# Group-based VR Training to Improve Hazard Recognition, Evaluation, and Control for Highway Construction Workers

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## ABSTRACT

The construction industry spends approximately $15billion/year for occupational injuries, and highway sector is the most dangerous. Highway construction workers have to work in close proximity to construction equipment and high-speed traffic, exposing them to an elevated risk of serious injuries/fatalities. Safety training has a direct impact on the prevention of construction accidents. The traditional lecture-based construction training curriculum has not been revisited and is designed to train the workers individually, thus the benefits of collective engagement in worker training is ignored. High-engagement Virtual Reality (VR) environments offer a more effective learning experience for training workers to identify hazards in the job site. We present a training platform for instructor-in-the-loop, group-based VR training to complement and increase the effectiveness of the current training program for highway workers. We develop a VR platform in which an instructor can create and improvise on work zone scenarios and share the virtual scenario easily with the entire class.

**Keywords**: Virtual Reality, Construction Training, Group VR.

## 1 INTRODUCTION

The construction industry has more fatalities than any other employment sectors in the U.S. economy [1,2]. Over the past ten years, the number of deaths occurring in highway work zones has increased from 546 in 2010 to 842 in 2019 [3]. During the same 10-year period, injuries in work zones have gone from 36,000 in 2010 to 39,000 in 2019 [4,5]. In addition to safety concerns and loss of lives, highway accidents and crashes result in substantial economic losses, with approximately 27,000 first-aid injuries and 26,000 lost-time injuries per year at a total annual cost of $2.46 billion [6]. Construction workers often fail to recognize between 30-40% of workplace hazards, which ultimately leads to unsafe behaviors. In addition, the sizable inexperienced and temporary workers that are hired for highway work are not accustomed to the hazardous conditions and environmental demands of a highway construction site. Proper safety training is crucial to work zone safety and has a direct impact on the prevention of highway accidents. Poor or inadequate training places workers at disproportionate risk for injury.

Safety training is most effective if it is well-designed, is delivered by people the learners can relate to, uses high engagement training methods, draws on the learners' experiences, and is contextually relevant [7-10]. However, the time constraint of the current training program limits the instructor's ability to cover the full breadth of hazardous situations faced in the construction work zones. Due to the disparity between the number of students and the number of training instructors, the only option that the instructors often have is giving traditional lectures, and they cannot involve workers in situated, active learning. For example, lecture-based training lacks access to construction sites and limits student engagement and experiential learning. We propose evidence-based experiential learning using high engagement VR, to provide a more effective learning experience than traditional methods for training workers to identify hazards in job sites [11-15]. However, interactivity using VR head-mounted displays (HMD) is often a solitary experience, isolating learners from the social and training context. Therefore, using VR HMDs cannot be easily integrated into the current setting of construction training, in which an instructor needs to teach a large group of trainees. The proposed group-based training aims to preserve the interactivity between instructors and trainees in a VR platform and make the content visible to a group of trainees. To this end, the developed VR scenario was experimented using 360 degree projections to enable situated learning and scenario-based training more scalable and interactive than the current lecture-based training or solitary VR-based training.

## 2 RESEARCH APPROACH

This project aims to increase the effectiveness of the current construction training programs through developing a training platform for instructor-in-the-loop, group-based VR training. This training module is designed to complement the existing training for highway workers. We accomplish this goal by developing and designing a VR platform in which an instructor can create and improvise on work zone scenarios depending on the needs of the class and share the virtual scenario easily with the entire group, that is, workers who are not necessarily wearing VR HMDs. In this approach, the instructor uses large displays/projection screens or mobile devices to share the designed VR environment with the entire class. The interactive setting of the training allows the instructor to change the scenario or the content within the scenario using a mobile device (tablet) based on the class's needs and change the perspective (viewing angle, zoom in/out) of the same scenario on the fly to emphasize potential risks in the environment, not noticed by the trainees. This sharable VR helps instructors engage with the class and develop various learning activities in different situations. For example, he/she can pair the students to identify what is wrong about what a worker in the scenario is doing and explain the hazards that are not recognized by the trainees. This approach enables the instructor to expose the students to realistic hazardous situations in a safe setting and multiple trainees can experience and learn the scenario collectively.

### 2.1 Development of VR Training Content

VR-based content is created that can simulate various scenarios of the hazards and situations that workers face in highway work zones. The VR content is developed to cover the safety knowledge in the current training that is directly or indirectly related to highway construction hazards, as well as the hazards/situations that are overlooked in current training. Among the fatal four hazards identified by the Occupational Safety and Health Administration (OSHA)—falls, struck by objects, caught-in or caught-between and electrocutions— we focus on the "caught-in-between" and "struck-by" situations as they are more relevant to highway accidents. The struck-by hazards occur due to misplaced objects, loose or shifting materials, and vehicle or equipment strikes. Caught-in or caught-

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between hazards involve workers caught in or between machines, devices, or tools. Using the shareable VR in a co-located setting (e.g., classroom, open space), the VR content will provide complex situations developed from real highway sites that can be used to teach a large group of trainees, augmenting the immersive training material with different layers of safety-related information. Scenario-based training in VR can help workers immerse into highly realistic and detailed representations of actual highway work zones without risking their safety. In addition, in order to create a realistic experience for the trainees, the training includes spatialized sound to accurately replicate the noisy environments faced in highway worksites. Furthermore, various factors including the variety of background knowledge of the people who we will be receiving training are taken into account in developing appropriate content for the scenarios. This is essential as some trainees, e.g., fresh construction students and novice workers, may not know or have direct experience in the highway environment and would need more progressive and detailed scenarios to grasp the required knowledge.


