iTrain – Immersive Training of Department of Transportation Work Zone Inspectors using Virtual Reality

August 2024
Final Report

Project number TR202118
MoDOT Research Report number cmr 24-013

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TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. cmr 24-013	**2. Government Accession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle iTrain – Immersive Training of Department of Transportation Work Zone Inspectors using Virtual Reality		**5. Report Date** July 2024 Published: August 2024 **6. Performing Organization Code**
7. Author(s) Praveen Edara, https://orcid.org/0000-0003-2707-642X Zhu Qing, https://orcid.org/0000-0002-3219-6971 Carlos Sun, https://orcid.org/0000-0002-8857-9648 Henry Brown, https://orcid.org/0000-0003-1473-901X Bimal Balakrishnan, https://orcid.org/0000-0002-0994-0213		**8. Performing Organization Report No.**
9. Performing Organization Name and Address Department of Civil and Environmental Engineering University of Missouri-Columbia E2509 Lafferre Hall Columbia, MO 65201		**10. Work Unit No.** **11. Contract or Grant No.** MoDOT project # TR202118
12. Sponsoring Agency Name and Address Missouri Department of Transportation (SPR-B) Construction and Materials Division P.O. Box 270 Jefferson City, MO 65102		**13. Type of Report and Period Covered** Final Report (August 2021-July 2024) **14. Sponsoring Agency Code**

15. Supplementary Notes

Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration. MoDOT research reports are available in the Innovation Library at https://www.modot.org/research-publications.

16. Abstract

This report presents the development, implementation, and evaluation of Virtual Reality (VR) training modules designed to enhance work zone safety training for the Missouri Department of Transportation (MoDOT) staff. The project aimed to provide immersive, realistic, and interactive training environments that improve knowledge retention, engagement, and practical skills application. The developed VR training modules were integrated into MoDOT's Advanced Work Zone Training and Flagger Training courses. For Advanced Work Zone Training, the modules focused on understanding typical applications and identifying deficiencies within work zones. For Flagger Training, the module emphasized hands-on practice of the 3-2-1 Cone Procedures. Both training programs incorporated measures of participants' actions and post-training surveys. Feedback from the surveys indicated high levels of training effectiveness and participant satisfaction of the realistic work zone representations and ease of VR use. Behavioral performance measures, not feasible with traditional training methods, showed that participants effectively performed flagger operations and identified work zone deficiencies. Outreach efforts and hands-on demonstrations in other states further validated the positive reception of the VR training modules, highlighting their potential for broader adoption across other DOTs and agencies. The feedback collected was used to further refine the VR training program. In summary, the VR training modules enhance work zone safety training, offering a more immersive, interactive, and effective learning experience to supplement existing training.

17. Key Words Virtual reality, Work zone safety, Inspector, Flagger, Training	**18. Distribution Statement** No restrictions. This document is available through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report) Unclassified.	**20. Security Classif. (of this page)** Unclassified.	**21. No. of Pages** 66	**22. Price**

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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Prepared for
Missouri Department of Transportation

July 2024

Final Report

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Acknowledgments

The authors would like to thank the FHWA Accelerated Market Readiness (AMR) Program and MoDOT for sponsoring this research. Special thanks are extended to Jeffrey Zaharewicz and Jawad Paracha of FHWA, Jen Harper of MoDOT, and the Technical Advisory Committee Members Chris Engelbrecht, Dan Smith, Ray Shank, and Randy Morris for their guidance. Additionally, the authors appreciate the contributions of MoDOT training instructors Scott Campbell, Zach Koenig, Joe Moore, Greg Bolon, and Jeremy Jackson. Graduate research assistants Dae Yeol Chang, Eddie Kang, and Ho Jun Baek also deserve recognition for their assistance with data collection and analysis.

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List of Abbreviations and Acronyms

DOT	Department of Transportation
EPG	Engineering Policy Guide
FHWA	Federal Highway Administration
MoDOT	Missouri Department of Transportation
MUTCD	Manual on Uniform Traffic Control Devices
SHS	Standard Highway Signs
SUS	System Usability Scale
TA	Typical Application
TMA	Truck-Mounted Attenuator
UI	User Interface
VR	Virtual Reality

Abstract

This report presents the development, implementation, and evaluation of Virtual Reality (VR) training modules designed to enhance work zone safety training for the Missouri Department of Transportation (MoDOT) staff. The project aimed to provide immersive, realistic, and interactive training environments that improve knowledge retention, engagement, and practical skills application. The developed VR training modules were integrated into MoDOT's Advanced Work Zone Training and Flagger Training courses. For Advanced Work Zone Training, the modules focused on understanding typical applications and identifying deficiencies within work zones. For Flagger Training, the module emphasized hands-on practice of the 3-2-1 Cone Procedures. Both training programs incorporated measures of participants' actions and post-training surveys. Feedback from the surveys indicated high levels of training effectiveness and participant satisfaction of the realistic work zone representations and ease of VR use. Behavioral performance measures, not feasible with traditional training methods, showed that participants effectively performed flagger operations and identified work zone deficiencies. Outreach efforts and hands-on demonstrations in other states further validated the positive reception of the VR training modules, highlighting their potential for broader adoption across other DOTs and agencies. The feedback collected was used to further refine the VR training program. In summary, the VR training modules enhance work zone safety training, offering a more immersive, interactive, and effective learning experience to supplement existing training.

Executive Summary

The iTrain project, in collaboration with the Missouri Department of Transportation (MoDOT), aimed to enhance work zone safety training of MoDOT staff through the development and implementation of Virtual Reality (VR) training modules. These modules were designed to provide immersive, realistic, and interactive scenarios to enhance knowledge retention, engagement, and practical skills application in work zone training courses.

The development process of immersive training scenarios is outlined in the report and includes the following steps: texture creation, 3D-model development, interaction programming, and user interface design. VR modules were developed targeting two MoDOT work zone training courses: Advanced Work Zone Training and Flagger Training.

In the Advanced Work Zone Training course, two VR modules were developed. The first VR module focused on learning work zone typical applications by providing participants with an immersive drive through VR experience. The second VR module concentrated on helping participants practice identifying deficiencies within work zones through various scenarios. A comparison test, a call-out practice, and a post-training survey were incorporated to gather information on participant learning, perceived realism, and overall effectiveness. The results from 147 participants from six separate trainings showed that 86.8% of participants agreed that the VR module was realistic and 85.1% agreed that VR is useful for training staff.

In the Flagger Training course (Figure E.1), the VR module emphasized hands-on practice of the 3-2-1 Cone Procedures. Participants' ability to perform flagging operations was tracked and evaluated using developed behavioral measures. Additionally, a post-training survey was conducted to obtain feedback on VR module usability, user engagement level, and training effectiveness. The industry standard system usability scale (SUS) score of 78.4 demonstrated that the usability of the VR flagger module was Grade B, indicating good usability (A $\geqq$ 80.8, B $\geqq$ 74.1, C $\geqq$ 65.0, D $\geqq$ 51.7, and F $<$ 51.7). Minor improvements could be made to further improve its usability.

Figure E.1. VR flagging training scenario and participant.

Post-training surveys indicated high satisfaction levels, with participants appreciating the realistic work zone representations, ease of use, and overall effectiveness of the VR modules. Behavioral measures demonstrated participants' ability to effectively identify deficiencies and perform flagging operations, capabilities not feasible with traditional training methods. Hands-on demonstrations and outreach activities confirmed the positive reception of the VR training modules and highlighted their potential for broader adoption across other DOTs and agencies. Nine outreach events were conducted as part of national and regional conferences and workshops, including Washington, D.C., Illinois, Indiana, North Dakota, and Iowa. The survey results showed that 95.8% agreed that VR was realistic, 94.4% agreed that VR was easy to use, 98.6% agreed that VR was effective, and 86.1% expressed a desire to include VR in future training at their agency.

In summary, the VR training modules developed through the iTrain project have proven to be effective tools for enhancing work zone safety training. The integration of advanced VR technology offers a promising approach to supplementing traditional methods and providing a more immersive, interactive, and effective training experience. The developed VR modules are intended for continued use in MoDOT training. The flexibility of VR training allows it to meet a variety of needs, staff backgrounds, and makes it suitable for different training purposes. Future efforts will focus on expanding VR scenarios, incorporating feedback for future development, and exploring new applications of VR technology in transportation safety training.

1. Introduction

Work zone safety continues to be a high priority area for state transportation agencies. The Federal Highway Administration (FHWA) reports that a crash occurs in a work zone approximately every five minutes. In 2021, 42,000 injury crashes occurred in work zones across the US resulting in 29,000 injuries and 956 fatalities (National Work Zone Safety Information Clearinghouse, 2024). State departments of transportation (DOTs) use various technologies and countermeasures to reduce crashes occurring in work zones. Improved work zone inspection practices and personnel training play key roles in ensuring safety for drivers and workers and reducing agency risk.

The Work Zone Safety and Mobility Rule (23 CFR § 630 Subpart J) established requirements and offers guidance to state transportation agencies for addressing the traffic safety and mobility impacts of work zones. As per § 630.1008(d), "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." Work zone training has not taken advantage of new technologies that could improve training effectiveness, immersion, cost, availability, and flexibility. Outdated training practices are not sufficiently engaging for the future generation workforce consisting of Millennials and Z generations.

State 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 recorded. A rating value is assigned for each factor based on discrepancies and deficiencies. The inspection team, typically consisting of 4 to 5 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 the Manual on Uniform Traffic Control Devices (MUTCD) 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 in order to satisfactorily review and rate them. The 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 documents related to temporary traffic control and reports from previous inspections, which are typically presented as PowerPoint files with pictures. To provide a realistic training experience that matches the effectiveness of field visits, while reducing the time and effort needed to visit multiple sites, a new training platform using virtual reality (VR) with varied training scenarios was developed. This training platform can be used to train DOT staff that setup, remove, and inspect work zones.

2. Literature Review

VR-based training has gained popularity across all areas of transportation, from aviation to the transit sectors. Due to the typically high expense and safety requirements associated with airline pilot training, VR-based training has been widely used and accepted by the aviation industry (Kearns, 2009). Fussell and Hight (2021) investigated whether a VR flight program could offer a low-cost, highly realistic training alternative for pilot training. The VR flight training programs aimed to develop and assess student pilots' flight skills. A usability test was conducted with 14 student pilots. All users reported positive experiences with the VR pilot training course. Oh (2020) conducted a similar empirical evaluation with ten users (five student pilots and five pilot instructors) to investigate how aircraft pilots perceived simulated flights in the VR environment compared to conventional mockup-based simulators. The results showed that the VR simulator was on par with or superior to the conventional simulators in terms of pilot perceptions of training effectiveness.

In the transit sector, VR technology has been used to help train both bus and train drivers. Burke and Sanders (2017) designed a prototype VR training program with two scenarios aimed at assisting train drivers to familiarize themselves with a new fleet and to practice braking techniques. The prototype program was demonstrated to over 800 individuals at a conference. The integration of theory and practice within the VR environment was expected to result in a 70% reduction in classroom theory time. Gardiner (2018) developed a similar VR train simulator with training scenarios for testing new railway signaling systems and rail lines. Aurecon provided a VR training program for all transit drivers of Red Bus in New Zealand during the construction of a new transit station (Dorn and Barker, 2005). The objective of the Aurecon study was to familiarize drivers with the new station design and to offer them a safer and smoother transition. The training scenario provided a realistic digital representation of the new station and roads. The results showed that Red Bus drivers showed interest in the VR training program and were able to complete it easily and quickly. All the aforementioned VR training programs are centered on evaluating the usability of VR technology for training using self-reported outcome measures.

Regarding VR applications for highway work zone personnel, Kim et al. (2011) designed a VR training system to analyze workers' risk habituation tendencies. The results of a 32-participant experiment showed that VR safety training could evoke habituation in workers and provide behavior interventions to reduce their risk habituation in work zones. Ergan et al. (2020; 2022) designed an integrated platform connecting sensors, traffic simulations, and VR environments to investigate the alert delivery mechanisms to work zone workers. Other studies (Kim, Anderson, and Ahn 2021; Ergan et al. 2020; 2022) explored trainees' behavior with the aim of laying the groundwork for future research on behavioral interventions and wearable technologies, rather than focusing on the evaluation of training outcomes or providing feedback to trainees. Aati et al. (2020) and Chang et al. (2020) developed a VR training program for MoDOT staff to inspect work zones for compliance. The program evaluations included a test exercise to call out any deficiencies and a survey to gather qualitative feedback on VR technology. A total of 34 MoDOT staff participated in the VR training program, with the vast majority agreeing that the program offered a realistic and effective way to train inspectors. The study provided trainees' performance measures derived from the VR training program, but it was constrained by limited visual interactions, and no behavioral data were collected and analyzed.

