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Immersive Work Zone Inspection Training using Virtual Reality

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Abstract

Can virtual reality tools be used to train engineers that inspect work zones? In this paper, we share the findings of a research project that developed an interactive and immersive training platform using virtual reality to train state department of transportation (DOT) staff that inspect work zones for compliance. Virtual reality offers an immersive platform that closely replicates the actual experience of an inspector driving through a work zone, but in a safer, cheaper, and quicker way than field visits. The current training practice involves reviewing temporary traffic control procedures, and reports and pictures from previous inspections. The developed platform consists of a *learning* module and an *immersive* module. The *learning* module is founded on the historical knowledge gained by DOT staff from inspections dating back at least 5 years. This knowledge incorporated representative inspection reports from previous years from all DOT districts including photographs of deficiencies. The synthesized knowledge was converted into a concise easy-to-consume format for training. The *immersive* module places the trainee in a vehicle moving through a work zone, thus providing a realistic experience to the engineer before inspecting a real work zone. The research team developed and tested two immersive scenarios of a freeway work zone. The training platform was tested by 34 individuals that worked for the Missouri Department of Transportation. An overwhelming majority (97%) agreed that virtual reality offered a realistic and effective way to train inspectors.

The Work Zone Safety and Mobility Rule (23 CFR § 630 Subpart J) established requirements and guidance to state departments of transportation (DOTs) for addressing the traffic safety and mobility impacts of work zones. As per § 630.1008(d) on training,

> States shall require that personnel involved in the development, design, implementation, operation, inspection, and enforcement of work zone related transportation management and traffic control be trained … States shall require periodic training updates that reflect changing industry practices and State processes and procedures (*1*).

Work zone management has incorporated the use of new technologies. For example, the use of intelligent transportation systems (ITS) technologies and application of simulation tools for impact analysis and scheduling has risen in the last decade. In contrast, work zone training has not taken advantage of new technologies that could improve training effectiveness, immersion, cost, availability, and flexibility.

An example of a DOT personnel category that requires training is work zone inspector. DOT staff inspect work zones in one or more districts each year. This annual exercise is demanding, as each work zone is inspected and rated based on several factors. Factors range from proper use of signage, channelizing devices, barriers, and lighting to signalization and traffic management. Any discrepancies from satisfactory performance are also recorded. A rating value is assigned for each factor based on discrepancies and deficiencies. The inspection team, typically consisting of four to five personnel, compiles the ratings for all work zones operational in the district, prepares a summary, and presents the findings to the district management. Staff on the inspection team are trained in several areas. They need to be familiar with the inspection worksheet and the different evaluation categories. They also need to be familiar with *Manual on Uniform Traffic Control Devices* (MUTCD) (*2*) typical applications (TAs) for different facilities and work activities. TAs provide the standard layout and specifications for the placement of signage and temporary traffic control devices. Finally, an understanding of the discrepancies and deficiencies of various work zone elements is necessary to satisfactorily rate them. The

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aforementioned knowledge attainment requires robust training of the personnel, which is difficult to accomplish without extensive field visits (i.e., prior experience). The current state of practice is to review the documents related to temporary traffic control and the reports from previous inspections, typically PowerPoint files with pictures. It would be beneficial if a new mechanism for training could be developed that is as effective as field visits but without the amount of time and effort required to visit multiple field sites. Alternately, this new training method could complement existing training by requiring fewer site visits.

In this paper, we offer an alternative training platform using virtual reality (VR) and illustrate it using Missouri Department of Transportation (MoDOT) data. The platform consists of two steps. The first step is a *learning* module that is founded on the historical knowledge gained by DOT staff from inspections dating back 5 years. Previous inspection reports, which include photographs of deficiencies observed at work zones across the state were used in building the learning module. The synthesized knowledge was converted into a concise, easy-to-consume format for training. The second step is an *immersive* module that places trainees in virtual work zones where their inspection performance will be observed and assessed (e.g., a quiz on work zone deficiencies such as poor signage or misaligned cones). Two training scenarios were created using the Unity 3D engine (Unity Technologies, San Francisco, CA) and the Oculus Rift VR headset (Facebook Technologies, Menlo Park, CA). Participants, wearing a VR headset, are placed in the passenger seat of a vehicle that drives through a work zone. As the subject travels past various signs and temporary traffic control devices, they note any issues. A focus group study of DOT engineers produced feedback on the utility and usability of the VR training module. Two questionnaire surveys were administered on completion of the module.

