8: Conceptual Framework of the Proposed Agent-Based Decision Support Tool

Figure 9 refers to the multifaceted nature of a construction site impacted by ABC methods. It highlights the need for meticulous planning and safety measures to mitigate the risk of accidents in an area where the interaction of construction activities and highway traffic creates a matrix of potential near-miss scenarios. The conceptual design visualizes the challenges of managing a construction site under these conditions and underscores the critical nature of safety protocols in such a dynamic setting.

Figure 9 shows a busy construction area with cars next to a road. There are two bridges: one old one that needs to be taken down and a new one that will be put in place using a big crane.

On the ground, workers are actively engaged on both sides of the bridges, with some directing the crane and others handling various construction materials and tasks. The mobility of the workers is primarily along the Y-axis, perpendicular to the traffic flow.

Vehicles, represented by cars and buses, traverse horizontally along the X-axis, indicating the flow of highway traffic adjacent to the construction site. The proximity of moving vehicles to the operational area of the workers suggests a high-risk environment where near-miss incidents could occur, not only with the passing traffic but also with the equipment in motion on the site.

The complexity of this environment is heightened by the presence of construction materials and equipment such as barrels, concrete blocks, and machinery, which add to the potential navigational hazards for workers and vehicles.

Workers are busy on both sides of the bridges. They move up and down (Y direction) while vehicles pass them, left to right (X direction). Because everything is so close, there is a chance that workers might almost get hit by cars or construction stuff moving around.

In short, the image gives us a clear view of how construction sites work when they're right next to where cars are driving. It shows why keeping workers safe from traffic and moving equipment is essential.

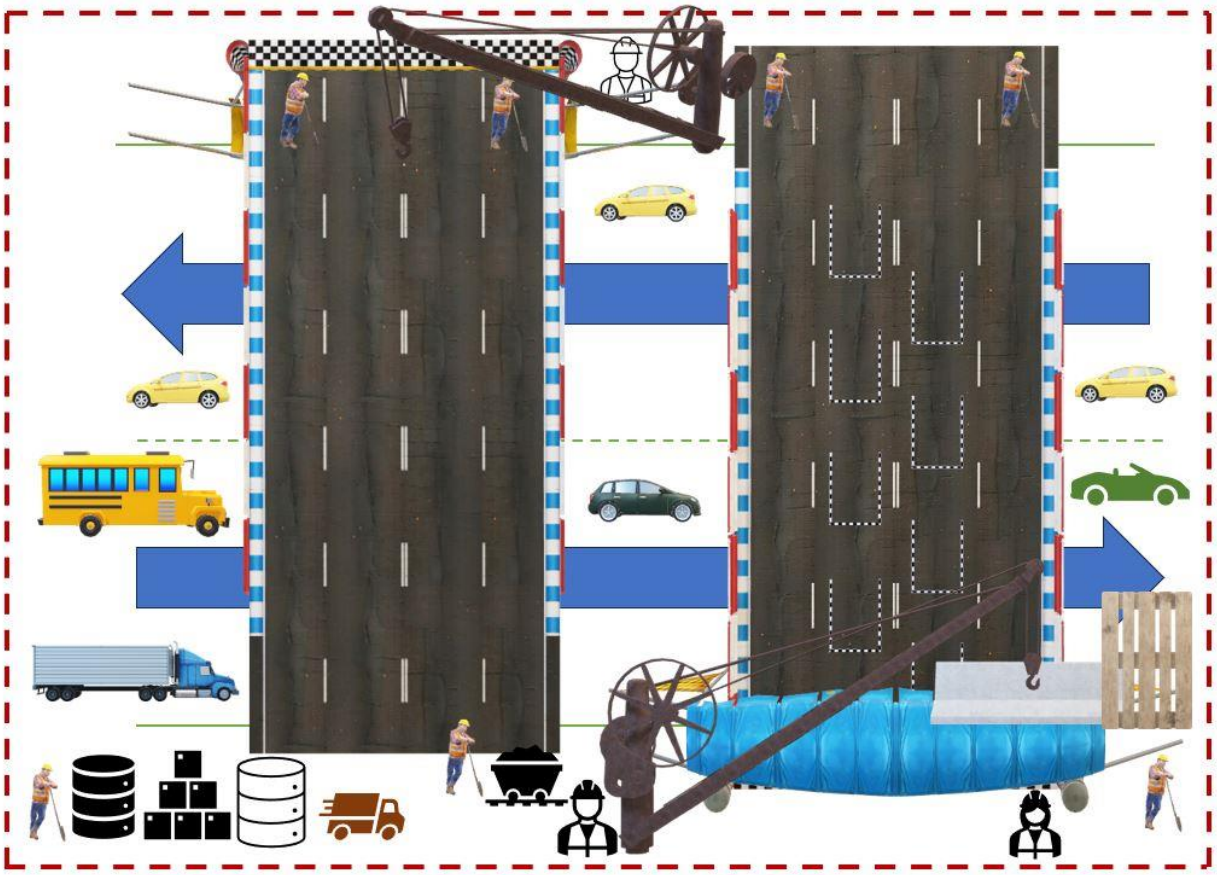


Figure 9: Conceptual Scenario Figure of the Proposed Case Study

4.1. INTRODUCING GAMA

GAMA is a user-friendly, open-source platform designed for building agent-based simulations, suitable for various fields such as urban planning, epidemiology, and climate change. With over two thousand users, GAMA's flexibility is evident in its plugin development and compatibility with other software like R and Python[28].

A key feature of GAMA is its ability to oversee diverse data forms, making it ideal for data-driven modeling. It supports GIS data, allowing users to create realistic agent environments, and can import various data types, including CSV and 3D files.

GAML, GAMA's dedicated modeling language, is designed for novices and advanced users. It facilitates quick simulation creation while offering sophisticated functionalities for complex modeling. GAML's ease of use is complemented by extensive educational resources and community support[29].

The GAMA interface stands out for its user-friendliness, offering multiple displays and visualization options, including 3D, for in-depth simulation analysis. Interactive features during simulations allow for agent inspection and user control, with additional modules for enhanced interactivity.

GAMA's versatility, ease of use, and robust data integration make it a unique tool for agent-based modeling. It offers a comprehensive suite for researchers and practitioners to simulate and analyze complex systems.

The developer interface of the GAMA software is depicted in Figure 10. Upon launching GAMA, several panels are displayed. The main panel, located on the right, serves as the editing panel where models are written using the dedicated language GAML. The left panel, known as the navigation panel, contains all projects and examples provided with the software. This arrangement of panels is referred to as a perspective. The perspective used for editing models is called the modeling perspective, while the perspective used for running simulations is known as the simulation perspective.