While all the above VR-based applications were designed for single participant training, there have been VR-based programs developed as multi-user platforms for training and safety research. For example, Saeidi et al. (2019) developed a shared VR platform to study safety in construction work zones. They developed two scenarios involving interactions between a flagger and a driver, aiming to assess potential corrections between the VR experience and multi-user involvement. Although the results showed the relationship was not statistically significant, the authors suggest that augmenting interaction levels among participants could significantly enhance their VR experience and co-presence. Additionally, Roofigari-Esfahan et al. (2022) utilized a 360-degree projection system named Cyclorama to develop an immersive VR training platform for groups of highway construction workers and instructors. The cube system was evaluated by a construction safety instructor and showed its potential to enhance participants' learning experience by providing customized scenarios.

In summary, most VR applications in transportation were conducted as pilot studies or proof-of-concept investigations. None of these applications have been incorporated into existing safety courses for participants. Prior research also focused primarily on subjective feedback from participants to improve the VR training. Limited consideration has been given to leveraging participants' interactions within the VR environment to enhance learning outcomes. In this project, interactive VR training modules were developed and evaluated in work zone training courses for the purpose of achieving this outcome.

3. Methodology

This chapter is organized into three sections, each outlining methodology used for: (1) immersive scenario development, (2) course-based VR module development, and (3) evaluation measurement.

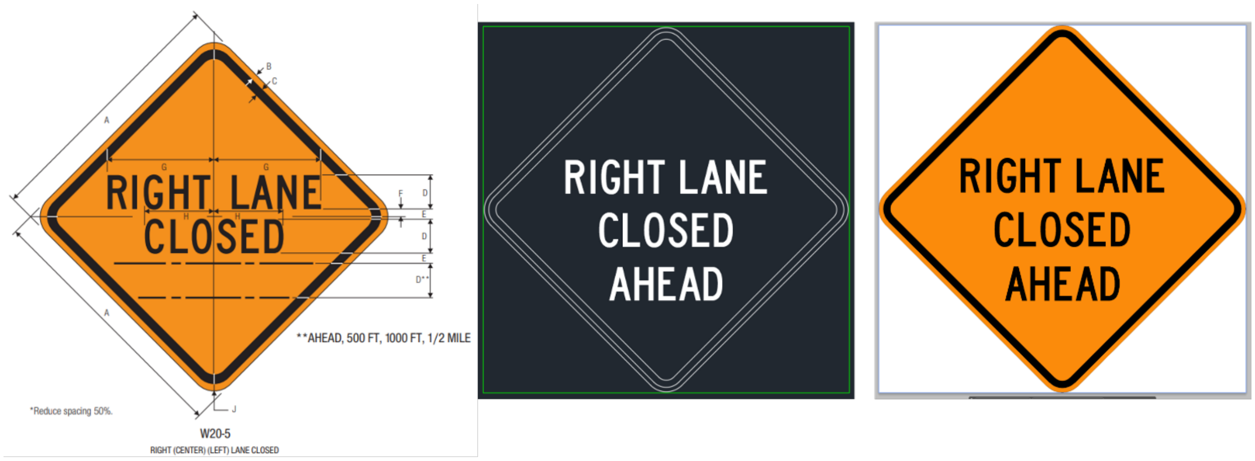
3.1 Immersive Scenario Development

Immersive scenarios can be created through different approaches or software. In this project, various tools and techniques were used to develop immersive scenarios specifically for work zone training. This section outlines the process of texture creation, 3D-model development, interaction programming, user interface (UI) development and details the necessary steps to ensure the efficiency and compatibility of VR immersive scenarios.

3.1.1 Texture Creation

The textures used in 3D modeling were collected through two approaches. First, actual photos taken from work zones and images extracted from work zone videos were used to create realistic textures. These sources provided authentic and detailed visual data that accurately represented the work zones. Second, fine textures were manually created by the research team using AutoCAD and Adobe Photoshop. These manually prepared textures strictly followed the standards and were designed to be seamless and suitable for high-quality 3D models.

For example, as shown in Figure 3.1, the work zone sign of RIGHT LANE CLOSED AHEAD was created by following the guidelines of Standard Highway Signs (SHS) (FHWA, 2012). First, the traffic signs are accurately drawn in AutoCAD with all fonts, sizes, and spacing designed according to SHS standards. The precise CAD layers were then exported to Photoshop, where they were colored, and various quality textures were generated. A lower-resolution 128×128-pixel image was created for low-end VR headsets or slow-motion scenarios, while a higher-resolution 2048×2048-pixel texture was used for high-end VR headsets or fast-motion scenarios. This process ensures that the visual fidelity of the signs meets the performance requirements of different VR headset configurations, thus providing an optimal experience for the device used.



(1) Standard Highway Signs (2) AutoCAD Drawing (3) Photoshop Drawing

Figure 3.1. Texture creation example - Right Lane Closed Ahead.

3.1.2 3D-Model Development

Based on the complexity of the object, two different software tools, SketchUp and Blender, were used for 3D modeling. SketchUp is a popular 3D modeling software due to its ease of use and flexibility while Blender is a free and open-source 3D computer graphic software offering a comprehensive suite of tools for modeling, rigging, animation, and rendering. Simple objects, such as traffic and road signs, were created using SketchUp. SketchUp's intuitive and straightforward interface made it ideal for quickly developing these basic models. On the other hand, more detailed and complex models were created using Blender. For example, the Truck-Mounted Attenuator (TMA) and its host trucks were modeled using Blender based on the TMA manual specifications (Figure 3.2). By using both SketchUp and Blender, a wide range of 3D models was efficiently developed to meet the requirements of varied training courses.

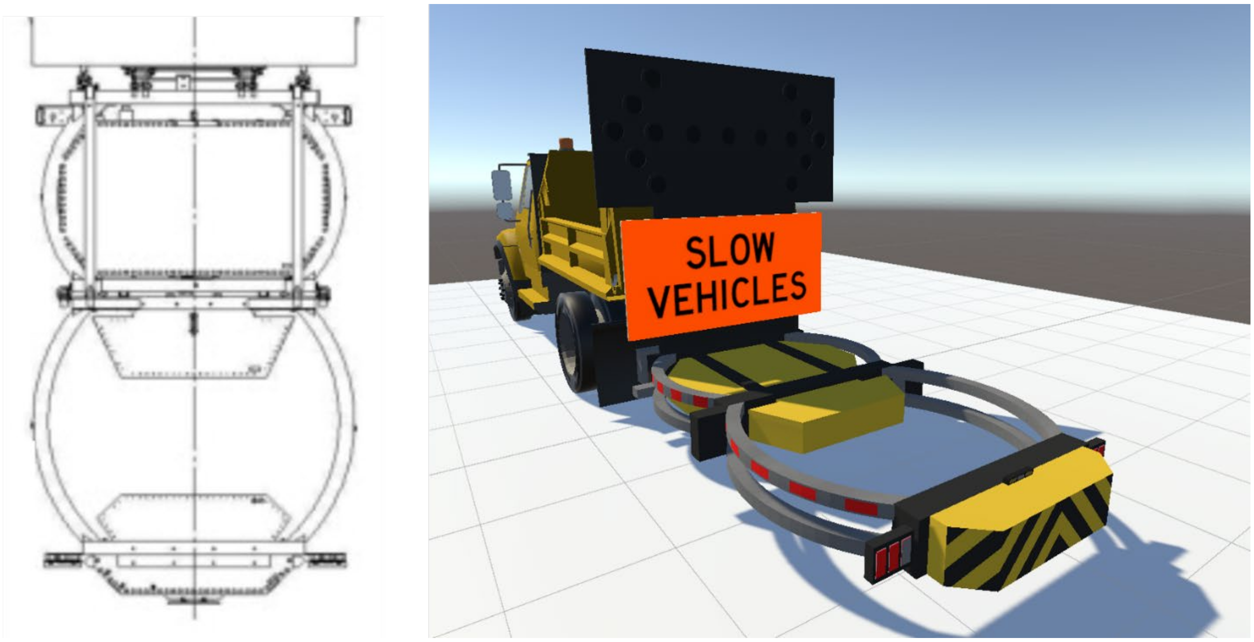


Figure 3.2. 3D model of a TMA created according to manual specifications.

3.1.3 Interaction Programming

After the 3D models were prepared, they were imported into Unity, a versatile development platform that provides tools for creating 3D simulations and VR interactive experiences (Jerald et al., 2014). An interactive environment plays a vital role in creating an effective VR training module, because it allows users to actively engage and perform activities in the virtual world (LaViola Jr. et al., 2017). Once the models were imported, Unity's scripting tools were used to program the interactions and behaviors necessary for the training scenarios. This involved adding logic, setting up triggers, and creating dynamic elements that may respond to user inputs.

Some of the models, such as traffic lights, arrow boards, and changeable message systems, were programmed without responding to user inputs. As shown in Figure 3.3, traffic lights at an intersection were programmed to change colors at predetermined intervals to simulate real-world traffic control scenarios. This was achieved by scripting in the C# programing language and implementing it onto the traffic lights models in Unity. These programmed objects serve as the foundation for the training scenarios.

```
private IEnumerator TrafficLightSequence()
{
    while (true)
    {
        // Red light
        redLight.SetActive(true);
        yellowLight.SetActive(false);
        greenLight.SetActive(false);
        yield return new WaitForSeconds(20);

        // Green light
        redLight.SetActive(false);
        yellowLight.SetActive(false);
        greenLight.SetActive(true);
        yield return new WaitForSeconds(18);

        // Yellow light
        redLight.SetActive(false);
        yellowLight.SetActive(true);
        greenLight.SetActive(false);
        yield return new WaitForSeconds(2);
    }
}
```

Figure 3.3. Programmed traffic lights at an intersection using scripting.

Other objects were programmed to respond to user inputs. An example is the interaction system for flaggers to navigate and interact with the STOP/SLOW paddle and traffic cones in the work zone. The input devices of the interaction system were a full HTC Vive Pro 2 kit, including a headset, a pair of controllers, and two base stations. Through the VR kit, participants' upper body movements, including head and hand movements, can be tracked. The overview of the interaction system is shown in Figure 3.4. Participants can perform the following activities using the pair of controllers: 1) turn the STOP/SLOW paddle by clicking the trigger on the right-hand controller; 2) teleport to the specific location by holding and releasing the touchpad on either controller; 3) pick up and move a traffic cone by holding and releasing the trigger on the left-hand controller. This allowed participants to explore the virtual work zone by looking, walking, and using hand movements, such as extending their arms and raising or lowering their hands to signal to the traffic. The teleportation feature is critical for navigating the virtual work zone since available physical space in training rooms is often limited. The interaction system was first presented to 13 MoDOT training instructors and staff as a pilot program in December 2022 and revised based on their feedback.