The paper is organized as follows. First, a review of pertinent literature related to two distinct topics—(1) work zone inspection, and (2) VR applications for training and education—is presented. The methodology section presents the study design and development of the learning and immersive modules. The results of the evaluation of the developed modules by a focus group of practitioners are presented in the next section. Conclusions are drawn and topics for future research are identified in the final section.

Literature Review

Literature on Work Zone Inspection Practices

In the United States, someone is injured in a work zone every 5.4 min. One study reported that work zones cause a 21.5% increase in crash rate on freeways (*3*). In 2015, 96,626 crashes occurred in a work zone, which resulted in 70,499 property damage, 25,485 injuries, and 642 fatalities, an increase of 7.8% from 2014 (*4*). Many factors contribute to crashes in a work zone. Speeding, inattention, and driving under the influence of alcohol are some examples of contributing factors. Transportation agencies have made numerous efforts to reduce work zone injuries and fatalities by using several methods including improved work zone inspection practices and personnel training. Efficient work zone inspection could improve safety for drivers and workers, reduce agency risk, and increase mobility (*5*).

The effectiveness of work zone inspection is a major concern to industry, the public, and transportation officials. The Federal Highway Administration provides a procedure for work zone review to improve safety and mobility, comply with standards, and reduce agency risk (*5*).

There are several agencies providing training for work zone inspections including the National Highway Institute (NHI) and state DOTs (*6*). NHI provides training in the inspection of traffic control devices, traffic control zones, and flagger operation (*7*). State DOTs offer customized training for their staff. For example, Kansas DOT offers training in temporary traffic control design, setup, maintenance, management and evaluation of work zone. Training is offered for inspecting both construction and maintenance work. Another example is the Rutgers Center for Advanced Infrastructure and Transportation, which offers training for inspecting sign retroreflectivity in compliance with MUTCD requirements (*6*).

The American Traffic Safety Service Association (ATSSA) offers a training program for traffic control supervisors and traffic control technicians (*5*). In this training program, they include reviewing standards and guidelines, traffic control devices, and human factors to make the temporary traffic control area safe for workers, motorists, and pedestrians. The current training practice uses pictures and slides for the inspection section.

MoDOT is composed of seven districts: central, northeast, northwest, southwest, southeast, St. Louis, and Kansas City. Each year, work zone inspection is conducted for a week in two of the seven districts. The inspectors rate a work zone on a scale from A to F, with A being the best and F being unacceptable (*8*). Signings, channelizers, barricades, crash cushions, and pavement markings are inspected. MoDOT inspectors document any issues and concerns they observe during their inspection. For example, among the 32 work zones inspected in Kansas City during 2016, 17% had signs in unacceptable condition, and 22% had issues with channelizers (*9*). All the aforementioned training programs (i.e., NHI, ATSSA, DOTs) could take advantage of the use of VR tools to improve the effectiveness and immersion level.

Literature on Virtual Reality Applications for Training and Education

VR has been used for training in diverse disciplines such as education, medicine, media, and defense. By immersing the learner in a 3D environment, VR can provide a more realistic setting for learning and knowledge discovery. VR offers a low-cost immersive training platform that can help enhance performance and reduce errors. Sowndararajan et al. mention that an inherent advantage of the immersive environment is that it allows a trainee to access a wide range of scenarios that are difficult or infeasible to train in the real world (*10*).

The use of VR for training has been addressed in several studies. McComas et al. explored using VR to train children to safely cross an intersection to determine the usefulness of VR for training (*11*). Training was tested at two schools, one urban and one suburban, for crossing intersections. The results revealed that students from the suburban school displayed significant improvement after training and successfully transferred their skill to actual intersections. However, no performance improvements were observed for students at the urban school.