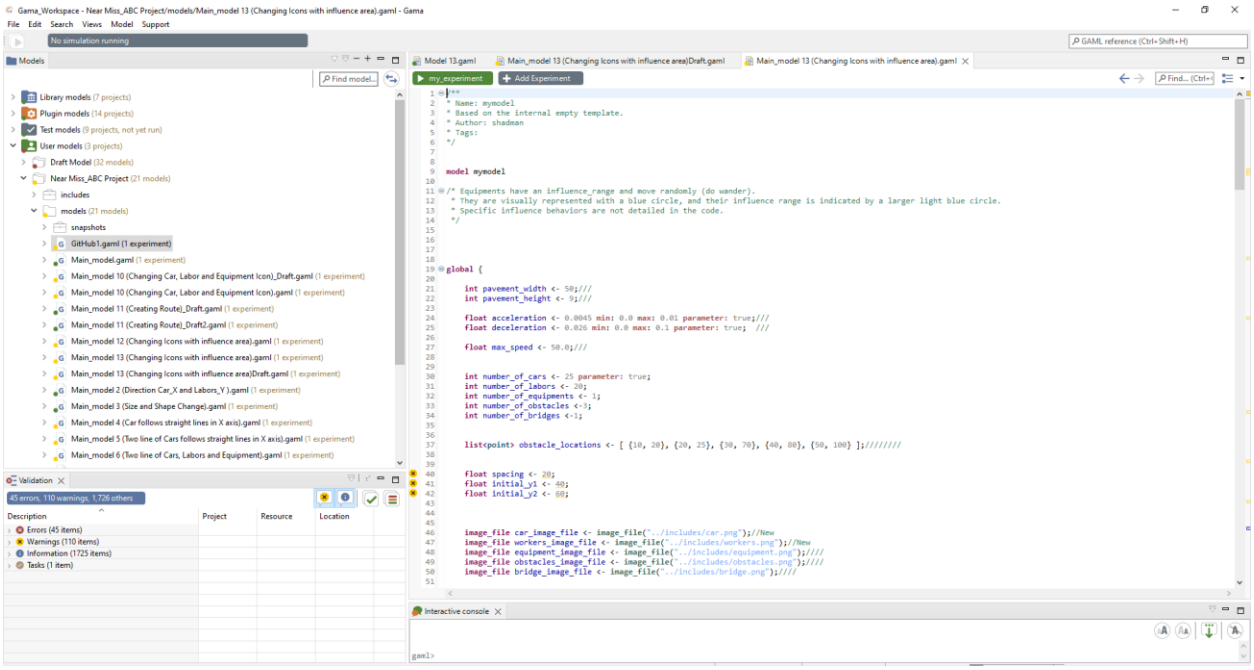


Figure 10: Developer Interface of the GAMA Software

4.2. STUDY AREA

A basic model has been established that features a construction site located next to a highway. In this setup, vehicles move in one direction while construction workers move in the opposite. A critical aspect being monitored is when vehicles and workers come into close proximity, which could potentially result in accidents or near misses.

To better understand the interaction dynamics, a chart tracking the frequency of these close encounters over time has been developed. It aims to shed light on how movements and interactions are simulated, specifically focusing on the number of vehicles involved in such incidents. Although the reach of construction equipment within the simulation has been defined, its interaction with vehicles and workers is not yet incorporated. This integration is slated for future updates.

The intention moving forward is to refine the simulation to more closely mirror an actual construction site that employs rapid construction techniques. The I-235 Broadway Extension Corridor Widening project in Oklahoma City, known for its use of Accelerated Bridge Construction (ABC) methods, serves as the primary case study[30]. There are plans to engage with the Haskell Company for an in-depth understanding of this project, and questions have been prepared for this purpose.

Figure 11 illustrates the study area, providing a visual representation of the real construction site, including the highway and the accelerated bridge construction zone. This figure serves as a foundational reference for understanding the layout used in the simulation model.

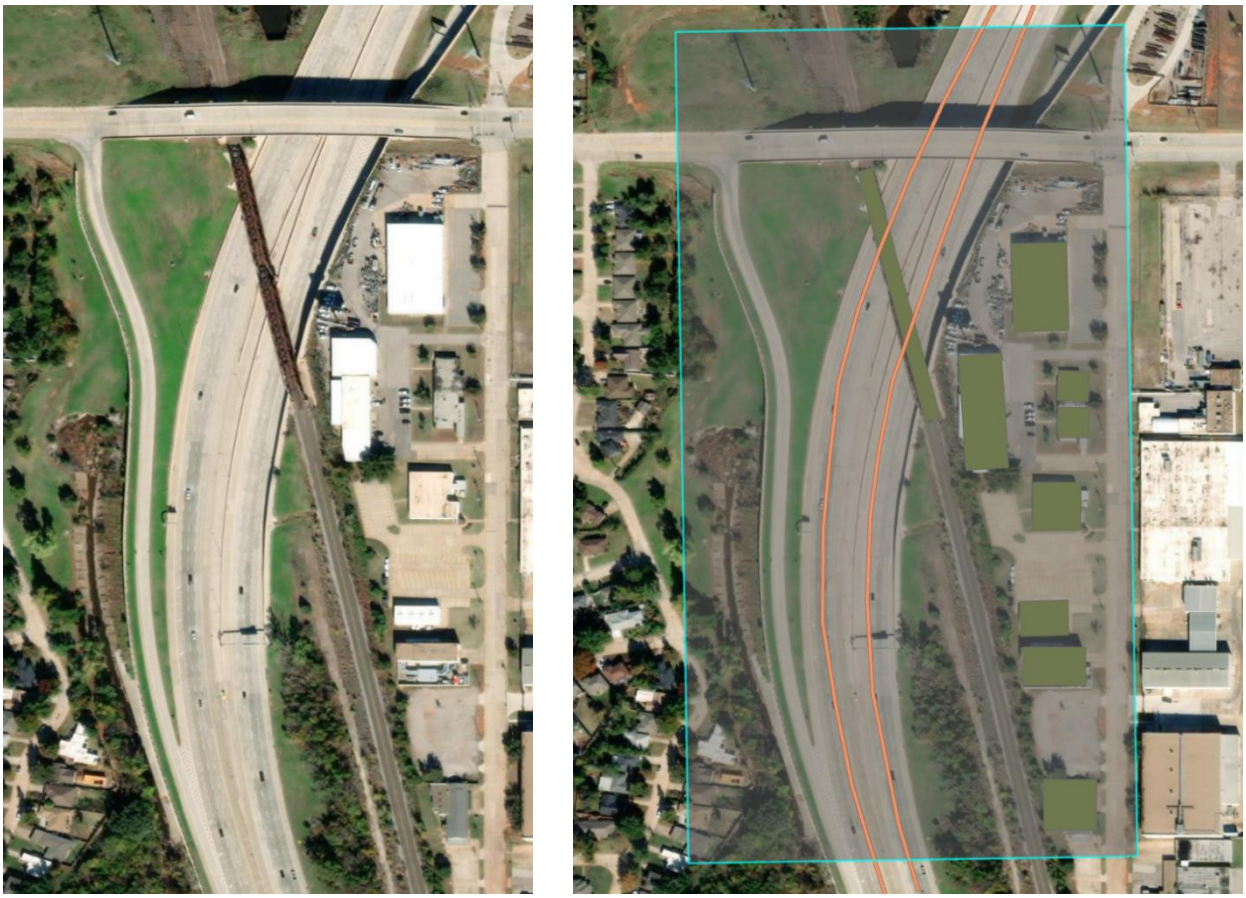


Figure 11: Study Area

A model is being developed to illustrate the workings of a construction site utilizing Accelerated Bridge Construction (ABC) methods, similar to those employed in the I-235 Broadway Extension in Oklahoma City. This project is under close examination as it serves as a recent example of ABC techniques.