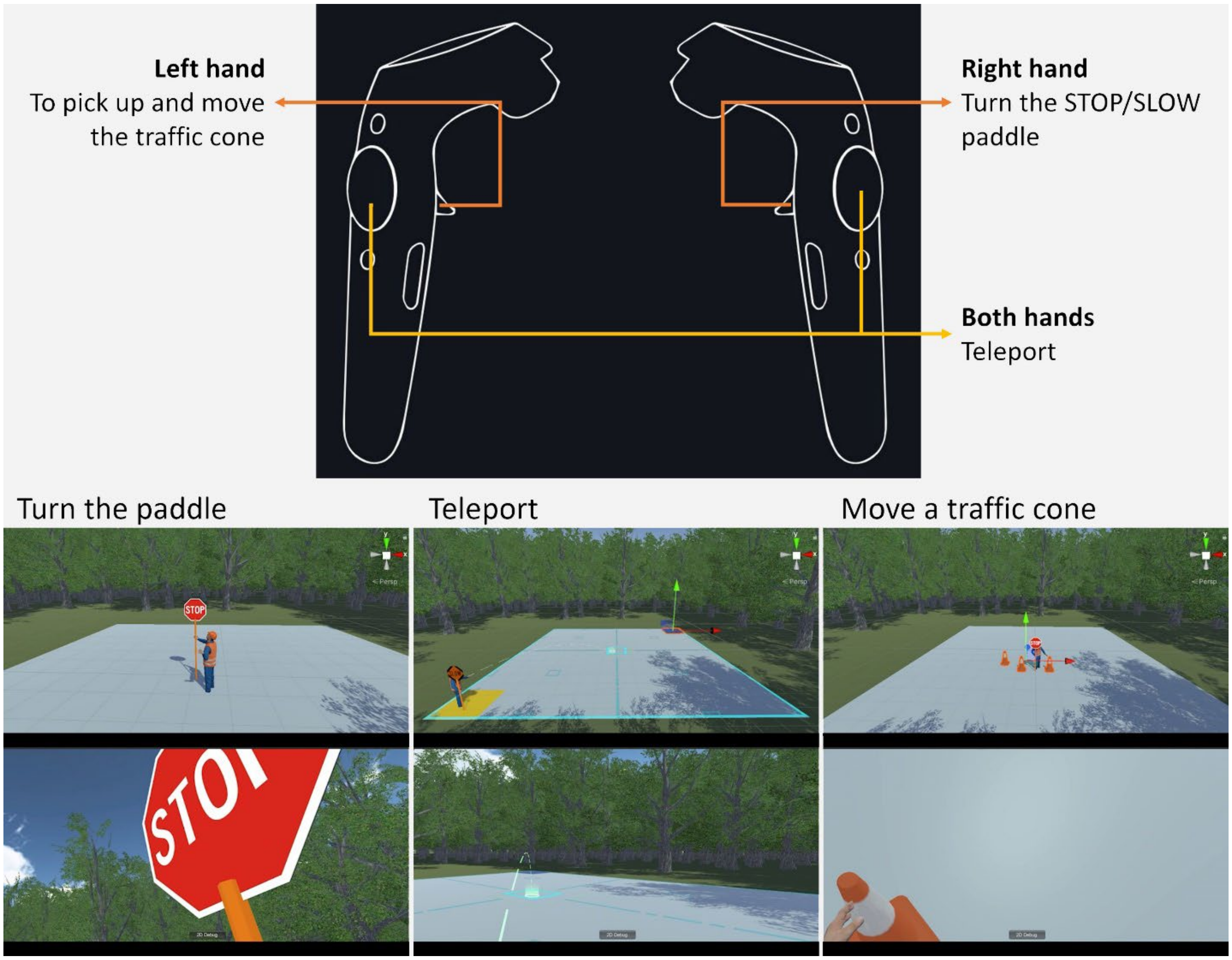


Figure 3.4. Flagger VR interaction system.

3.1.4 User Interface

In addition to the VR training scenarios, a UI system was developed and incorporated into the program based on feedback from the training sessions. The UI system was designed to enable instructors to run the VR training module independently without requiring extensive technical support. It also allowed for personalized settings for participants, making them more comfortable using the VR system.

As shown in Figure 3.5, the UI system provides the buttons for instructors to select the VR training scenarios based on the type of facilities and location of the work zone. The UI replaced the manual code command and made the start of VR module more intuitive and user friendly.

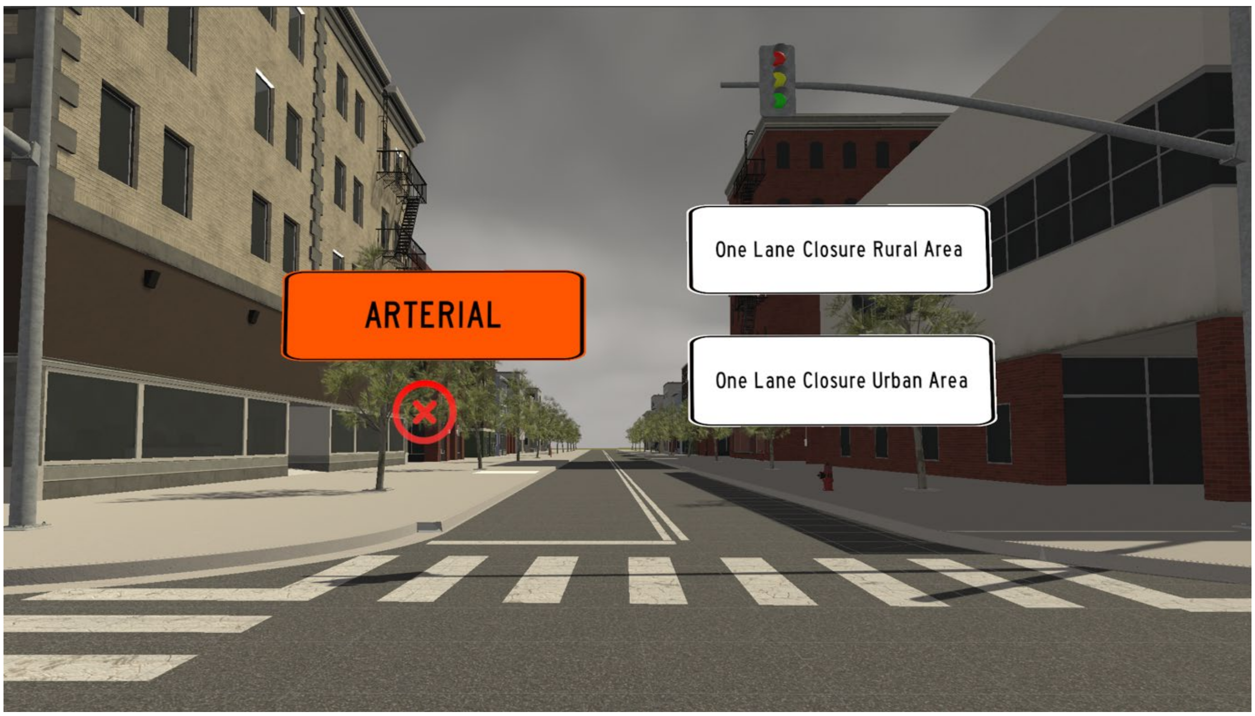


Figure 3.5. User Interface system for selecting VR training scenario.

A comprehensive UI system was developed for participants as shown in Figure 3.6. This UI design allows them to read detailed instructions for the training tasks, manage their training progress, and adjust the vehicle speed when driving through the virtual work zone. The UI system aims to enhance participant engagement and effectiveness by providing a user-friendly interface that supports various training aspects, making the VR experience more intuitive and productive.

Figure 3.6. User Interface system for participants in drive through scenarios

By leveraging Unity's powerful features, realistic and engaging scenarios were created to provide effective training experiences for work zone safety. This integration of 3D models and interaction programming was crucial in achieving a high level of immersion and interactivity in the training scenarios.

3.2 Course-Based VR Module Development

3.2.1 Course Description

The VR training modules were developed to integrate with existing training courses offered by MoDOT, aiming to enhance the effectiveness and experience of the training rather than serving as stand-alone courses. After collaborating with MoDOT training instructors, two training courses, Advanced Work Zone Training (Course Code: 24509) and Flagging Training with 3-2-1 Cone Procedures (Course Code: 92021), were selected for VR integration.

Advanced Work Zone Training

MoDOT Advanced Work Zone Training is a two-day course that covers applicable standards, guidelines, interpreting plans, specifications, coordinating temporary traffic control requirements, meeting the requirements of the contract or field operation guidelines, and supervising traffic control personnel.

The training primarily uses lectures and group discussions. Instructors cover an 80-page training manual and organize group activities to design work zones. A closed-book exam is administered at the end of the training. Participants who score above 80% will be certified as a “Work Zone Specialist” and will need to recertify every four years.

Flagger Training with 3-2-1 Cone Procedures

MoDOT Flagger Training with 3-2-1 Cone Procedures is a half-day training course offered to MoDOT staff who may be assigned flagging duties. Its content is also covered in other courses, such as Gear-Up training for new MoDOT employees. The inclusion of flagging training was primarily based on suggestions from MoDOT trainers, as flagging operations are part of the work zone inspection process and flaggers are at risk of injury. Providing hands-on flagger training will allow flaggers to experience proper flagging practices in a safe environment, helping to prevent injuries. The VR module aims to create a realistic and immersive training environment where participants can learn and practice the 3-2-1 Cone Procedures safely.

The course covers topics such as appropriate equipment usage, hazard identification, effective communication and coordination among workers, and the correct utilization of personal protective equipment. Training methods include lectures and group discussions. Instructors cover a 104-page training manual, organize group discussions, and demonstrate the use of flagging equipment. A closed-book exam is administered at the end of the training. Participants who pass the exam and an on-the-job skills review will be certified as approved flaggers for four years. While this existing training course familiarizes workers with safety procedures, instructors acknowledged that improving situational awareness, hazard recognition, and communication skills can be challenging in a traditional training setting.

3.2.2 Course Integration

To ensure the immersive scenarios were not only realistic but also aligned with the training courses and objectives, the VR scenarios were developed based on the training curriculum and input from training instructors. A crucial aspect of this process was adhering to the MUTCD standards. As a core material included in both training courses, the MUTCD provides standardized guidelines for temporary traffic control and TAs, ensuring consistency and safety across various situations. By following these guidelines, the VR scenarios were able to accurately represent common work zone setups and traffic management strategies.

Advanced Work Zone Training

For the Advanced Work Zone Training course, a total of ten immersive scenarios were developed. As shown in Table 3-1, the VR training scenarios cover a range of work zone conditions including different work zone locations, times, and classifications. The TA for each scenario is provided in Appendix A, and the developed immersive scenarios can be accessed on the YouTube VR channel: www.youtube.com/@muitrain.

Table 3-1. Immersive scenarios developed for Advanced Work Zone Training.

#	Facility Type	Classification	Urban	Rural	Daytime	Nighttime	TA
S1	Freeway	One lane closed	✓		✓		TA-33
S2	Freeway	One lane closed	✓			✓	TA-33
S3	Freeway	Two lanes closed	✓		✓		TA-37
S4	Freeway	Two lanes closed	✓			✓	TA-37
S5	Freeway	Head-to-head		✓	✓		TA-31
S6	Arterial	One lane closed	✓		✓		TA-23
S7	Two lane highway	Flagging operation		✓	✓		TA-10
S8	Complex interchange	Diverging diamond interchange	✓		✓		Construction plan
S9	Mobile	One lane closure	✓		✓		TA-35
S10	Mobile	One lane closure		✓	✓		TA-35

The Advanced Work Zone Training not only aims to demonstrate the correct setup of work zones, but also requires participants to identify deficiencies from the field work and make necessary changes. Therefore, several different types of deficiencies were introduced into the VR scenarios development. These deficiencies include, but are not limited to, damaged/misused signs, malfunctional traffic control devices (e.g., arrow boards, changeable message signs, and traffic lights), incorrect spacing or locations of traffic control devices, and work zone personnel behaviors with safety risks. The ability to identify these deficiencies can be used to evaluate participants' knowledge retention and effectiveness of the work zone training.

The VR-integrated training course framework is shown in Figure 3.7. In addition to the current training content, two VR training modules (VR Modules 1 and 2) were incorporated into the two-day training, and one post-training survey was conducted.

The first VR module was designed to evaluate the impact of the VR training on learning a work zone TA. The entire class was divided into two groups. Both groups were asked to review a TA for five minutes, but one group then drove through the TA in its immersive VR scenario and completed a closed-book test. The other group proceeded directly to the closed-book test, followed by the post-test VR scenario to experience the VR training. VR module 1 was designed to enhance participants' understandings and reinforce their retention through the VR experience.

The second VR module was used to test participants' ability to identify deficiencies in work zones. Participants were asked to put on the VR headset to inspect a VR work zone. During the drive through scenario, participants needed to call out any deficiencies they noticed during the virtual drive through.

After the two VR modules, a post-training survey was conducted to gather participants demographic information and feedback on the VR training module.