Koskela et al. conducted a study to determine how virtual learning is appropriate in an occupational safety engineering course and compared it with a conventional lecture (*12*). The results revealed that 20 students who underwent a virtual learning session achieved a high score of 14 points, whereas only five students attending the conventional lecture scored 14 points. Shirazi and Behzadan established a mobile augmented reality visualization in the field of construction and civil engineering for students and instructors (*13*). In a survey, students rated the use of technology using a five-point Likert scale. The authors reported high satisfaction rates and students being passionate about learning when using augmented reality.

In the mining field, conveyor belt safety is an important training topic as any inappropriate use could lead to severe injury or death. Lucas and Thabet developed a VR-based training module that allows trainees to safely interact with the 3D prototype (*14*). The results revealed that five of the participants preferred VR because it provided a safe interactive experience, whereas the other three participants preferred the conventional training method. They agreed that VR is an effective method for training the current generation of miners, who are more computer literate. Hui developed a training module by VR for drilling underground mines (*15*). The author evaluated two VR training systems—one based on a head-mounted display (HMD) and the other using a screen projection to determine the level of immersion, intuitiveness, interactivity, ease of use, and ease of learning by a study group of 10 participants. VR training by HMD obtained a higher score (4.8 out of 5) according to the immersion level than the screen-based training. The HMD system scored 1.5 to 2 times higher than the screen-based version on intuitiveness, interactivity, and ease of use measures. Ninety percent of the trainees preferred training with HMD as it provided a better overall experience and for its ease of use.

VR has also been used for training in the medical field. Ahlberg et al. explored training by VR for residents (*16*). Resident performance on the first 10 cholecystectomies surgeries were measured to assess the effect of VR training before performing actual surgery on patients. The results revealed that VR training led to significantly fewer errors made by residents. Yang et al. conducted a study using training by VR to improve ambulation for people affected by a stroke (*17*). Nine participants received nine sessions of treadmill training. Eleven participants received nine sessions of VR-based treadmill training. The participants were evaluated before training, at the end of training sessions, and one month after training on walking speed, community walking time, and walking ability questionnaire (WAQ). The participants' walk speed improved after the training by VR. The participants who trained by VR also showed significant improvements in community walking time and walking ability. Johnsen et al. explored the use of immersive VR to train medical students on communication skills (*18*). Seven participants reported VR to be a useful training tool to improve communication between patients and doctors. The study found that only four participants passed the test on correct greeting, acute abdominal pain diagnosis questions, and differential diagnosis, indicating a need for additional training. Stevens et al. developed a VR module to train medical students to diagnose and treat a patient with a head injury (*19*). The results revealed that identifying the object is easier when using tools in VR.

VR has also been used for training firefighters. Tate et al. developed a training module by using VR for shipboard firefighters to enhance their experience and familiarity with ship parts (*20*). Trainee performance was compared between VR and traditional training. The results revealed that VR training improved firefighter skills and their performance translated well into the real world. Smith and Ericson explored immersive VR to train children to understand the dangers of fire and escape procedures (*21*). Although there was no significant improvement in pretest and posttest scores for participants in the experimental group, children found training by VR to be more enjoyable than the traditional approach.

A few other areas reported limited use of VR for training. These include teaching about earthquake safety, welding procedures, training substation electricians, and teaching dance lessons. Li et al. developed a virtual module to train people on how to survive an earthquake while they are in an indoor environment (*22*). The participants were divided into four groups and each group experienced a different training mode: VR, video, manual, and no training. The authors concluded that the VR training module was effective in training people about successful practices related to earthquake safety. Xie et al. established real-time welding training using VR (*23*). After a series of experiments using single-camera vision to track the position of the torch and helmet, they found that the error of tracking was <1.5 mm, which meets the training requirement currently used in practice. Tanaka et al. developed a virtual substation to train electricians for operating equipment and emergencies (*24*). The trainees and instructors found this module to be a useful tool for training. Finally, Chan et al. developed a new dance training module using VR and motion capture (*25*).