An initial review of over a hundred projects identified those similar to the I-235 project, particularly those near busy roads. The objective was to select projects aligned with the I-235 project, with a focus on those close to highways, to enhance the model's accuracy and relevance.

The next phase of research involves conducting sophisticated simulations on construction sites employing Accelerated Bridge Construction (ABC) techniques. Utilizing the widely accessible GAMA simulation software, detailed data collected in the initial phase will be inputted to model specific scenarios established in the subsequent planning stage. The focus will be on various types of near-miss incidents to assess the safety, resilience, and accessibility of these construction environments. An illustration in the report, labeled Figure 12, depicts the user interface of the simulation.

The model illustrates a dynamic construction site scenario where vehicles, workers, and equipment are in constant motion:

- Initially, vehicles are shown moving in a single direction while workers move perpendicular to them, demonstrating potential points of close encounters between vehicles and personnel.
- Alterations are then made to the simulation by varying the sizes and shapes of both vehicles and workers, adding complexity to the scenario and observing the resulting interactions.
- Subsequently, vehicles are arranged in an orderly fashion to simulate a more organized and controlled traffic flow within the site.
- Finally, traffic flow is adjusted to mimic real-life road conditions with vehicles moving in both directions, akin to opposing traffic lanes. The simulation adjusts traffic flow to mirror real-life conditions by implementing two-way traffic. This involves movement patterns that replicate actual traffic behavior observed in similar settings.

Specifically, the model simulates vehicles moving in both directions along the X-axis, mimicking the dynamics of incoming and outgoing traffic lanes. Vehicles move from left to right and from right to left, accurately representing typical bi-directional traffic flow in real-world scenarios. By incorporating these elements, the simulation offers a detailed and realistic depiction of traffic flow at a construction site adjacent to a busy highway. This approach aids in identifying potential risks and developing strategies to improve safety and efficiency in Accelerated Bridge Construction (ABC) projects.

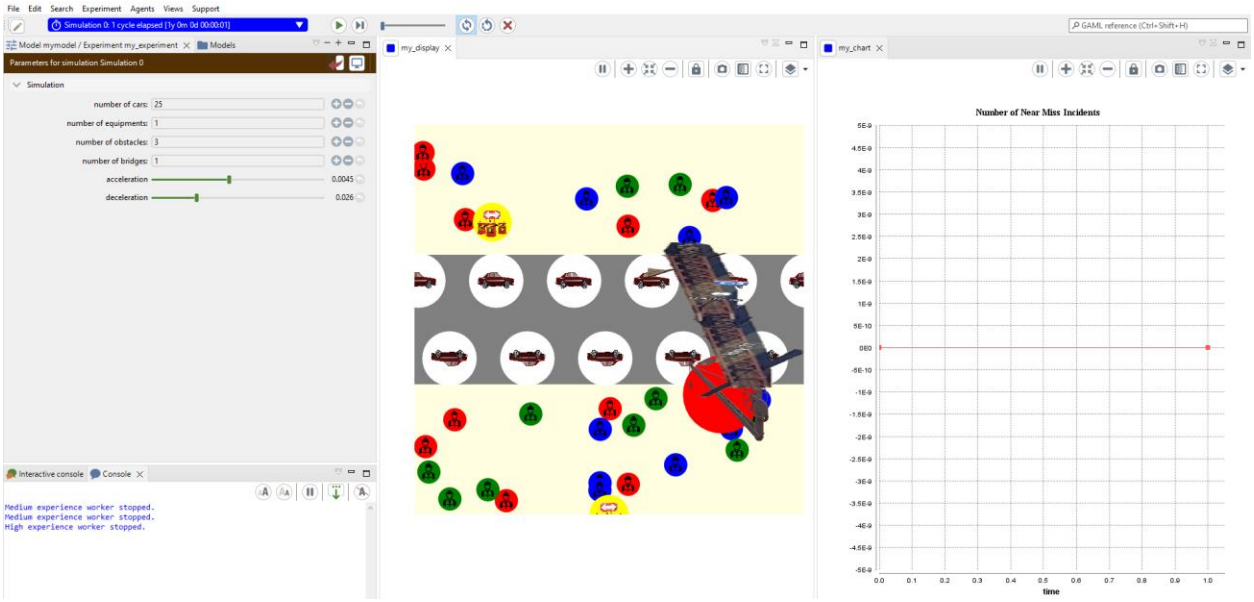


Figure 12: User Interface of the Simulation

A graphical representation has been created to document each instance where a vehicle comes dangerously close to a worker, providing a visual understanding of movement patterns and interaction frequencies on site.

The simulation monitors the frequency of vehicles entering high-risk proximity to workers. While the reach of construction machinery is accounted for, direct interactions between machinery, vehicles, and workers have yet to be simulated and are slated for future exploration.

This simulation presents a vivid portrayal of a bustling construction site adjacent to heavy traffic, underlining the potential for hazardous situations due to the proximity of construction activities to ongoing vehicular movement. Essentially, the simulation offers a comprehensive view of the operational dynamics of construction sites near busy roadways, emphasizing the critical need for stringent safety measures to protect all involved.

5. AGENT-BASED EXPERIMENTS AND ANALYSES

The next phase of research applies insights from initial investigations to create real-life simulations of construction sites using Accelerated Bridge Construction (ABC) methods. These simulations are conducted using the GAMA platform, which serves as a robust tool for visualizing and analyzing complex interactions within dynamic environments.

In these simulations, labeled Figure 13, workers move within the simulated construction site in patterns that reflect their daily tasks, alongside vehicles that traverse the site from left to right and vice versa. Each vehicle has a defined area of influence, indicating the potential risk zone for a near-miss incident.

The simulation captures interactions between moving vehicles and workers of varying experience levels. The focus is on identifying near-miss incidents where vehicles enter into high-risk proximity with workers or construction equipment. Adjusting parameters such as the movement speed and paths of both vehicles and workers helps observe how different levels of worker experience affect the frequency and nature of these incidents.