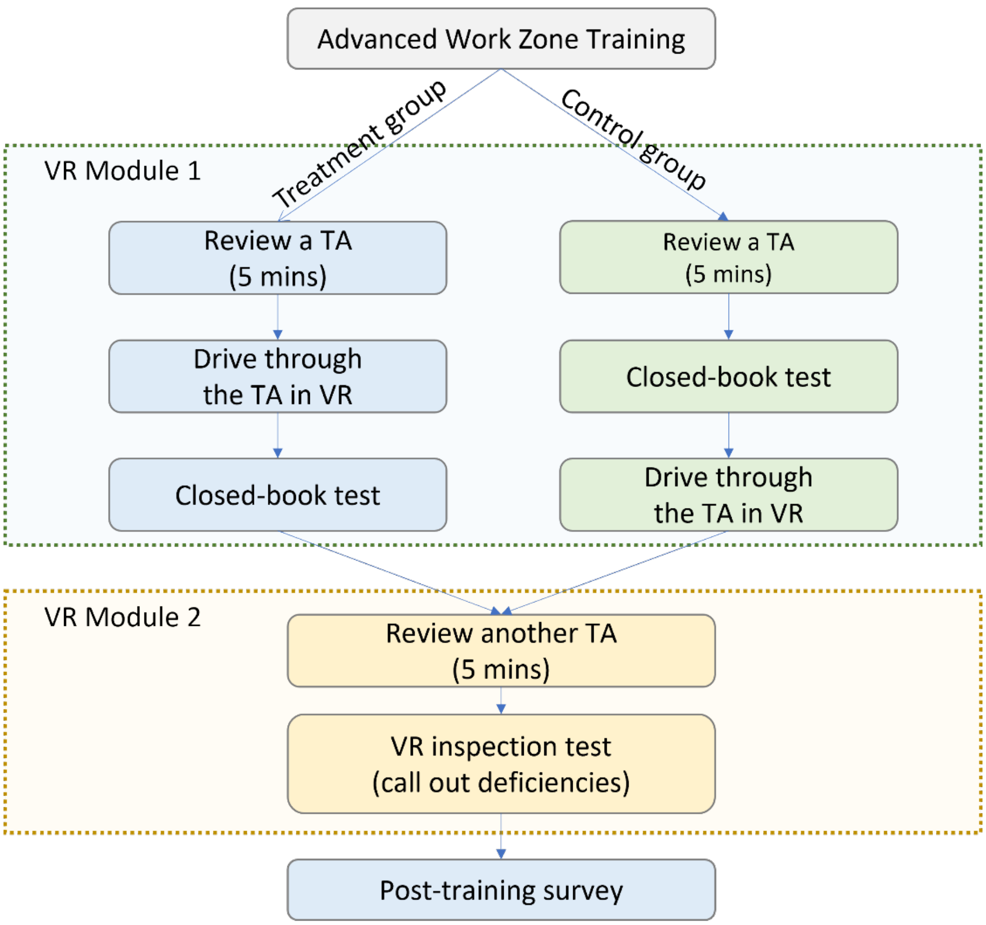


Figure 3.7. Framework of VR-integrated Advanced Work Zone Training.

Flagger Training with 3-2-1 Cone Procedures

After consulting with Flagger Training instructors, a TA-10 Lane Closure on a Two-Lane Road Using Flaggers (from the MoDOT Engineering Policy Guide) was considered as the most suitable training scenario due to its frequent usage across the state. As shown in Figure 3.8, the environment was designed as a rural short-term, one-way two-lane road work zone with a speed limit of 55 mph, where the distance between each of the signs, labeled A, B, and C, is 500 feet. To simulate real-world conditions with randomly arriving traffic, approaching traffic can be automatically generated or manually assigned by the instructor for each training session. There is a pair of flaggers, one at each end of the work zone. Participants were not able to see the other virtual flagger due to the long physical length of the work zone and the presence of protective and work vehicles.

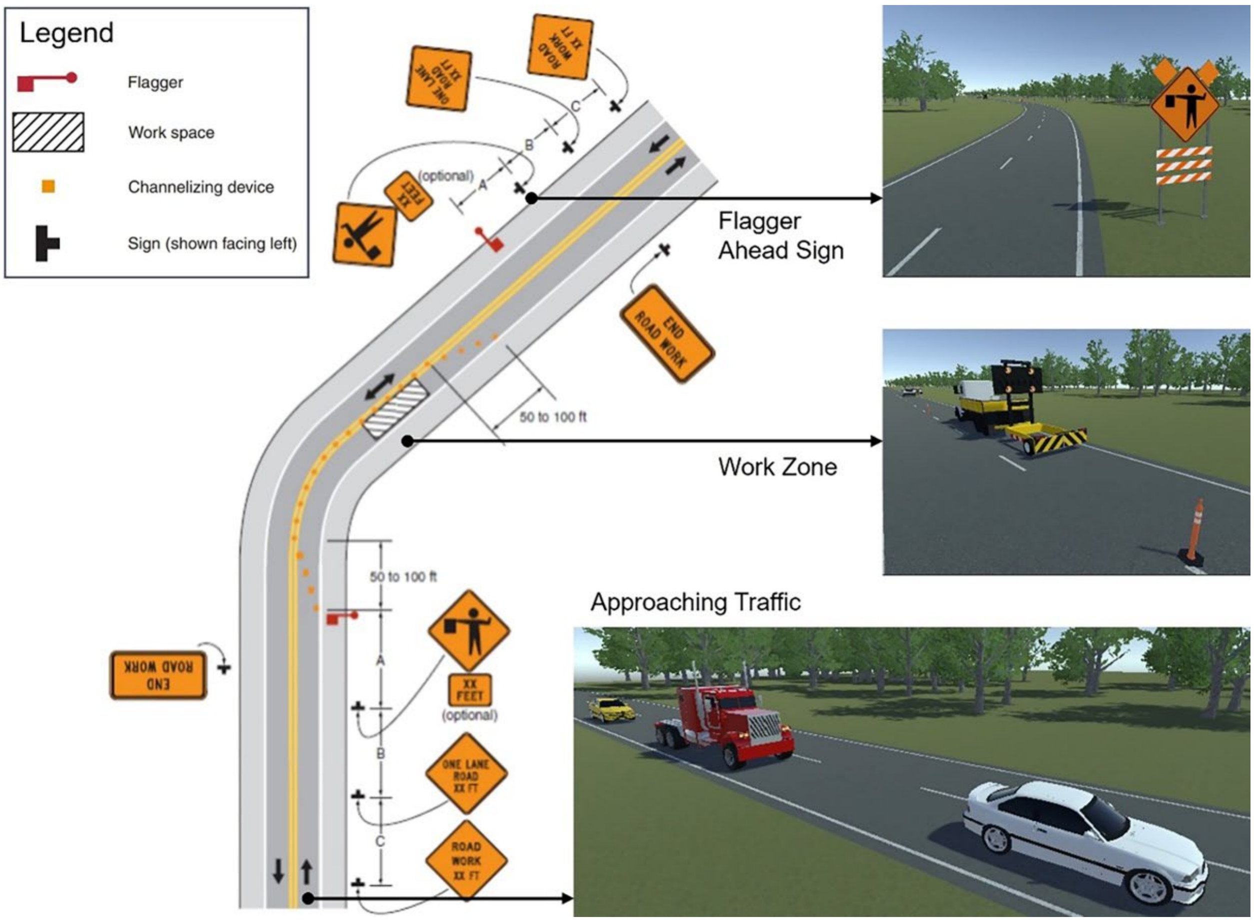


Figure 3.8. Training scenario for Flagger Training.

The framework of Flagger Training is shown in Figure 3.9. The VR training module began with a 5-minute warm up session after providing VR instructions. The VR user instructions (Appendix B) and warm up session were designed to help participants become familiar with the interaction features of turning the paddle, teleportation, and moving traffic cones. Then, participants would follow the audio instructions to perform the tasks of checking the flagger station, stopping/releasing the traffic, and communicating with the other virtual flagger. After practicing flagging skills in the VR module, a post-training survey was conducted to collect feedback on the VR module.

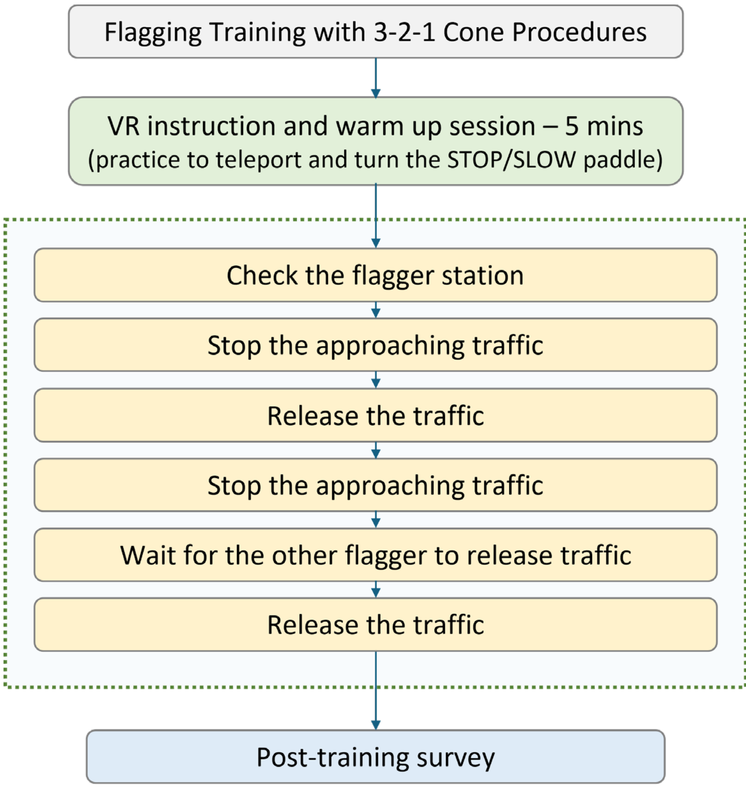


Figure 3.9. Framework of VR-integrated Flagging Training with 3-2-1 Cone Procedures.

3.3 Evaluation Measurement

In order to capture feedback from participants and instructors as well as evaluate the effectiveness of the developed VR training modules, surveys were developed and conducted as a critical part of this project. Additionally, a set of participant behavioral measures were developed based on the training courses and objectives.

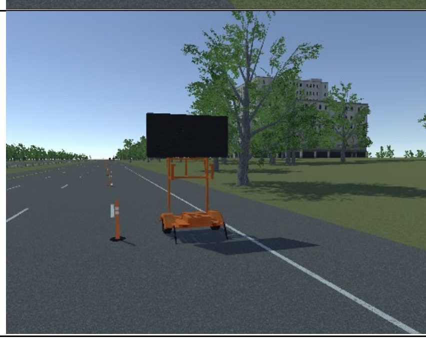
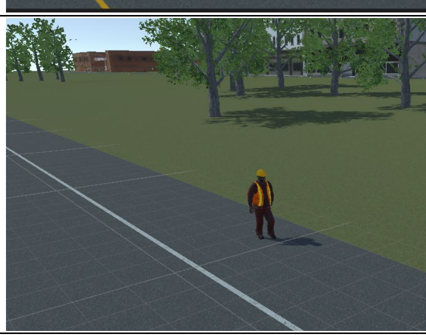
3.3.1 Measures for Advanced Work Zone VR Training

In the VR-integrated Advanced Work Zone Training, two surveys were developed: a test questionnaire for VR Module 1, and a feedback questionnaire for the post-training evaluation. Additionally, a call-out measure was developed for VR Module 2.

For the first VR module, a TA-10 Lane Closure on Two-Lane Highways Using Flaggers was selected for testing participants' learning effectiveness, with and without VR training. A corresponding five-question test was created regarding TA-10 (Appendix C). The multiple-choice questions aimed to evaluate participants' knowledge retention on five key aspects: (1) sign package, (2) sign usage, (3) location of traffic control device (i.e., the arrow board), (4) flagger behavior, and (5) traffic control device configurations (i.e., the TMA's arrow board), with and without the VR training content. This comparison between the treatment and control groups helped in evaluating how well participants retained the training content with and without the VR training experience.

For the second VR module, a TA-37 Lane Closure of an Interior Lane on Multi-Lane Highways (Figure A.5) was chosen to test participants' ability to identify deficiencies in the work zone. Participants were asked to review TA-37 for five minutes, and then required to wear the VR headset and inspect a VR work zone of TA-37. As shown in Table 3-2, a total of five deficiencies were added to the drive through scenario. Participants were asked to call out deficiencies as they noticed them during the drive through.

Table 3-2. Deficiencies included in VR module 2.

#	Deficiency	Reason
1		Damaged “ROAD WORK AHEAD” sign (CW20-10)
2		Incorrect sign – Merge Sign (W4-2) was used instead of a Missouri Merge Sign (State MUTCD sign)
3		The arrow board display lights are off
4		The TMA is too close to the active work zone
5		Unprotected worker walking outside the work zone area.