Figure 1: Translation of real highway environment into VR content

## 2.2 Development of Immersive VR Scenarios

After extracting required content from traditional trainings and common practices, the content was translated into scenarios that can be represented through VR. The power of VR in the context of safety training lies in its ability to allow showcasing things that cannot be done safely in the real-world. In this research, the immersive media is used to simulate the hazardous environment of a highway work zone for assessing trainee's knowledge, skills, and abilities in an authentic context. A roadside worksite, is a spatial environment with various cues, including sound and multiple tasks in process concurrently: multiple pieces of heavy equipment, differing weather conditions, differing time conditions (daytime versus night), and vehicular traffic conditions. As a result, the scenarios include components that significantly influence safety and hazard: day shifts with and without noisy environment, nightshift, high-speed traffic, adverse weather, various worker roles- e.g., flagger, driller, etc. The scenarios also involve vehicle and worker movement, tools, equipment, and personal protective equipment, to represent struck-by and caught-in-between hazards.

Iterative design via script building and storyboarding was used to develop the components and actions required in each scenario. The activities are both pre-designed and designed on the fly by the instructor considering alignment with the envisioned learning objectives. Environment design of the scenarios includes a combination of collecting data (e.g., noise) from real work sites and creating virtual work sites, characters, and equipment. Additionally, scripted actions of characters (workers in different roles, vehicle traffic, on-site heavy equipment) are programmed as part of the environment design. Spatial audio is an important part of hazard recognition. The sound output of the virtual environment is designed to be updated in real-time to adapt to the instructor's selection of the next step during the learning process. When necessary, spatialized sounds will be used to create a more immersive experience for the learner (e.g., jackhammering, equipment warning alarms). The scenario design involves required programming to allow the instructor to alter the scenario —change the time of day, change the number of pieces of equipment moving, load a different scenario, pause for feedback, etc.— as well as the artwork required to create a usable interface for both the instructor and the students.

## 3 Experiment

A proof-of-concept experiment was conducted to evaluate efficiency of the proposed immersive platform in augmenting current highway training curriculum. A new median crossover construction site was simulated through a VR environment. The environment was designed to include various construction equipment (e.g., dump truck and excavator), workers dispersed at different locations of the work zone conducting various roles, different work zone barriers (e.g., cones vs. Jersey barriers). Three strategic locations (presented as scenes in Figure 2) were considered as viewing points to show how the perspective of the workers and detected hazards change based on location.


Figure 2: Designed VR Environment for the new median crossover construction site

Three 5-minute-long animated videos were developed at each scene, representing daylight, night light and adverse rainy weather to reinforce worker learning through repeated actions in different situations as shown in Figures 3 and 4. The scenarios are designed to follow OSHA's Hazard Identification and Assessment process and reinforce trainees' knowledge to recognize potential hazards, evaluate the severity of the hazard, and decide on control strategies (e.g., elimination, substitution, engineering, administrative, personal protective equipment). Depending on each case, the scenarios provide the trainees with different experiences.


Figure 3: Example of Daylight Scenario

Figure 4: Example of Night Condition

The developed VR scenarios were projected on Cyclorama, a 32' diameter, 360 degree immersive projection environment at Virginia Tech (see Figures 5 and 6). In addition, a Qualisys motion capture system and a 140-channel spatial audio system provide a social, multimodal VR environment on a large scale required for this research. The Cyclorama allows groups of people to experience the immersive visual and sonic environment at the same time.

Figure 5: Cyclorama environment

The designed scenario was evaluated by an experienced construction safety instructor. The developed platform was proven to provide the instructors with flexibility in ameliorating their class's learning experience based on the needs of the trainees.

Figure 6: Designed Scenario projected on Cyclorama

## 4 Discussion

The interactive VR approach proposed here is expected to be more effective than the linear and passive lecture-based training and assessment based on text and video presentation of information. Including the developed materials as a part of training programs for highway workers will complement the current traditional training by adding interactive real work zone scenarios and allowing the instructor to adjust training content per different groups of workers from various ages, experience levels, and backgrounds. In the future work, we will conduct more formative study which will include interviewing more training instructors, investigating critical past incidents, and identifying the hazardous factors from videos taken from real highway construction worksites. We will also involve construction workers in the study to ensure that the developed platform enhances their experience and addresses their needs.

The proposed approach is expected to significantly reduce worker-involved work zone accidents and, accordingly, contribute to economic benefits nationwide. Because of the wide use of the current traditional construction training programs, the resulting complementary approach, when translated into practice for trainers, is expected to generate far-reaching improvements in highway workers' safety and health. The proposed training can be used to enhance the learning experience of diverse groups of workers from both genders with different levels of education, experience, age, and background as instructors can customize the VR content on the fly and change the scenario depending on who their students are. The proposed framework can be easily adapted to designing worker training in other sectors of the construction industry as well as other industries - such as training approaches for manufacturing or healthcare workers.

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