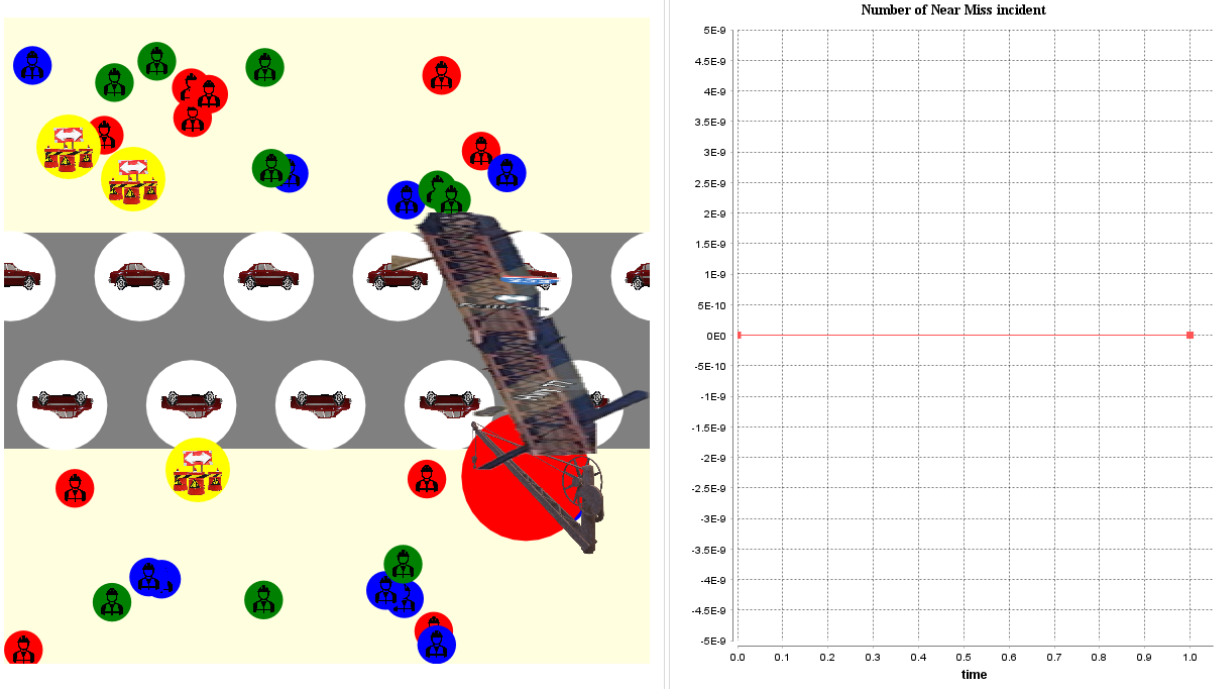


Figure 13: Initial Setup for Scenario Simulation of the Model

The current phase of the simulation, labeled in Figure 14, integrates a behavioral dimension into the model, focusing on how worker experience influences decision-making and actions near potential hazards. This phase introduces three tiers of workers, differentiated by their safety training and experience, each displaying distinct behavioral patterns in response to the moving vehicles and equipment on the construction site:

- Highly experienced workers, depicted in green, demonstrate cautious behavior by stopping before entering the influence area of vehicles or equipment, adhering strictly to safety protocols.
- Medium-experienced workers, shown in blue, exhibit variable behavior. Sometimes they may choose to cross the influence area, displaying a mixed understanding of safety practices.
- Least experienced workers, represented in red, often display risky behavior by crossing into the influence area even when it is unsafe, leading to a higher incidence of near-miss events.

The simulation aims to craft a decision-support tool to aid in understanding and improving construction site safety by analyzing the behavior of workers in real-time and under varying conditions to identify key factors contributing to near-miss incidents.

An integral feature of the simulation is a chart that quantifies the number of near-miss incidents, providing a statistical overview of safety on the site. This real-time data is crucial for further analysis and decision-making, allowing for correlations between the experience level of workers and the incidence rate of near misses to inform potential safety interventions and training requirements.

The model highlights the nuances of worker behavior in proximity to moving vehicles and the importance of experience in mitigating risks. It offers a detailed visual and analytical representation of an active construction site located next to heavy traffic, underscoring the critical need for stringent safety measures and targeted training to protect workers. Future iterations of the simulation are planned to include direct interactions between machinery, vehicles, and workers to enhance the analysis of construction site dynamics and safety.

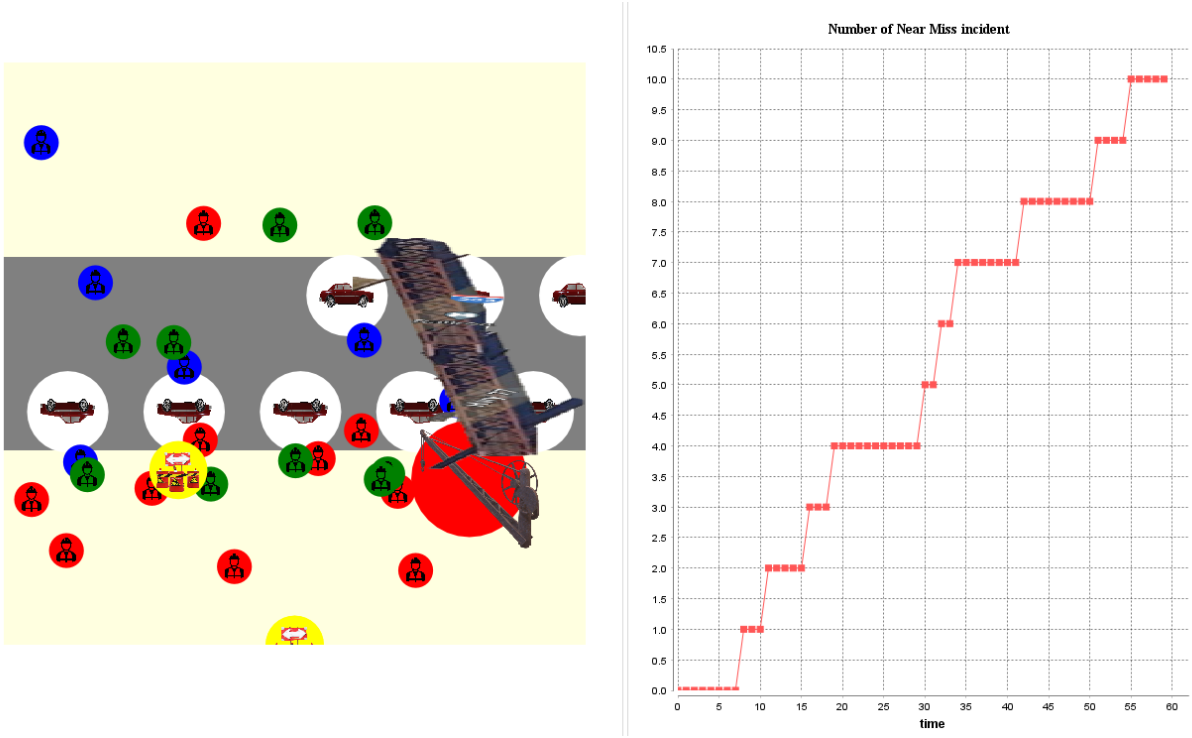


Figure 14: Scenario Simulation: Model After Execution

Future enhancements to the simulation will incorporate data on workers' risk perception, collected through surveys reflecting variables such as age, gender, and education. Integrating these factors aims to provide a more nuanced understanding of how personal characteristics influence workers' behaviors in potentially hazardous situations.