The post-training survey, as shown in Appendix D, consists of three parts: (1) participant information which includes age, job title, district office, work experience, and prior VR experience; (2) VR spatial presence questionnaires; (3) VR cognitive involvement questionnaires. This comprehensive evaluation provided valuable insights into the effectiveness of the VR training modules and highlighted opportunities for enhancing future training sessions.

3.3.2 Measures for Flagger VR Training

To provide valuable insights to instructors and to enhance the effectiveness of flagger training, a set of participant behavioral measures were developed based on the MoDOT Flagger Training materials. As shown in Table 3-3, the measures are categorized into the following four phases of the flagging operation cycle: 1) stopping the traffic, 2) after stopping the traffic, 3) releasing the traffic, and 4) after releasing the traffic. Each phase includes measures related to five categories: the STOP/SLOW paddle status, hand movements, head movements, location, and communication. A total of 25 measures were collected across the four phases and five categories by reviewing the actions of the avatar within the VR environment recorded using a screen recorder software.

Table 3-3. Behavioral measures for the VR flagger module.

	1. Stopping the traffic	**2. After stopping the traffic**	**3. Releasing the traffic**	**4. After releasing the traffic**
Example				
SLOW/STOP Paddle	• Show the STOP paddle • The STOP paddle is fully extended	• Show the STOP paddle and position it out towards the center line • Do not cross the line with the paddle	• Rotate the paddle to SLOW	• Rotate the paddle to STOP after
Hand Movement	• Left hand is up in the STOP position	• Left hand raised in STOP position until traffic has stopped	• Bring the traffic cone to the shoulder* • Motion traffic by sweeping the arm	• Bring the traffic cone to the center of the lane* • Left hand is up in the STOP position
Head Movement	• Face traffic	• Face traffic • Periodically check on the traffic coming from behind	• Look behind and confirm that all opposing traffic is cleared before releasing • Face traffic	• Face traffic
Location	• On the shoulder	• Move out towards the center of the lane after the second vehicle has stopped • Do not cross the center of the lane	• Move back to the shoulder	• On the shoulder
Communication	• Let the other flagger know you have stopped vehicles	n/a	• Let the other flagger know the characteristics of the last vehicle released and/or the number of vehicles	n/a

The post-training survey, as shown in Appendix E, consists of three parts: (1) participants' information, (2) System Usability Scale (SUS) measurements, and (3) engagement level. The participants' information section was the same as the survey for work zone inspectors. However, as the flagger VR training module is relatively new to most participants, it is important to assess its usability and gather feedback for further development and improvement of the user experience. Studies have shown that early and frequent usability tests can help reveal issues and offer room for enhancement (Kivijarvi and Parnanen, 2023; Tuli and Mantri, 2021; Karwowski, 2006). In this study, the SUS was employed to measure the usability of the VR training module. SUS is a widely used tool for evaluating the usability of new technologies and designs including VR and Augmented Reality-based educational and learning applications (Hamzah et al., 2021; Huang, Lin, and Cai, 2021; Meldrum et al., 2012). SUS is a standardized questionnaire that consists of 10 questions, each with a 5-point Likert scale ranging from strongly agree to strongly disagree. The scale is designed to be simple and convenient, making it a popular choice for usability testing among product managers, designers, and researchers (Sauro, 2011; Bangor, Kortum, and Miller, 2008).

The VR training modules provide immersive learning experiences to enhance engagement. Studies have shown that learners retain information better, apply it more effectively to real-world situations, and enjoy the learning process more (Carrion et al., 2020; Liu, 2019; Makransky, Borre-Gude, and Mayer, 2019). In order to identify areas for improvement and develop strategies to enhance learning outcomes and improve the overall learning experience, questions regarding the participants' level of engagement during the training were included in the post-training survey. The self-reported engagement survey measures cognitive, social, and emotional engagement during training courses.

4. Results

4.1 VR Training for Work Zone Inspectors

A total of 147 MoDOT staff from three districts attended the VR integrated Advanced Work Zone Training course (Table 4-1) and experienced the VR training module (Figure 4.1). Of the participants, 140 were male and 7 were female. As it was an advanced training course, the age distribution was skewed toward senior staff: 5% of the participants were in the 18-24 age group, 12% were in the 25-34 age group, 17% were in the 35-44 age group, 39% were in the 45-54 age group, 27% were in the 55-64 age group, and 1% were over 65 years old. The median age group was 45-54 years. Ninety percent of participants were Senior Maintenance Workers or Crew Leaders, while the remaining 10% were Traffic Specialists. The average work experience with MoDOT was 14.6 years.

Figure 4.1. Inspector VR training module and participants.

Table 4-1. Overview of the VR-integrated Advanced Work Zone Training sessions.

Date	MoDOT District	Number of Participants
5/18 - 5/19/2022	Central District	23
8/30 - 8/31/2022	Central District	18
9/20 - 9/21/2022	Central District	21
10/27/2022	St. Louis District	17
11/17/2022	St. Louis District	12
12/6 - 12/7/2023	NW District	56
	Total	147

The results of the first VR module are shown in Table 4-2. Of the 147 participants, 91 completed the test questionnaire after the TA-10 drive through scenario as the treatment group, and the remaining 56 participants took the test questionnaire before the VR scenario as the control group.

The average correct rate of the treatment group was 87.5%, slightly higher than the 87.1% of the control group. The treatment group performed better on Question 3, regarding the use of arrow boards, while the control group did better on Questions 1, 4, and 5, covering the sign package, flagger direction, and TA arrow board pattern. Both groups correctly answered Question 2 regarding the flagger sign. There was no statistically significant difference in performance between the treatment and control groups. This may be because all participants in the advanced course were already experienced in work zone setup and management, resulting in similarly high correct rates (87%). Consequently, the benefits of the VR training were not fully realized in the first VR module.

Table 4-2. Correct answer rate for VR Module 1.

	Question 1	Question 2	Question 3	Question 4	Question 5	Total
Treatment group	91.2% (83/91)	100% (91/91)	68.1% (62/91)	94.5% (86/91)	83.5% (76/91)	87.5%
Control group	96.4% (54/56)	100% (56/56)	57.1% (32/56)	96.4% (54/56)	85.7% (48/56)	87.1%

The results of the second VR module are presented in Table 4-3. There were 146 participants, one less than in the first VR module, due to a dropout caused by motion sickness. However, severe motion sickness was rare in the VR integrated training course, as each VR module was kept within five minutes.

The average deficiency identification rate in the second VR module is 85.5%, closely mirroring the average score of the first VR module. However, the results showed varying levels of success in identifying different deficiencies. The malfunctional arrow board was the most easily identified with a 100% rate, while the unprotected worker was the most challenging for participants, with an identification rate of 72.6%. The results were shared with instructors to provide additional teaching and address potential "expert blind spots" where experienced professionals may overlook areas that are challenging for learners.

Table 4-3. Identification rates for deficiencies in VR Module 2.

	Deficiency #1 (Damaged sign)	**Deficiency #2 (State MUTCD sign)**	**Deficiency #3 (Arrow board)**	**Deficiency #4 (TMA location)**	**Deficiency #5 (Unprotected worker)**
Number of participants that correctly identified	132	125	146	115	106
Total number of participants	146	146	146	146	146
Identification rate	90.4%	85.6%	100%	78.8%	72.6%

Although only five deficiencies were programmed into VR module 2, these deficiencies can be easily modified or added. As shown in Figure 4.2, other potential deficiencies may include, but are not limited to, an unattended flagging station and a knocked-down sign. This flexibility allows the VR training program to be tailored to specific requirements, expanding to accommodate different participants and training needs.

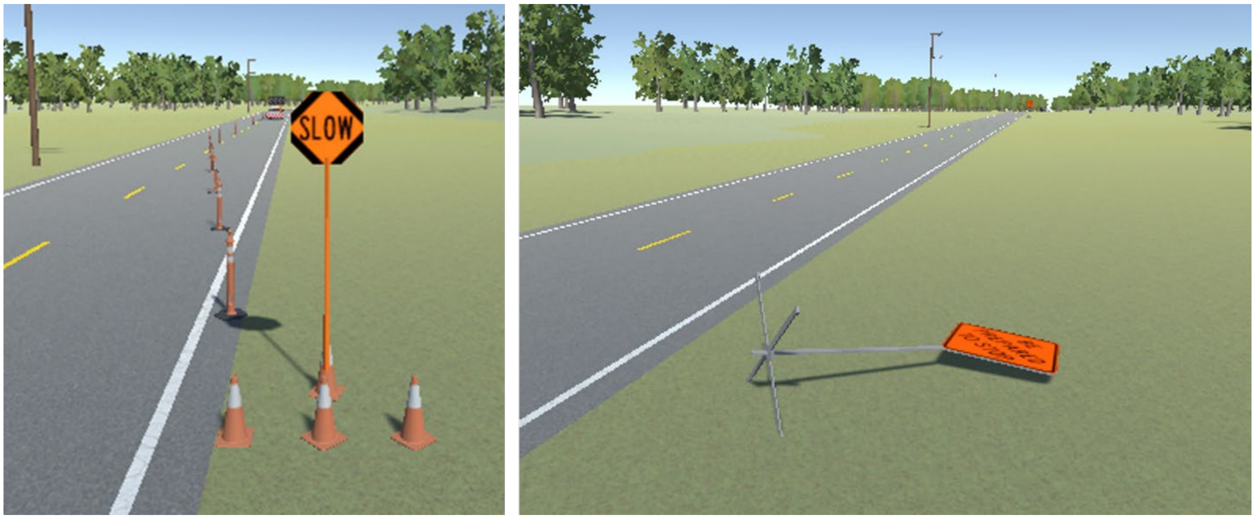


Figure 4.2. Examples of alternative deficiencies in VR Module 2.

The results of the post-training survey are shown in Table 4-4. A total of 86.8% of participants strongly agreed or agreed that the VR module provided a realistic representation of an actual work zone. Similarly, 83.5% of participants strongly agreed or agreed that they were comfortable wearing the VR headset. Additionally, 84.7% strongly agreed or agreed that they could distinguish between good and bad signage. A significant 86.9% of participants strongly agreed or agreed that there was enough time to read the work zone signage. Furthermore, 88.0% felt that they had sufficient time to notice any work zone concerns. Moreover, 83.1% strongly agreed or agreed that they could recall the related TA during the VR training. Finally, 85.1% of participants strongly agreed or agreed that the VR module is useful for training staff that inspect work zones. These results indicate a generally positive reception to the VR training module, with high levels of agreement on its realism, comfort, and effectiveness. Some participants noted areas for improvement, such as the challenge level of the module and feelings of nausea.

Table 4-4. Post-training survey results.

Question	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
1- Virtual reality provided a realistic representation of an actual work zone.	42.9%	43.9%	5.6%	5.5%	2.2%
2- Comfortable wearing the VR headset.	50.5%	33.0%	6.6%	6.6%	3.3%
3- Distinguish between good and bad signage.	35.2%	49.5%	3.3%	8.8%	3.3%
4- VR module was not challenging.	29.1%	28.6%	30.9%	5.5%	3.6%
5- Enough time to read the work zone signage.	39.6%	47.3%	6.6%	5.5%	1.1%
6- Not nauseated while using the VR headset.	52.7%	22.0%	6.6%	15.4%	3.3%
7- Sufficient time to notice any work zone concerns.	38.5%	49.5%	3.3%	6.6%	2.2%
8- Recall the related typical application during the VR training	33.6%	49.5%	10.1%	5.8%	1.1%
9- Overall, I believe that the virtual reality module is useful for training staff that inspect work zones.	48.4%	36.7%	8.3%	3.3%	3.3%

4.2 VR Training for Work Zone Flaggers

The VR training module was implemented in two Flagger Training courses organized by MoDOT held on January 12th and January 26th, 2023, in Jefferson City, Missouri for Central District staff. The first training session was attended by 13 participants who flagged in the closed lane of the work zone. A closed lane indicates that work activity is occurring in that lane, with only the adjacent lane open for traffic. As shown in Figure 4.3, the flagger in a closed lane will stand behind three cones and direct traffic into the open lane when releasing it. The second session had 15 participants training as flaggers in the open lane. A flagger in the open lane places a single cone to stop approaching traffic and removes it to allow traffic to proceed.

Figure 4.3. Flagger VR training module and participants.

Out of the 28 participants, 19 reported having no prior experience with VR. The age distribution of participants was 29% in the 25-34 age group, 18% in the 35-44 age group, 43% in the 45-54 age group, and 10% in the 55-64 age group. Their average work experience at MoDOT was 15.9 years, with an average work zone experience of 13.7 years. All 28 participants in the study were male.