In summary, VR has been successfully applied in various disciplines for training and education. A majority of these studies reported improvement in performance resulting from the use of VR. There are no studies documenting the experiences, advantages, and limitations of using VR to train work zone inspectors.

Methodology

This chapter is divided into two sections. The first section describes the development of the learning module as a set of slides consistent with the current training practice at MoDOT. In the second section, generation of two scenarios of a virtual work zone with a lane closure in a 3D immersive environment is presented.

Learning Module Development

There are several elements that need to be inspected to ensure safety and mobility in a work zone. To be consistent with current training practice at MoDOT, the learning module was developed as a set of slides. Historical data in the form of previous inspection documents, that is, photographs and videos from MoDOT staff, was synthesized. The learning module also synthesized the guidance on TAs, traffic control devices, and positive protection from the MoDOT *Engineering Policy Guide* (EPG) (*26*) and *Manual on Uniform Traffic Control Devices* (MUTCD) (*2*). In addition, the reports were reviewed to synthesize commonly observed issues in work zones. After a trainee reviews the learning module, their learning is assessed using a quiz. The quiz consists of 13 questions. Each question presents a picture of a work zone temporary traffic control device (e.g., signage, striping, truck mounted attenuator (TMA)) as shown in

Figure 1. A work zone sign shown in the learning module quiz.

Figure 1, and the participant provides a rating of the quality and accuracy of the device. For the rating, MoDOT's Temporary Traffic Control Inspection Worksheet (criteria shown on the next page) was used. The quiz was administered using an online survey tool with instantaneous feedback. After the trainee answered a question, they were provided with instant feedback on whether their answer was right or wrong. If wrong, then the correct rating that an expert inspector would have chosen was provided. An example of accurate placement or better condition of temporary traffic control and signage is also shown. Thus, the learning quiz serves both assessment and training needs. A sample question from the quiz and the feedback is provided next.

1. *How would you rate this sign?*

Select the rating from the below options (as provided in MoDOT's inspection worksheet).

[ ] A—Above and beyond the standards and specifications of the project.
[ ] B—Meeting the standards and specifications of the project.
[ ] C—A couple of deficiencies meeting the Category 3 severity.
[ ] D—Several deficiencies meeting the Category 3 severity or a couple of deficiencies meeting the Category 2 severity.
[ ] F—Several deficiencies meeting the Category 2 severity or one or more deficiencies meeting the Category 1 severity.

The three categories of severity are defined as follows:

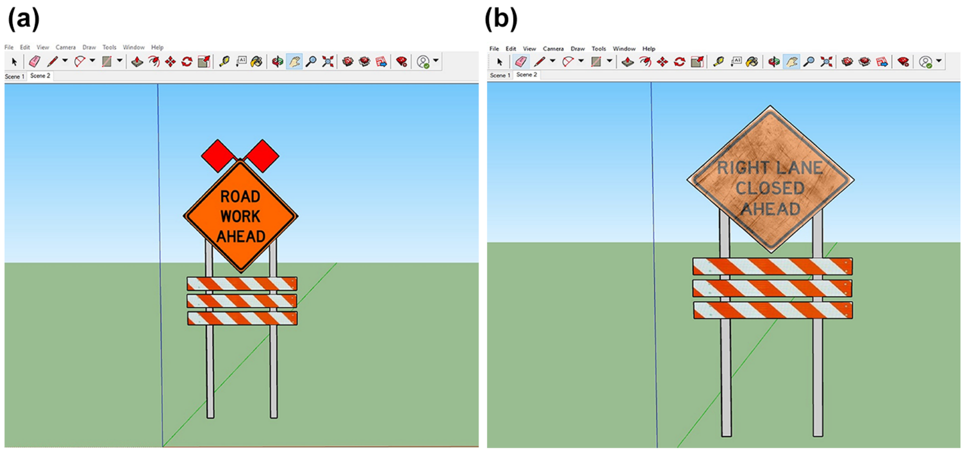

Figure 2. Examples of temporary traffic control coded in SketchUp: (*a*) good signage and (*b*) deficient signage (faded, no flags).