Linking individual risk perceptions with observed behaviors in the simulation helps predict patterns and design targeted interventions. This could range from personalized safety training to an optimized site layout that considers the varying risk thresholds of different worker groups, ultimately aiming to reduce the occurrence of near-miss incidents by tailoring safety measures to the needs and behaviors of all workers on a construction site.

This simulation scenario illustrates how the simulation operates and how to interpret the chart provided. Figure 15 in the report illustrates an initial scenario simulation analysis.

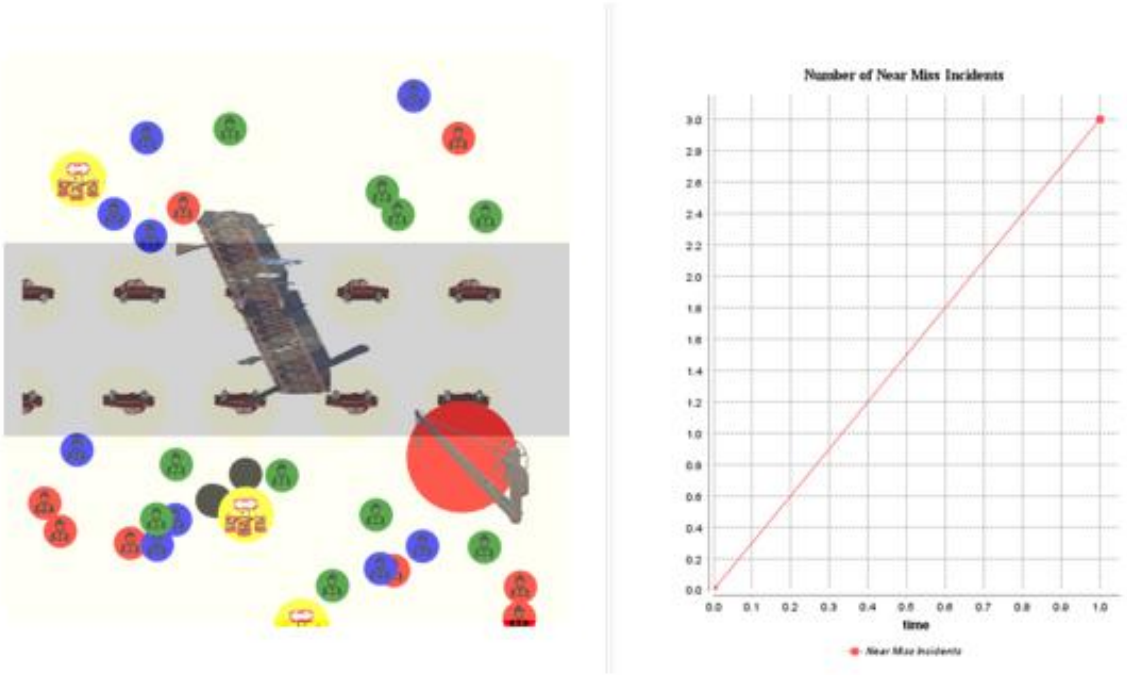


Figure 15: Initial Scenario Simulation Analysis

The scenario initially defines three types of workers:

- The highly experienced workers, depicted in green, demonstrate cautious behavior by stopping before entering the influence area of vehicles or equipment, strictly adhering to safety protocols.
- The medium-experienced workers, shown in blue, exhibit variable behavior. Sometimes they choose to cross the influence area, displaying a mixed understanding of safety practices.
- The least experienced workers, represented in red, often display risky behavior by crossing into the influence area even when it is unsafe, leading to a higher incidence of near-miss events.

The chart on the right side of the simulation displays how many near-miss incidents are occurring over time, tracking the number of such incidents.

During the simulation, workers' colors change, turning black after they create any potential near-miss situations, as seen in the figure. The chart also changes based on the scenarios.
In this simulation scenario, the red workers are most affected due to their lower experience level. They move frequently, creating more near-miss incidents compared to the blue and green workers. The green workers, being the most experienced, demonstrate behavior where they avoid moving until they have cleared a potential near-miss zone. The medium and less experienced workers create more near-miss incidents based on their behavior, while the green workers stop before entering the influence area.

After the vehicles move away and the road is clear, the green workers then begin moving. Figure 16 presents the parameters of the scenario simulation.

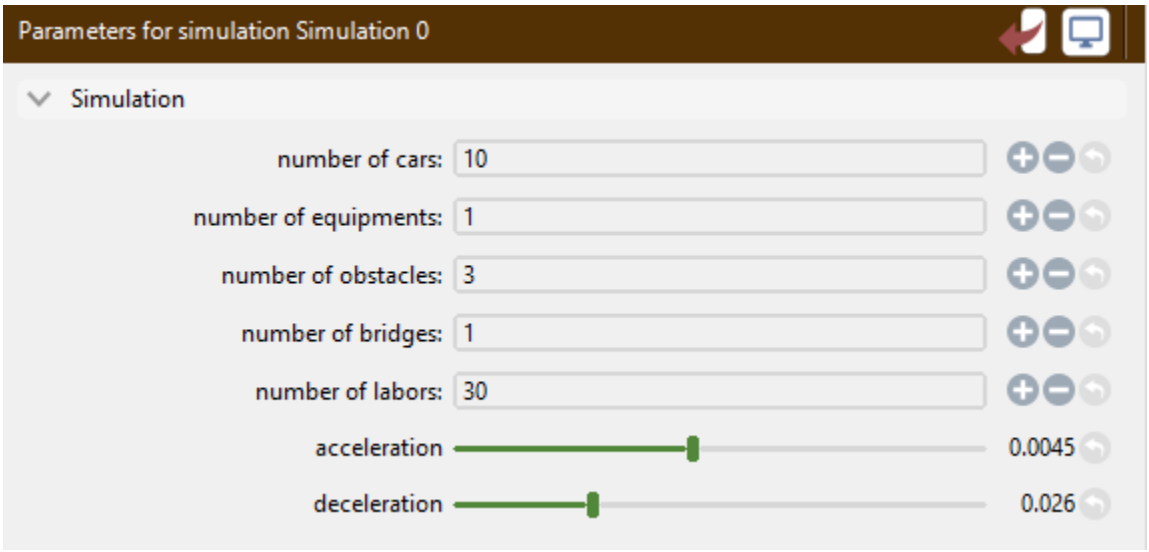


Figure 16: Parameter of the Scenario Simulation

In this simulation, parameters include 10 cars and 30 workers, with 10 workers each of green, blue, and red representing varying levels of experience. The site also features on-site obstacles, one crane as equipment, and one bridge component as part of the ABC site.

To visualize near-miss incidents, workers' colors change to black temporarily, marking areas where these incidents occur. The simulation also updates a chart in real-time, reflecting the count of near-miss incidents. After a brief period, the workers return to their original colors.