The results of participant behavioral measures are shown in Table 4-5. Overall, participants were able to complete the majority of the flagging operations in accordance with safety procedures. This was expected since most of the participants were experienced and skilled staff members. All participants effectively directed the traffic using hand gestures and communicated with the virtual flagger at the other end of the work zone.

Regarding the errors, one participant did not rotate the paddle back to “STOP” in a timely fashion after releasing the traffic, and another participant’s paddle crossed the center line while his body didn’t. Head movement was generally in accordance with the safety guidance, except for one participant who did not pay sufficient attention to the approaching traffic, instead watching the traffic behind and only checking the approaching traffic twice. The location of the flagger was not fully compliant in some instances. For example, three participants stopped the approaching traffic while standing in the travel lane instead of on the shoulder. Two participants were observed staying in the lane when directing traffic to proceed through the work zone.

Additionally, two participants either moved too early to the center line after the traffic was stopped or did not move to the center line at all.

Table 4-5. Results of participant behavioral measures.

	1. Stopping the traffic	2. After the traffic is stopped	3. Releasing the traffic	4. After the traffic is released
SLOW/STOP Paddle	100% (28/28)	96.4% (27/28)	100% (28/28)	96.4% (27/28)
Hand Movement	100% (28/28)	100% (28/28)	100% (28/28)	100% (28/28)
Head Movement	100% (28/28)	96.4% (27/28)	100% (28/28)	100% (28/28)
Location	89.3% (25/28)	92.9% (27/28)	100% (28/28)	92.9% (26/28)
Communication	100% (28/28)	n/a	100% (28/28)	n/a

The post-training survey consisted of ten questions to assess the system usability scale (SUS) score. These questions and the scores are shown in Table 4-6. The positive response rates for odd-numbered questions were calculated by dividing the ‘strongly agree’ and ‘agree’ responses by the total number of responses. For even-numbered questions, the positive response rates were calculated by dividing the ‘strongly disagree’ and ‘disagree’ responses by the total number of responses. The individual scores were aggregated to obtain the overall SUS score of 78.4 out of 100 points. Based on the large-scale SUS usage, studies (Sauro, 2019; Sauro and Lewis, 2016) suggest that SUS scores can be interpreted with the following grades: A ≧ 80.8, B ≧ 74.1, C ≧ 65.0, D ≧ 51.7, and F < 51.7. The SUS score of 78.4 indicated that the usability of the VR training was good and minor improvements could be made to improve its usability further.

As shown in Table 4-6, most participants found the immersive VR module to be user-friendly and agreed with its inclusion in future Flagger Training sessions. Participants expressed a need for technical assistance in using the VR module (Question 4). This was expected given that nearly 70% of participants had no prior experience with VR applications. The SUS score for Question 7 showed that more time should be reserved for new users to practice and become familiar with the VR module.

Table 4-6. System Usability Scale scores for the flagger VR training module.

	SUS Question	Positive Response	SUS Score
1	I would like for the VR module to be included in future flagger training.	92.9%	8.9/10
2	I found the VR module unnecessarily complex.	85.7%	8.7/10
3	I thought the VR module was easy to use.	85.7%	8.2/10
4	I think that I would need the support of a technical person to be able to use the VR module.	46.4%	5.6/10
5	I found the various functions in the VR module were well integrated.	89.3%	8.1/10
6	I thought there was too much inconsistency in the VR module.	85.7%	8.1/10
7	I would imagine that most people would learn to use the VR module very quickly.	78.6%	7.4/10
8	I found the VR module very cumbersome to use.	75.0%	8.0/10
9	I felt very confident using the VR module.	82.1%	7.8/10
10	I needed to learn a lot of things before I could get going with the VR module.	82.1%	7.6/10
			78.4/100

The SUS scores show that the VR training module could be further improved by adding a more detailed introductory warm-up session to allow participants more time to familiarize themselves with the technology before they embark on the actual flagger training.

The results of the level of engagement experienced by participants with the overall training course are presented in Table 4-7. Regarding cognitive and emotional engagements, over 82% of participants strongly agreed or agreed that the VR module helped them focus more during the overall work zone training, and 93% of participants stated that VR made them feel more positive about their overall training experience. When asked if the VR module increased the interaction with colleagues during training (i.e., social engagement), 25% strongly agreed or agreed, 57.1% were neutral, and 10.7% disagreed. In this project, the training instructor invited participants to experience the VR module during scheduled breaks and group project time. Participants tested the VR module alone and did not have opportunities to discuss their experience with others. In the future, social engagement can be enhanced by integrating the VR module into the overall training curriculum. For example, the training course can allocate dedicated time for all participants to observe the performance of their colleagues experiencing the VR module. Subsequently, a group discussion can be facilitated by instructors, allowing participants to share their observations and insights following the VR module. This strategy will also promote active participation and interaction among participants, fostering a more engaging and socially connected training experience.

Table 4-7. Results of self-reported engagement levels in VR training.

	Question	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
1	The VR module helped me focus more on the overall work zone training.	28.6%	53.6%	14.3%	0%	0%
2	The VR module allowed me to interact more with my colleagues during training.	14.3%	10.7%	57.1%	10.7%	0%
3	The VR module made me feel more positive about the overall training experience.	28.6%	64.3%	7.1%	0%	0%

In summary, the evaluation results showed that the VR Flagger Training module achieved the majority of the intended outcomes. The SUS results indicated the VR module is an effective and user-friendly training tool overall. Cognitive and emotional engagement improved significantly while social engagement improved slightly. Social engagement can be enhanced by updating the existing course curriculum to allocate time for observing the VR training and encouraging group discussions among participants. Through participant behavioral analysis, instructors observed that most participants accurately followed the safety procedures and guidelines within the VR environment, allowing instructors to provide tailored feedback to participants.

The evaluation provided valuable feedback from instructors, trainees, and other experts, offering opportunities for further improvements to the VR module. One feedback was to provide participants with additional preparation before experiencing the flagger module to help them become comfortable using the VR headset and the interactive features of the controllers. This suggestion led to the addition of a warm-up module for participants to practice teleportation and other features.

4.3 Outreach Activities for VR Training

Effective outreach activities are essential to the successful implementation and adoption of the VR training program. To promote the use of VR in transportation training, the VR training modules have been showcased at various conferences and workshops. These hands-on demos primarily used the flagging training module and the second VR module from the Advanced Work Zone Training, featuring simplified instructions and tasks. These events provide a platform to demonstrate the capabilities and benefits of VR training to a wider audience, including potential adopters and collaborators. A list of outreach activities is shown in Table 4-8.

Table 4-8. VR training outreach activities.

Date	Conference/Location	Type
10/13/2022	National Work Zone Traffic Management and Safety Conference, virtual	Presentation
11/4/2022	10th TRB International Symposium on Visualization, Washington D.C.	Presentation
3/26/2023	IEEE VR 2023 Conference workshop, virtual	Presentation
6/19/2023	Illinois DOT, Springfield, IL	Demonstration
9/6 - 9/7/2023	Indiana LTAP, Lafayette, IN	Demonstration
10/17/2023	Illinois Traffic Engineering and Safety Conference, Champaign, IL	Presentation and demonstration
12/4/2023	Iowa DOT, Ames, IA	Demonstration
12/5/2023	Iowa DOT Work Zone Information Share Workshop, Ames, IA	Presentation and demonstration
3/11 - 3/12/2024	ATSSA Northland "How To" Conference, Fargo, ND	Presentation and demonstration

Besides promoting awareness and engaging with stakeholders, the hands-on demonstrations provided valuable opportunities to collect feedback on the VR training program and technologies. As shown in Appendix F, a short survey was designed and handed out to the participants who experienced the hands-on demonstration. The results of 72 surveys returned are shown in Table 4-9.

The hands-on interactive demos have garnered significant interest and a highly positive reception from transportation professionals. A total of 95.8% of respondents agreed or strongly agreed that the VR module provided a realistic representation of an actual work zone. Additionally, 94.4% found the VR module easy to use, with only 4.2% disagreeing or strongly disagreeing. The usefulness of the VR module for training staff was acknowledged, with 98.6% of participants agreeing or strongly agreeing on its effectiveness. Furthermore, 86.1% of respondents expressed a desire to include the VR module in future training at their agency, demonstrating strong support for the integration of VR technology in training programs. This feedback highlights the potential of VR training modules to enhance traditional training methods and improve overall training effectiveness.

Table 4-9. Results of the VR demonstration survey.

#	Question	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
1	I believe the VR module provided a realistic representation of an actual work zone.	51.4%	44.4%	2.8%	0%	1.4%
2	I thought the VR module was easy to use.	70.8%	23.6%	0%	2.8%	1.4%
3	I believe that the virtual reality module is useful for training staff.	70.8%	27.8%	0%	0%	1.4%
4	I would like to include the virtual reality module in future training at my agency.	65.3%	20.8%	9.7%	2.8%	1.4%

5. Conclusion

The implementation of VR training modules in two MoDOT work zone training courses demonstrated the potential benefits of leveraging new visualization technologies to enhance training. The VR modules provided realistic and engaging scenarios that were also well-received by participants. The results of the post-training surveys indicated high satisfaction levels, with participants appreciating the realistic representation of work zones, ease of use, and overall effectiveness of the training. The developed VR training modules are intended for continued use in future MoDOT training. User instruction videos were prepared for both trainers and participants. VR headsets and laptops loaded with the VR modules will be provided to MoDOT district offices for use in future training courses. The research team will provide ongoing technical support, as needed, to keep the modules updated with the latest VR developments, typical applications, and emerging training needs.

Behavioral measures, collected for flagger training, showed that participants could effectively identify deficiencies in work zones and safely perform flagging operations. The VR training modules allowed for detailed tracking of participants' actions, such as head and hand movements and adherence to safety protocols while flagging. This data provided valuable insights into the effectiveness of the training and areas for further improvements.

The developed VR training modules showcased the flexibility of VR training by accommodating the training needs of both inspectors and flaggers. The VR training content can be easily extended to simulate various work zone conditions allowing for tailored training experiences that address other requirements of different roles such as TMA operators and internal work zone supervisors. This adaptability ensures that the training remains relevant and effective for a wide range of participants, thus enhancing the overall impact of the program.

Outreach activities and hands-on demonstrations further validated the positive reception of the VR training modules and highlighted the potential for broader adoption across other DOTs and agencies. The feedback collected from these activities provided valuable insights for future development and refinement of the VR training program.

In conclusion, the VR training modules have proven to be an effective tool for enhancing work zone safety training. The integration of advanced VR technology offers a promising approach to training, addressing the limitations of traditional methods and providing a more immersive, interactive, and effective learning experience. Future efforts should focus on expanding the VR scenarios, incorporating additional feedback to further enhance the user experience, and exploring new applications of VR technology in training transportation workforce.