Category 1—Presents an immediate safety issue for the traveling public or workers and needs to be addressed immediately.
Category 2—The situation does not pose an immediate safety issue for either the public or the workers, but can impact the proper functioning of the work zone.
Category 3—The situation does not impact the functioning of the work zone but is more of a maintenance or aesthetic issue.

Instantaneous Feedback. The correct answer for this question is D—Several deficiencies meeting Category 3 severity or a couple of deficiencies meeting Category 2 severity. If any participant selects an incorrect answer such as A, B, C, or F, they will receive a message that shows the recommended rating along with a picture showing the correct signage.

Immersive Virtual Reality

The immersive VR module for work zone was developed in three steps. The first step involves the design of roadway geometrics and traffic control using a 3D modeling program (e.g., SketchUp). An I-70 road segment was coded using an aerial photo with contour line information and imported into the modeling program. The program captures the terrain of the selected segment from the aerial photograph. The roadway section was coded by adding materials (e.g., pavement textures) and making the lane boundaries.

In addition, temporary traffic control was created in SketchUp as a 3D object such as signage, channelizer, and arrow board. Each object needed defined materials. For example, the "Road Work Ahead" sign has three different materials that are signage, flags, and advance warning rail system. A screenshot of the temporary traffic control coded in SketchUp is shown in Figure 2. To have a realistic representation of all objects in the virtual environment, we scaled objects according to MUTCD. Finally, the designed roadway and temporary traffic control were exported into Filmbox (.fbx).

The second step involved the use of a simulation engine and C# programming language to simulate the movement of a vehicle in a virtual work zone environment. One example of a simulation engine is Unity. The Unity engine can create a simulated and interactive experience in both 2D and 3D, and it offers C# for coding scripts to move any objects. The roadway geometrics and temporary traffic control (signage, channelizers, etc.) created in the previous step were imported into the simulation environment. A screenshot of the simulation environment is shown in Figure 3. The C# code was used to move the car constantly in the designed scenario with predefined waypoint (car location). The car was programmed to move without needing to be driven. The engine incorporated Terrain Editor, which was used to simulate the real terrain to match it with recorded video of the I-70 road segment.

The third step of the immersive module was to port the simulation scenario into a head-mounted display (HMD). HMD provides the visual and immersive experience in the virtual work zone. The software development kit of the Unity engine supports HMD to visualize the designed scenario in a 3D environment.

Several HMDs are commercially available, such as Oculus Rift, HTC Vive, and Google Cardboard. In this study, we used Oculus Rift VR headset to immerse participants in the virtual work zone scenario. Two simulation scenarios of a virtual work zone were developed. Both work zones consisted of closing one of the two lanes on a freeway in one direction. The first scenario serves as a