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5.1. ALGORITHM MODEL FOR WORKER'S EXPERIENCE

Algorithmic Model for Worker's Experience

The model in the code uses this data to set the behavior of workers in the simulation. Here is an explanation of the algorithmic model for worker's experience based on the scenario:

Initialization:

- Workers are created with experience levels and steps taken based on the labors.csv file.
- Workers' experience affects their behavior when encountering potential near-miss incidents.

Behavioral Logic:

- High Experience (0.9): Workers stop if they detect an obstacle or vehicle within their stop range. They wait for a defined period before resuming movement.

- Medium Experience (0.5): Workers have a chance to stop (30% probability) when an obstacle or vehicle is detected within the stop range. They wait for a shorter period compared to highly experienced workers.

- Low Experience (0.1): Workers do not have explicit stopping behavior and are more likely to create near-miss incidents.

Near-Miss Detection:

- Workers check their proximity to cars, equipment, and obstacles to determine if they are in a near-miss zone.

- When a worker is in a near-miss zone, their color changes to black temporarily to visualize the incident.

5.2. NEAR MISS INCIDENT ANALYSIS

The data in the labors.csv file is structured as follows:

Table 4: Random Data for the Simulation

Experience Level	Steps Taken	Count
0.1	**1**	**10**
0.5	**2**	**10**
0.9	**3**	**10**

Figure 17 shows the initial analysis of the scenario simulation using random data from the labors.csv file, displaying the number of near-miss incidents on the graph. The image displays two parts: a visual simulation on the left and a chart on the right.

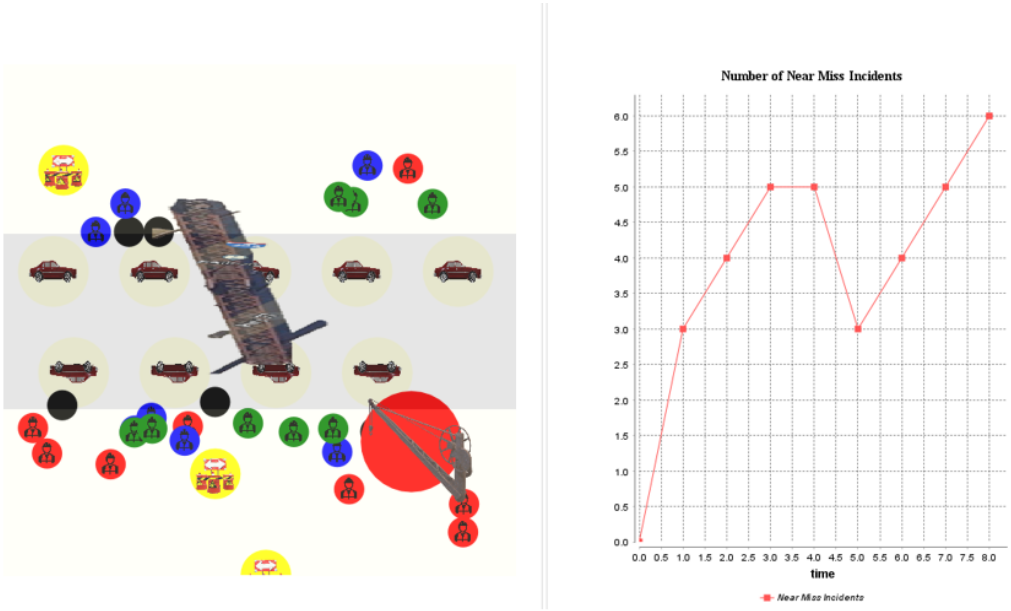

Figure 17: Initial Near-Miss Incident Analysis

Figure 18 continues the analysis from Figure 17, highlighting an increase in near-miss incidents. The chart indicates 12 reported near-miss incidents at that time, with affected laborers temporarily changing color to black for visual indication.

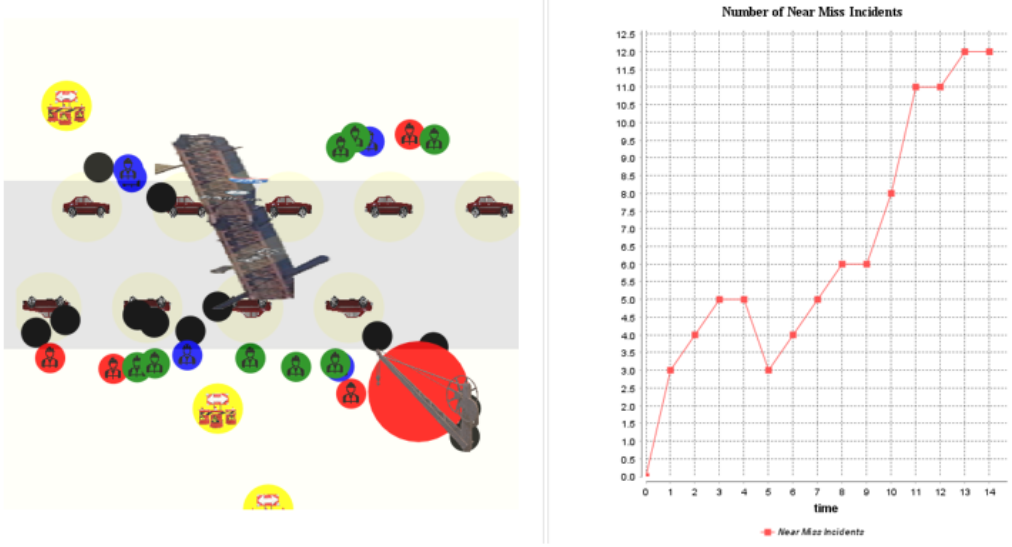

Figure 18: Continued Near-Miss Incident Analysis

This simulation incorporates an Excel file to test the functionality of the model with random data inputs. The file includes information such as the workers' experience and speed, along with algorithms that dictate behavior based on experience levels. For instance, the most experienced workers, depicted in green, will halt their movement when approaching a potential near-miss incident area, adhering to strict safety protocols. In contrast, the blue workers, who have less experience, and the red workers, who are the least experienced and most vulnerable, behave less cautiously.

The success of integrating the Excel file demonstrates the model's capability to simulate complex worker behaviors under varied conditions. The next step involves utilizing real survey data to analyze the risk perceptions of workers and their corresponding behaviors in Accelerated Bridge Construction (ABC) site scenarios. This approach will enhance the accuracy of the simulation, offering deeper insights into safety dynamics on construction sites.

6. APPLICATION OF THE PROPOSED METHODOLOGY

6.1. EXPLANATION OF DATA USAGE IN THE SIMULATION (HOW THE DATA IS READ)

Data Explanation

- Experience Level 0.1 (Low): 10 workers taking 1 step each.
- Experience Level 0.5 (Medium): 10 workers taking 2 steps each.
- Experience Level 0.9 (High): 10 workers taking 3 steps each.

CSV File Loading:
The simulation model reads the labors.csv file using the **csv_file** command and loads it into a matrix (**labor_matrix**).