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Appendix A: Typical Applications for VR scenarios

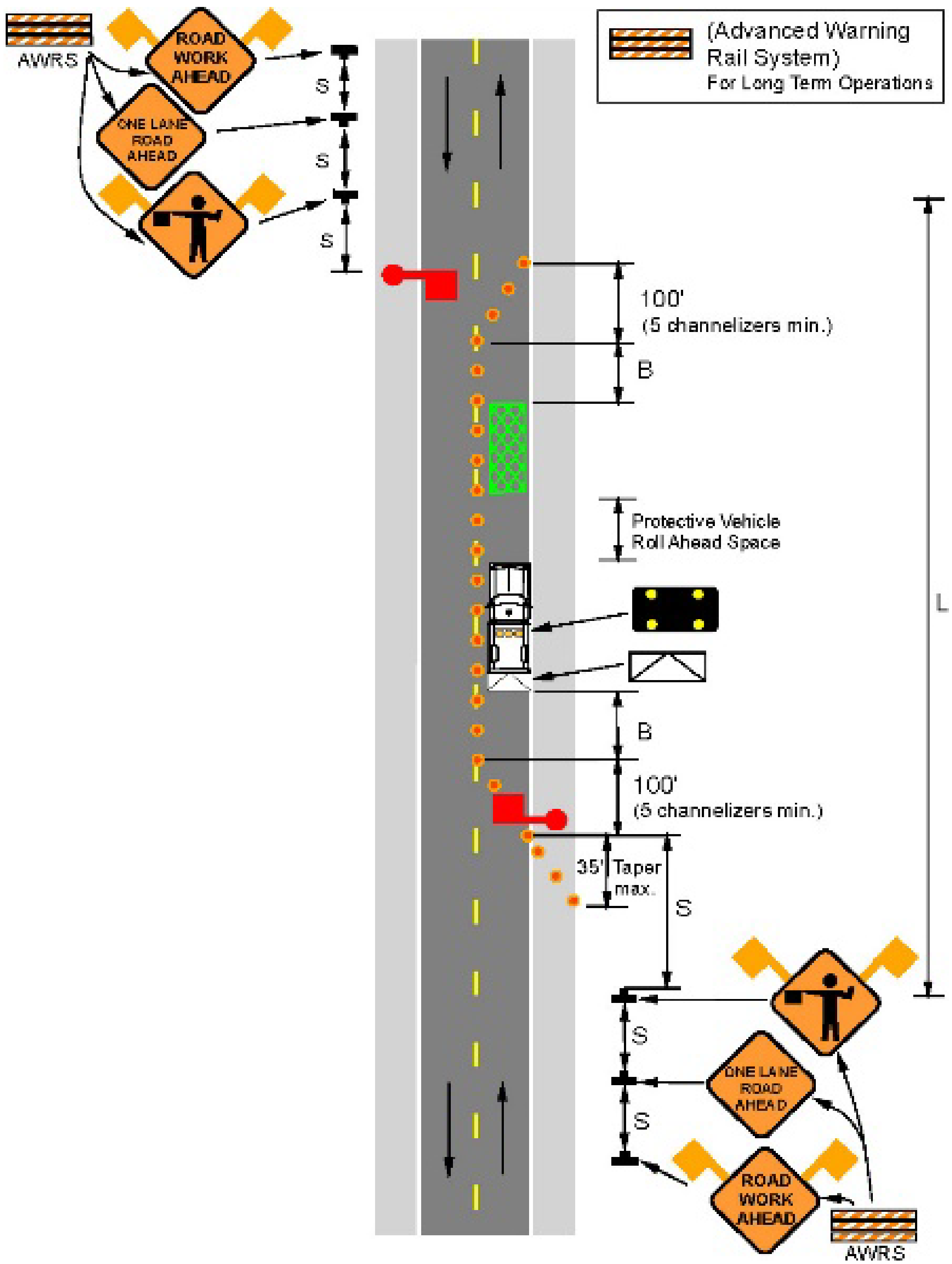


Figure A.1. TA-10 Lane Closure on Two-Lane Highways Using Flaggers. (MoDOT, 2024)

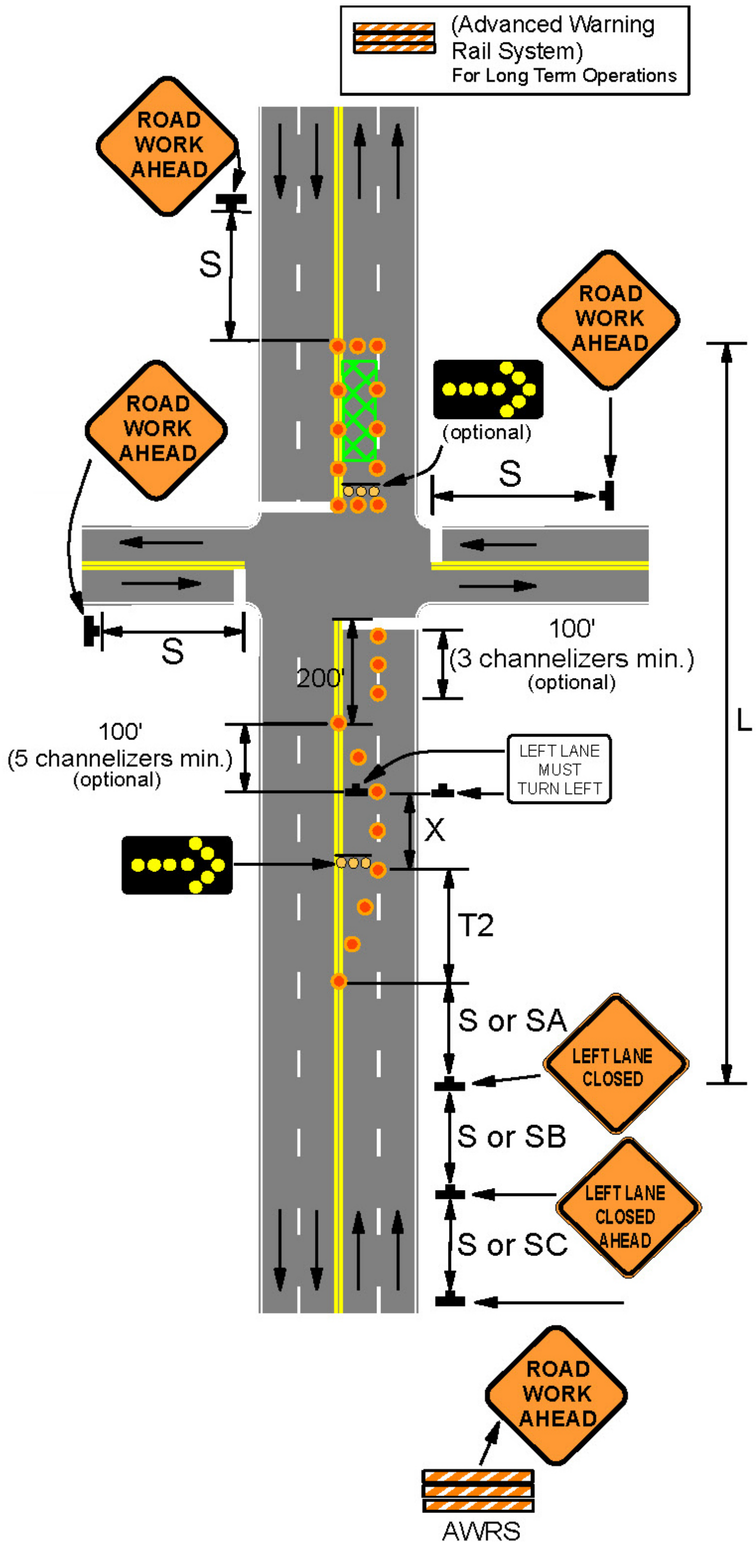


Figure A.2. TA-23 Lane Closure of Left Lane on Far Side of Intersection. (MoDOT, 2024)

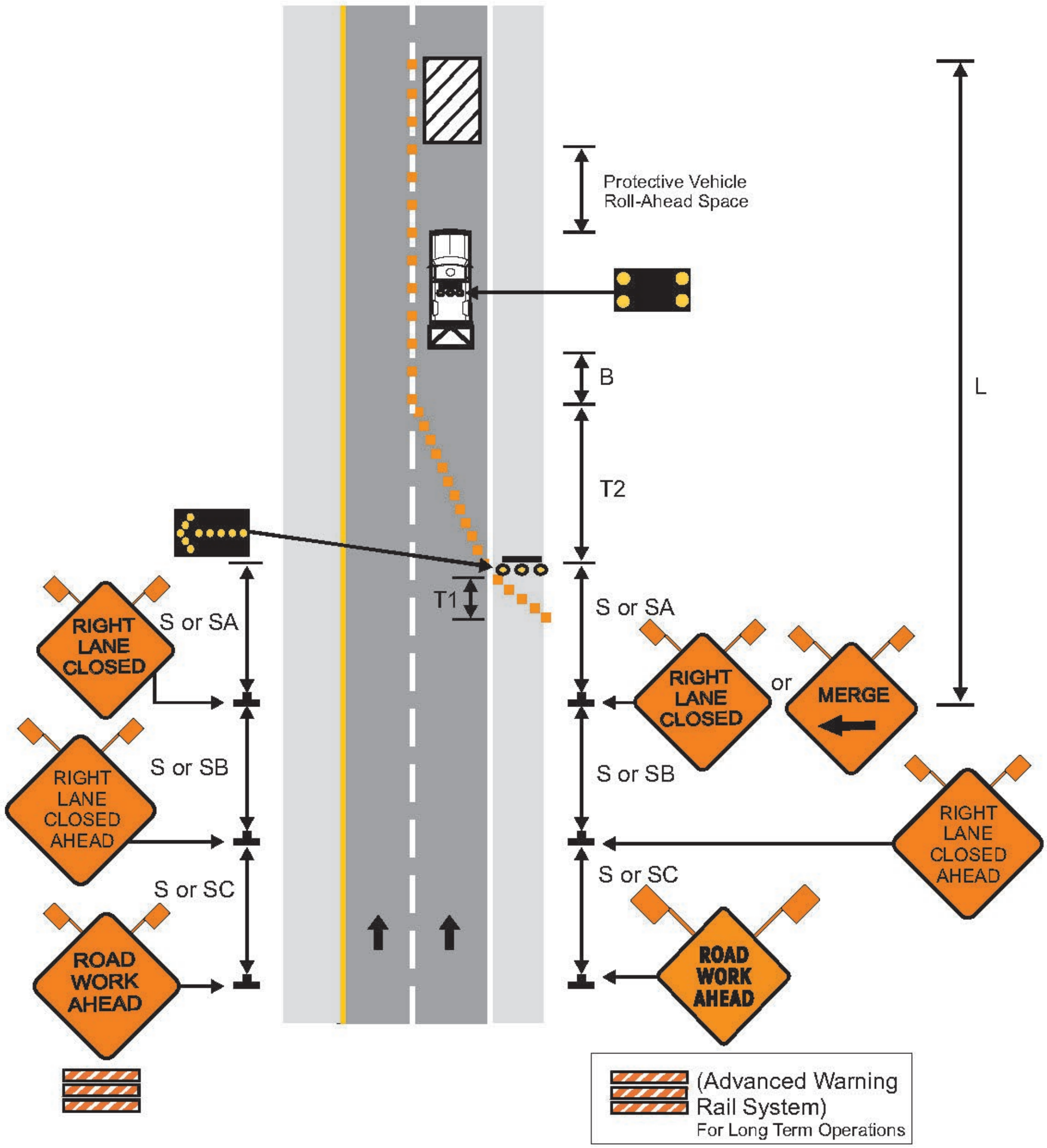


Figure A.3. TA-33 Lane Closure on Right Lane on Divided Highway. (MoDOT, 2024)

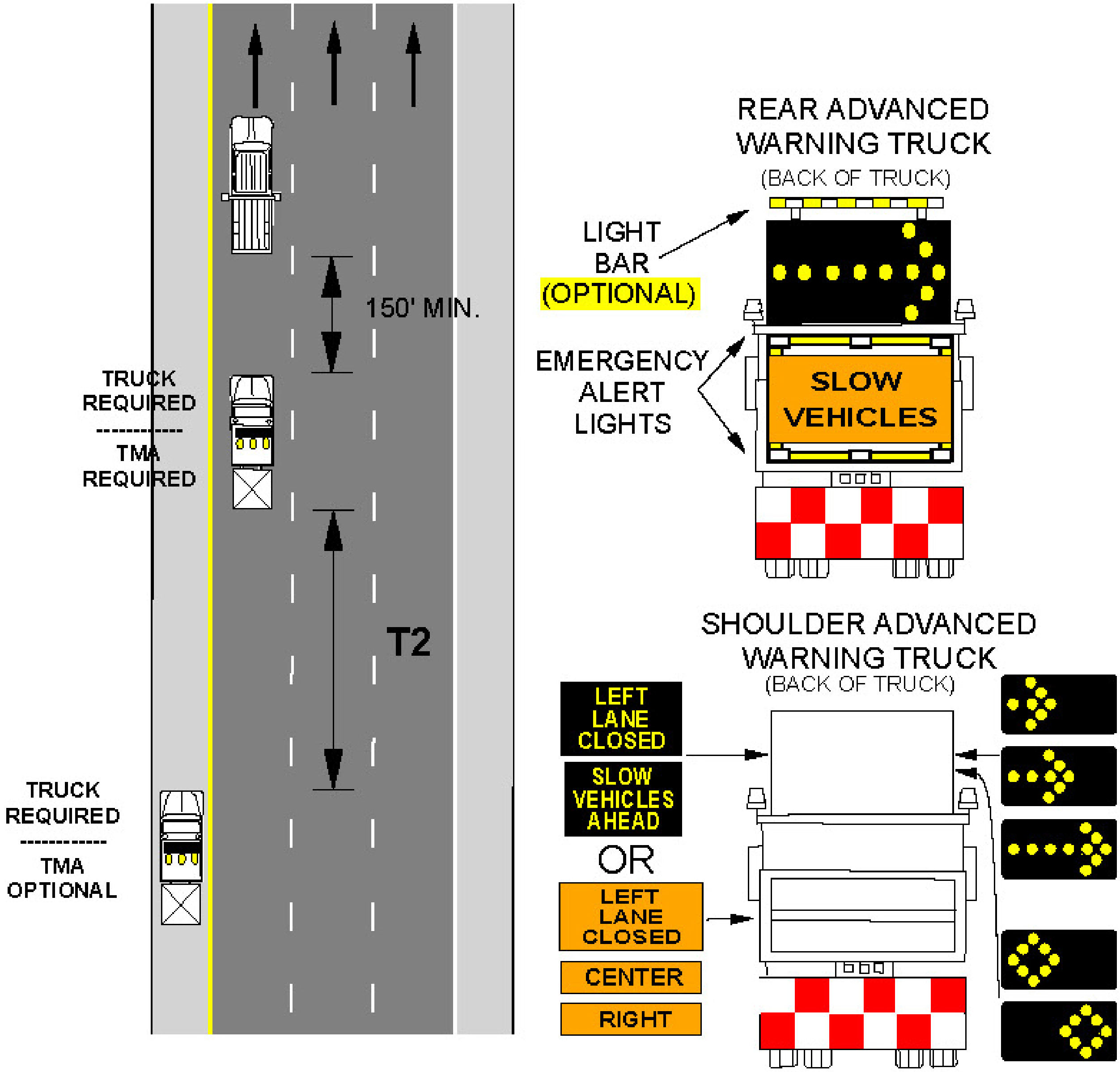


Figure A.4. TA-35 Mobile Operation on Divided Highways. (MoDOT, 2024)