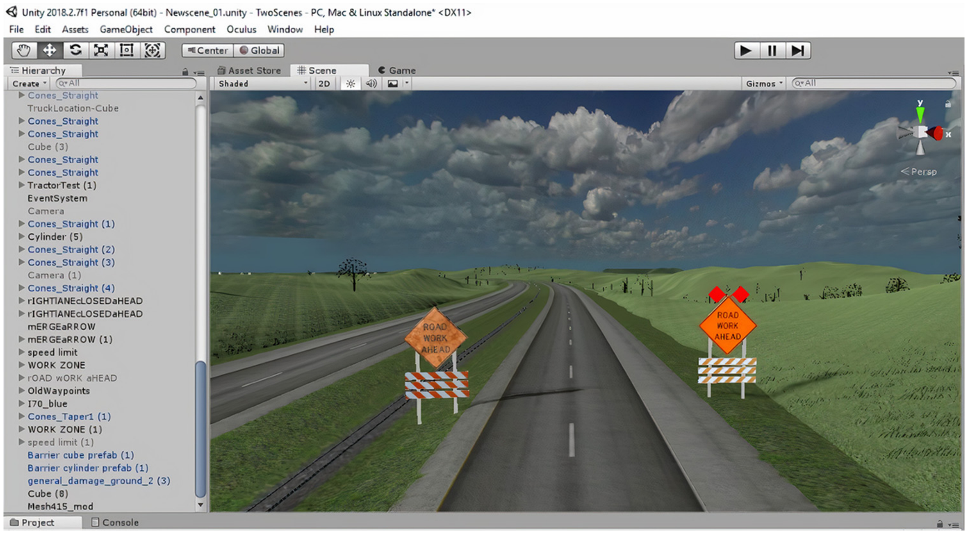

Figure 3. Screenshot of the 3D environment in Unity.

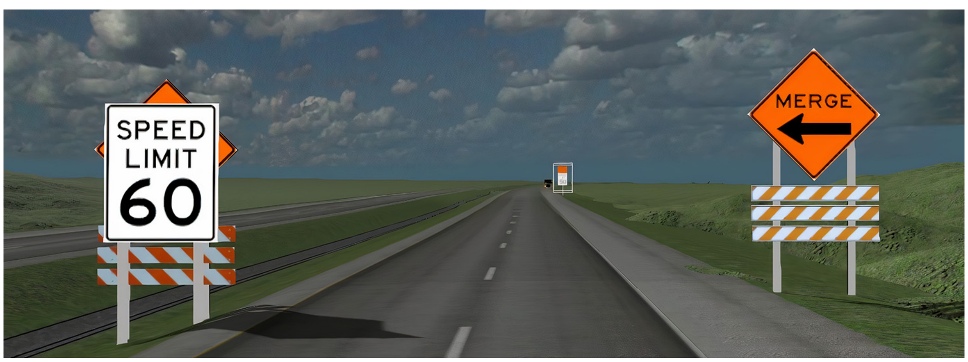

Figure 4. Screenshot of deficient signage: "Right Lane Closed" sign covered by "Speed Limit" sign.

practice and the second scenario is used to test the trainee performance. Both scenarios include a mix of good and bad signage. MoDOT's EPG guidance on temporary traffic control was adopted for correct spacing between signage, channelizers, and so forth. One example of deficient signage presented to the trainees is shown in Figure 4.

Nausea and motion sickness were reported in the literature when using VR for training (*14*, *18–20*). Limiting the duration of the immersive experiment and taking short rests and breaks between experiments have been recommended. In this study, we ensured that each immersive scenario did not exceed 3 min.

Results

The training modules were tested by MoDOT staff and their performance recorded. A total of 34 participants (25 males, nine females) participated in the evaluation of learning and immersive modules. The level of knowledge about work zones varied across participants: some having minimal knowledge, some having over 10 years of experience inspecting work zones, and several having a reasonable understanding of work zone temporary traffic control procedures. The results of their performance are presented next.

Learning Module

Each question in the learning module quiz could be rated on an A to F scale, described earlier. The recommended rating for each question (i.e., correct answer) was based on the consensus of work zone experts from MoDOT who have prior experience in inspecting work zones across the state. The percentage of correct answers was