Extracting Columns:
The columns from the matrix are extracted into two lists:

- **exp_labor**: List containing the experience levels (0.1, 0.5, 0.9).
- **step_labor**: List containing the steps taken by each worker (1, 2, 3).

Assigning Data to Workers:
When workers are created in the simulation, each worker is assigned an experience level and the number of steps they will take from these lists based on their index.

Running Different Scenarios
The data in the labors.csv file allows the simulation to run different scenarios by varying the experience levels and behavior of the workers.

Experience Levels:

- Low Experience (0.1):

Workers with low experience are less cautious. They do not stop for obstacles or vehicles and are more likely to create near-miss incidents.

- Medium Experience (0.5):

Workers with medium experience have a probability (30%) of stopping when encountering obstacles or vehicles. They exhibit mixed behavior.

- High Experience (0.9):

Workers with high experience are very cautious. They stop when they detect obstacles or vehicles within their stop range and resume only when it is safe.

Steps Taken:
The number of steps taken by each worker determines their speed and movement pattern in the simulation. This can influence how quickly they encounter obstacles or vehicles.

Behavioral Responses:
Workers' responses to near-miss zones are programmed based on their experience levels. This helps in visualizing and analyzing different safety scenarios on the construction site.

Overall, the simulation shows a construction site scenario involving workers, vehicles, and equipment. Different colored circles represent workers with varying experience levels:

- **Green Circles:** Highly experienced workers who exhibit cautious behavior.
- **Blue Circles:** Medium-experienced workers with variable behavior.
- **Red Circles:** Least experienced workers who often display risky behavior.

The construction equipment and vehicles are also depicted, interacting with the workers in the simulation. The bridge component and construction machinery (such as a crane) are included to simulate an Accelerated Bridge Construction (ABC) site.

The chart on the right in Figure 19 tracks the number of near-miss incidents over time. It shows a time series graph indicating the frequency of near-miss incidents at different points in the simulation:

- **X-Axis (Time):** Represents the simulation time.
- **Y-Axis (Number of Near-Miss Incidents):** Indicates the number of near-miss incidents occurring at each time point.

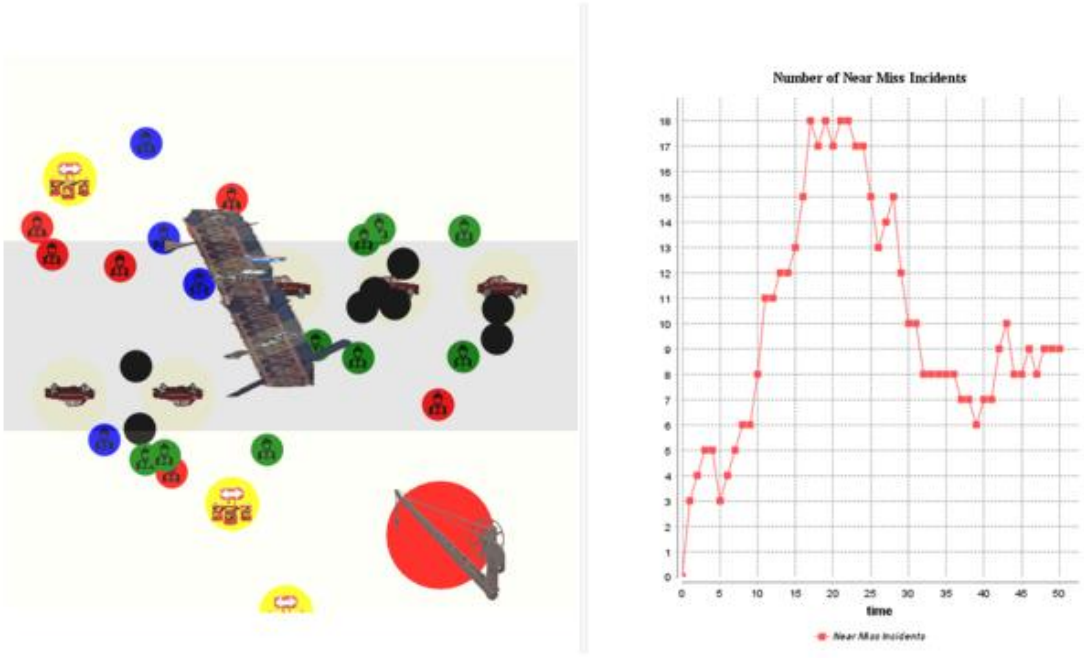

Figure 19: Tracking Near-Miss Incidents

Workers' colors temporarily change to black when they are involved in near-miss incidents, highlighting the areas and times of potential danger.

Initially in Figure 20, the number of near-miss incidents rises, peaking around the middle of the simulation. This indicates periods when workers are at higher risk, due to increased interactions between workers, vehicles, and equipment. After peaking, the number of incidents starts to decline but shows fluctuations, suggesting that while some safety improvements might be occurring, there are still significant risks present.

Overall, this visualization helps in understanding the dynamics of worker interactions with vehicles and equipment on a construction site, emphasizing the importance of managing worker experience, traffic flow, and equipment placement to minimize near-miss incidents.

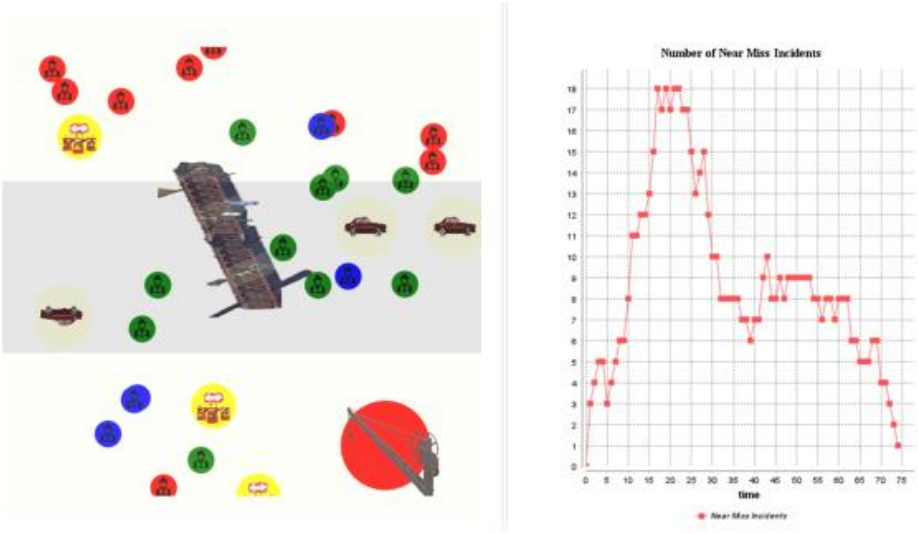

Figure 20: Real-Time Chart Tracking Near-Miss Incidents in Simulation

6.2. DISCUSSION OF THE FINDINGS

The primary objective of this project is to use agent-based modeling (ABM) to analyze and predict near-miss incidents in Accelerated Bridge Construction (ABC) projects. This study focuses on enhancing safety and accessibility on construction sites by examining the interaction dynamics of workers, vehicles, and equipment.