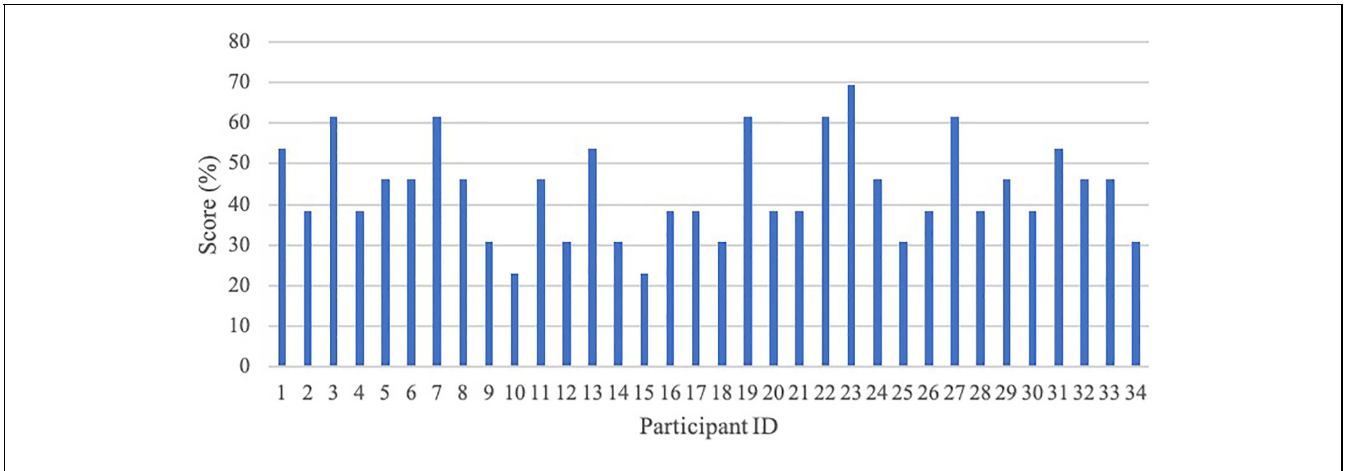

Figure 5. Participant performance on the learning module quiz.

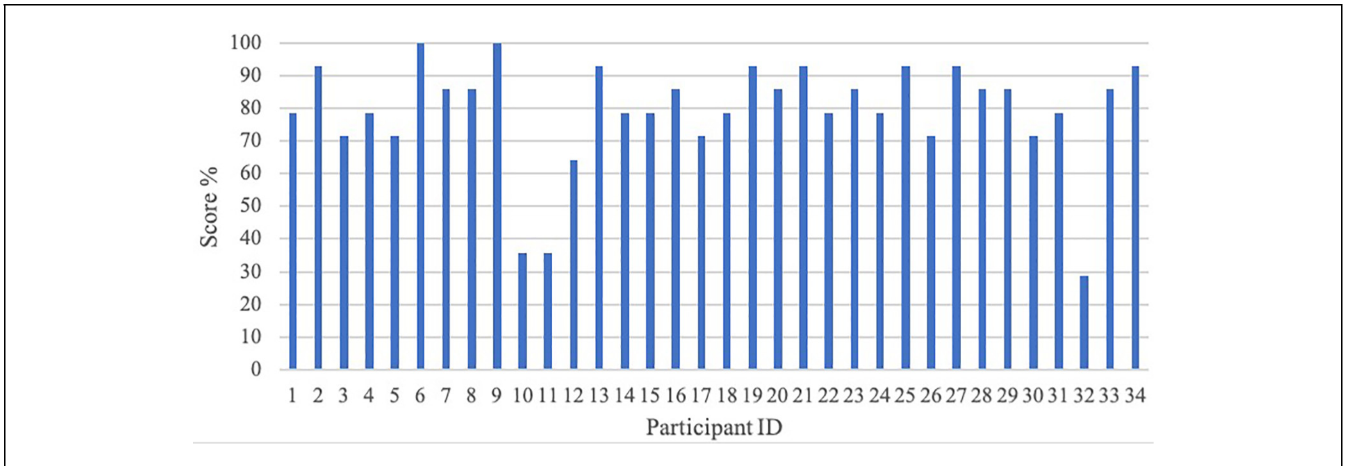

Figure 6. Participant performance on the immersive training module.

calculated for each participant. Individual performances are shown in (Figure 5). The average score was 44%. The results revealed that only nine participants received a score above 50% (those that were involved with work zones in their job: work zone coordinator, maintenance supervisor, etc.). Over half of the participants scored under 50%. These scores further validated the need for proper training of staff before they inspect and rate actual work zones.