6.3. ANALYSIS OF SIMULATION RESULTS

The simulation results provide valuable insights into the behavior of workers with unique experience levels and the frequency of near-miss incidents in various construction scenarios. The key findings from the simulation tasks are as follows:

- **Worker Behavior and Near-Miss Incidents**: The simulations revealed distinct behavioral patterns among workers based on their experience levels. Highly experienced workers (green) exhibited cautious behavior, stopping before entering the influence area of vehicles or equipment. Medium-experienced workers (blue) showed variable behavior, occasionally entering the influence area. Least experienced workers (red) frequently crossed into unsafe areas, leading to a higher incidence of near-miss events.
- **Impact of Traffic and Equipment**: The movement of vehicles and the presence of construction equipment significantly influenced the occurrence of near-miss incidents. Managing traffic flow and strategically placing equipment are crucial for minimizing these incidents. The findings indicate that near-miss incidents were more frequent in scenarios with higher traffic volumes and more complex equipment layouts.

- **Safety Interventions and Protocols**: The simulation results emphasize the importance of safety protocols and training programs. Implementing targeted safety interventions based on the behavior of workers with unique experience levels can significantly reduce the number of near-miss incidents. The use of visual indicators, such as changing worker colors to black during near-miss incidents, proved effective in highlighting potential risk areas.

6.4. RECOMMENDATIONS FOR SAFETY IMPROVEMENTS

Based on the findings, several recommendations can be made to enhance safety and accessibility in ABC projects:

- **Enhanced Training Programs**: Develop comprehensive training programs tailored to workers' experience levels, focusing on risk perception and safe behavior in construction environments. Regular safety drills and refresher courses can reinforce safe practices.
- **Traffic Management Strategies**: Implement effective traffic management strategies, including the use of barriers, signs, and designated pedestrian pathways, to separate vehicle movement from worker activities. This can help reduce the risk of near-miss incidents involving vehicles.
- **Equipment Placement and Use**: Optimize the placement and use of construction equipment to minimize interactions with workers. Strategic planning of equipment locations and movement paths can help create safer work zones.
- **Real-Time Monitoring and Feedback**: Utilize real-time monitoring systems to track worker movements and provide immediate feedback on potential risks. Integrating technology such as wearable devices can enhance the effectiveness of safety protocols.

6.5. FUTURE WORK AND INTEGRATION OF REAL DATA

Future iterations of the simulation will also include direct interactions between machinery, vehicles, and workers to provide a more comprehensive analysis of construction site dynamics and safety incorporating real survey data to analyze workers' risk perceptions and behaviors more accurately. This will enhance the realism and applicability of the simulation model.

7. CONCLUSIONS, LIMITATIONS, AND RECOMMENDATIONS

The construction industry is significantly impacted by accidents, many of which stem from unpredictable risks on-site. Accelerated Bridge Construction (ABC) has emerged as a promising alternative to traditional construction methods, offering advantages in reducing life-cycle costs, and construction time, and improving overall quality. This study aimed to develop a comprehensive framework using agent-based modeling (ABM) to better understand and mitigate near-miss incidents at ABC sites. By examining the interactions between workers, vehicles, and equipment, the study provides insights into enhancing safety and accessibility on construction sites. The study's findings underscore the importance of worker experience in preventing near-miss incidents. Highly experienced workers exhibit cautious behavior, significantly reducing near-miss incidents compared to their less experienced counterparts. The results also highlight the critical role of traffic management and equipment placement in minimizing risks. Managing traffic flow effectively and strategically positioning equipment can reduce the likelihood of near-miss incidents. Additionally, the integration of real-time monitoring and feedback mechanisms can further enhance safety protocols, providing immediate insights into potential hazards.

Despite the comprehensive approach and valuable insights provided by this study, several limitations highlight areas for future research and refinement to enhance the model's accuracy and applicability. The model, although based on the I-235 Broadway Extension Corridor Widening project in Oklahoma City, was generalized and not site-specific, potentially overlooking unique factors such as local traffic patterns and environmental conditions. Additionally, the interaction dynamics between workers, vehicles, and equipment were simplified, possibly not fully capturing the complexity of real-world scenarios, including varying weather conditions and unexpected equipment failures. The study primarily relied on random data and predefined scenarios, lacking real-time data integration, which limits its immediate applicability to ongoing projects. Environmental factors like noise levels and lighting conditions were not explicitly included, potentially limiting the comprehensiveness of the safety analysis. Worker experience was assumed to be uniform across three categories, which may oversimplify the variability in behavior and risk perception. Furthermore, extensive validation with real-world data was not conducted, which would provide more robust evidence of the model's accuracy and reliability. Future research should focus on developing site-specific models, incorporating real-time and environmental data, and conducting extensive validation with real-world data to enhance the model's precision and practical utility in improving safety in Accelerated Bridge Construction projects.

The information provided in the study offers a comprehensive understanding of how different Accelerated Bridge Construction (ABC) projects have been managed, highlighting key factors such as traffic and safety, equipment use, construction methods, and environmental conditions. By examining these aspects, future projects can leverage these insights to enhance planning and execution. For instance, understanding the effectiveness of overnight work and high-capacity cranes in urban settings, as demonstrated by the I-95 project, can inform traffic management strategies to minimize disruptions. Additionally, the lateral slide method used in the OR213 and Larpenteur Ave projects showcases an efficient technique that reduces traffic impact and improves work-

zone safety, which can be adapted for similar environments. The table also underscores the importance of selecting appropriate equipment and methods tailored to specific site conditions, as seen in the varied approaches across urban and rural settings. Utilizing these insights, particularly the lessons learned from each project's unique challenges and solutions will enable more precise risk assessments and implementation of best practices, ultimately leading to safer and more efficient ABC projects. These learnings are particularly valuable for simulating near-miss incidents and developing proactive safety measures, thus contributing significantly to the broader goal of improving construction site safety and efficiency.

The proposed framework and its findings offer several practical recommendations for improving safety in ABC projects. Enhanced training programs tailored to workers' experience levels can reinforce safe practices and improve risk perception. Effective traffic management strategies, such as the use of barriers and designated pedestrian pathways, can help separate vehicle movement from worker activities, reducing the risk of near-miss incidents. Optimizing equipment placement and movement paths can create safer work zones, while real-time monitoring systems can provide immediate feedback on potential risks, enhancing the overall safety environment. Future work will involve incorporating real survey data to analyze workers' risk perceptions and behaviors more accurately, further refining the simulation model's realism and applicability.

By systematically compiling and analyzing the results, this research provided actionable insights and practical tools for improving safety and efficiency in Accelerated Bridge Construction projects. The ultimate goal is to create safer and more resilient construction environments, ensuring the successful implementation of ABC methods. The findings and recommendations will be disseminated through the ABC-UTC website, providing valuable resources for construction and transportation agencies. The decision-support tool developed from this study will enable practitioners to simulate various construction scenarios and assess safety risks in real time, contributing significantly to the field of construction safety management.

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