Immersive Module

All 34 participants also participated in the immersive module and the testing exercise of the virtual work zone. During the test, the participants called out any deficiencies they noticed while going through the scenario. The research team developed a rubric to record the participant responses. There were 10 main instances where there were deficiencies in the work zone. In four of these instances, there were two deficiencies at the same location. Thus, the rubric contained grading for 14 questions. The number of deficiencies correctly identified by each participant were counted and the percentages are shown in (Figure 6). On average, the participant score was 79% whereas 88% of the participants earned a score of over 70%. Two participants were able to call out all deficiencies. With regard to identifying a deficiency, seven participants identified 93% whereas another eight participants identified 86%. Twenty-four percent of the participants answered 79% of the test correctly; 15% of the participants answered 71% of the test correctly.

A short survey was administered after the participants completed the immersive training module. The goal of this survey was to gather qualitative feedback on VR technology. The survey included questions about their experience wearing the HMD, ability to discern

Table 1. Survey Responses Related to the Use of Virtual Reality Technology

Question	Strongly agree (%)	Agree (%)	Neutral (%)	Disagree (%)	Strongly disagree (%)
1. I believe the virtual reality module provided a realistic representation of an actual work zone.	53	47	0	0	0
2. I was comfortable wearing the virtual reality headset.	35	56	9	0	0
3. I was able to distinguish between good and bad signage in the work zone.	65	35	0	0	0
4. I did not find the virtual reality module to be challenging.	9	41	32	18	0
5. I had enough time to read the work zone signage.	35	56	6	3	0
6. I did not feel nauseated while using the virtual reality headset.	56	38	3	3	0
7. I had sufficient time to notice any concerns in the work zone.	32	68	0	0	0
8. Overall, I believe that the virtual reality module is useful for training staff that inspect work zones.	62	35	3	0	0

deficiencies in the work zone scenarios, and the overall utility of immersion. Column 1 in (Table 1) lists the survey questions. The remaining columns in (Table 1) show the percentage responses for each category. All participants agreed that the VR module provided a realistic representation of an actual work zone with 47% agreeing and 53% strongly agreeing. Over 90% strongly agreed or agreed that they were comfortable wearing the HMD. Most of the participants indicated that they were able to distinguish between good and bad signage in the virtual work zone—65% strongly agreeing and 35% agreeing.

When asked whether the VR immersive module was challenging, about 50% said they did not find it challenging, 32% found it neither challenging nor not-challenging, and 18% found it to be challenging. Ninety-four percent of participants said they did not feel nauseated while using the VR headset. Overall, 97% of participants either strongly agreed or agreed that the VR module was useful for training staff that inspects work zones.

Conclusion

In this paper, we presented the first documented use of VR for training work zone inspection staff at state DOTs. VR technology has been used for training in other fields and shown to be effective. This study developed an immersive training platform using VR and illustrated it using MoDOT data. Most of the DOT staff that participated in the focus group agreed that the use of VR enhanced the quality of training for work zone inspectors. All participants agreed that the VR module provided a realistic representation of an actual work zone. Most of the participants indicated that they were able to distinguish between good and bad work zone signage. Overall, 97% of the participants either strongly agreed or agreed that VR was useful for training staff that inspect work zones. Though the training modules were developed for and tested by state DOT staff, they could also be used for training work zone staff for contractors, utility agencies, and local agencies (e.g., cities, counties) that regularly inspect work zones.

Future research could build on this successful demonstration project and expand the set of training scenarios. Of particular interest are work zone scenarios for urban and rural areas, nighttime and daytime conditions, impact of weather, flagger operations, and complex projects on different roadway types (freeway, arterial, two lane highways). In addition to creating new scenarios, the fidelity of the virtual scenarios could also be improved for increased realism, and interactive features added to make it easier for trainees to rate the temporary traffic control elements while in the virtual world. Although cost considerations were not examined in this project, a study on the tradeoff between VR scenario quality and headset costs could help DOTs choose a suitable technology for their needs and constraints.

Author Contributions

The authors confirm their contribution to the paper as follows: study conception and design: KA, DC, PE, CS; data collection: KA, DC, PE; analysis and interpretation of results: KA, DC, PE, CS; draft manuscript preparation: KA, DC, PE, CS. All authors reviewed and approved the final version of the manuscript.

Declaration of Conflicting Interests

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