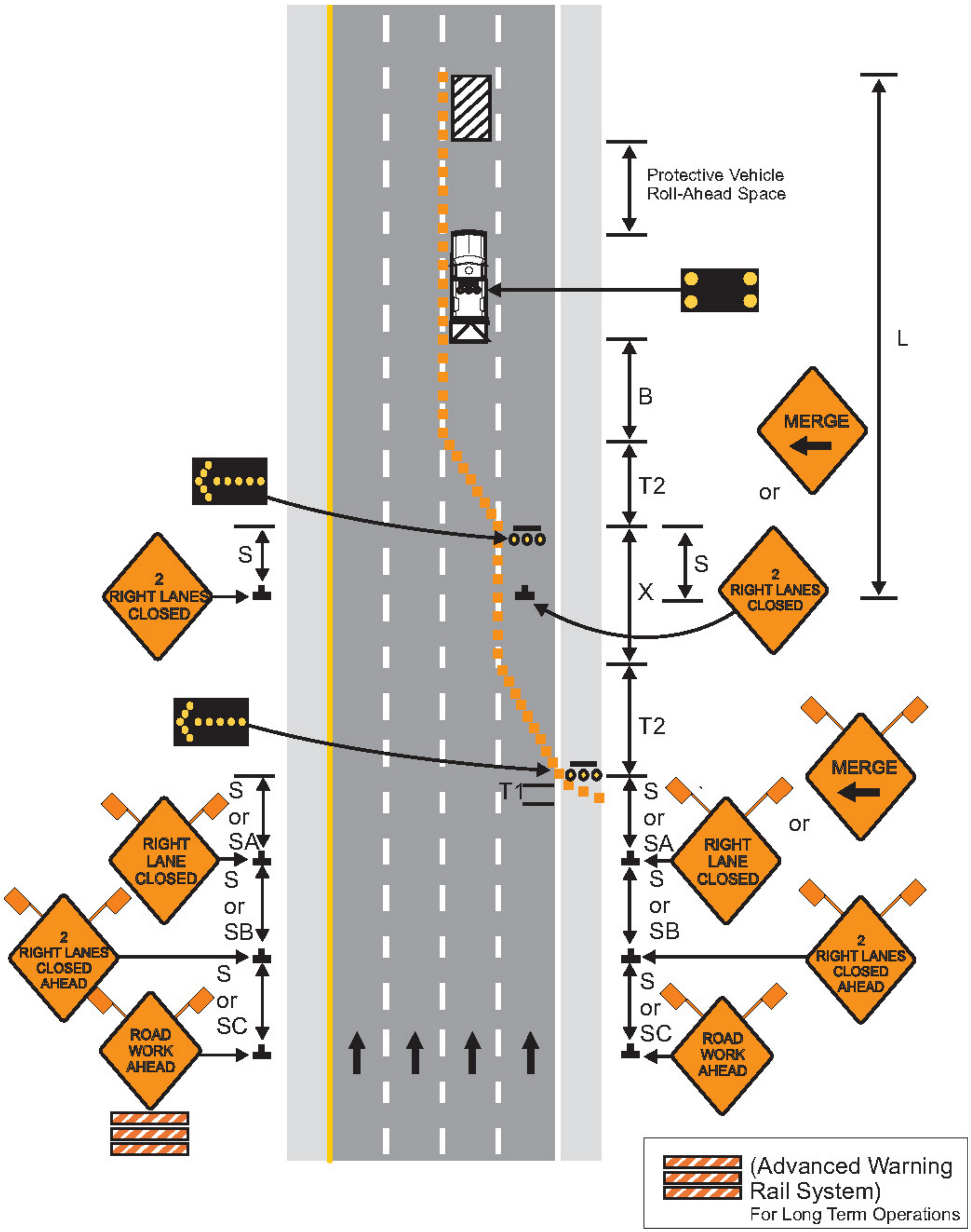
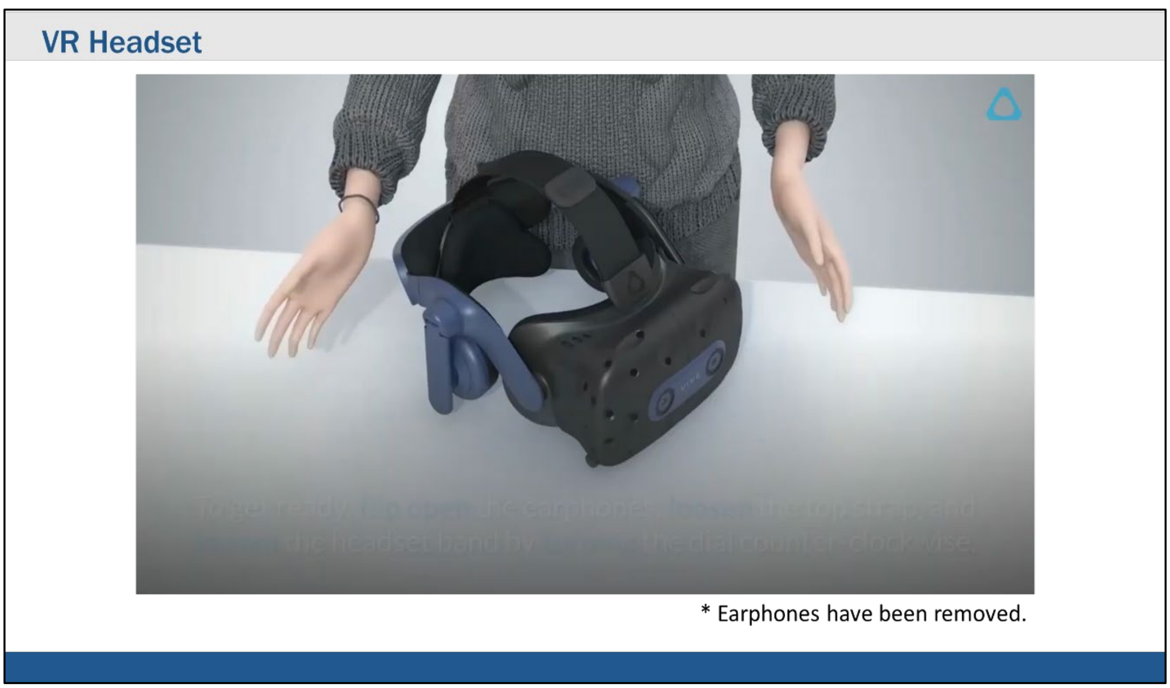
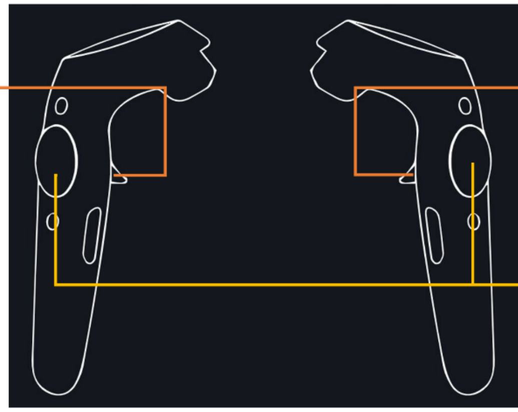


Figure A.5. TA-37 Lane Closure of Interior Lane on Multi-Lane Highways. (MoDOT, 2024)

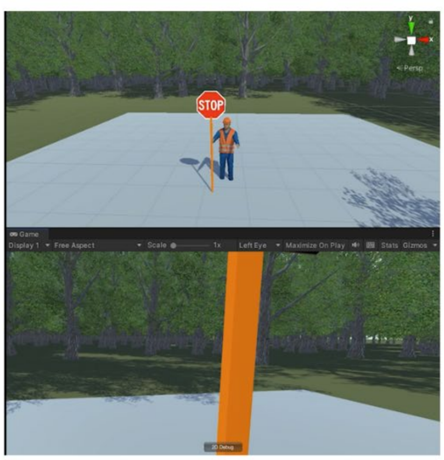
Appendix B: Slides of VR User Instructions



VR Controller

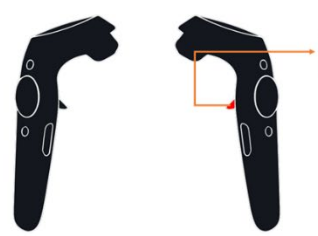


VR Module Instructions

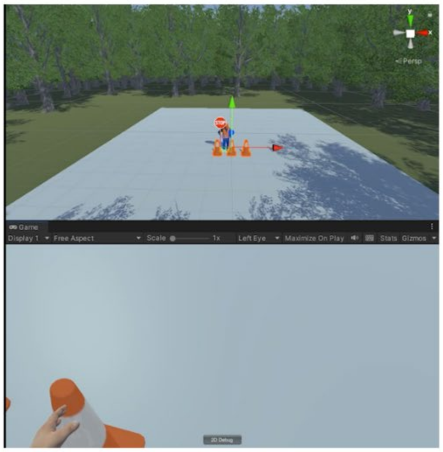


Turning the STOP/SLOW Paddle

- Every time you press the trigger (right hand), the STOP/SLOW paddle will change display.



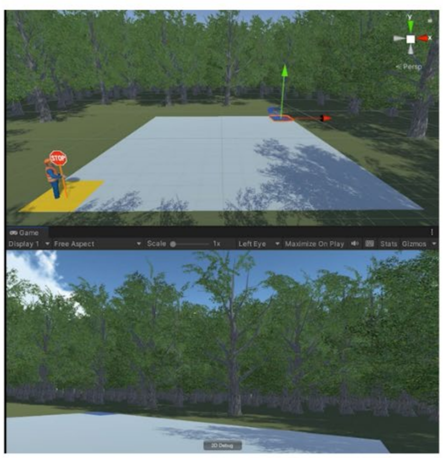
VR Module Instructions



Moving the Traffic Cone

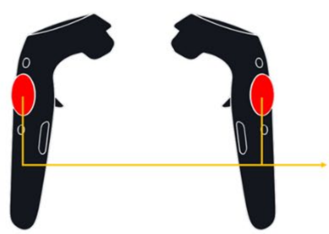
- When you reach for the traffic cone, it will be highlighted in yellow.
- Press and hold the trigger (left hand) to pick up and move the traffic cone.
- Release the trigger to drop the traffic cone.

VR Module Instructions



Teleporting

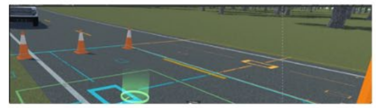
- Teleporting can move your avatar from point A to point B instantly.
- When you press the trackpad, use the teleport arc to move to the desired location.



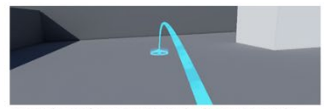
VR Controller

Example – Teleport

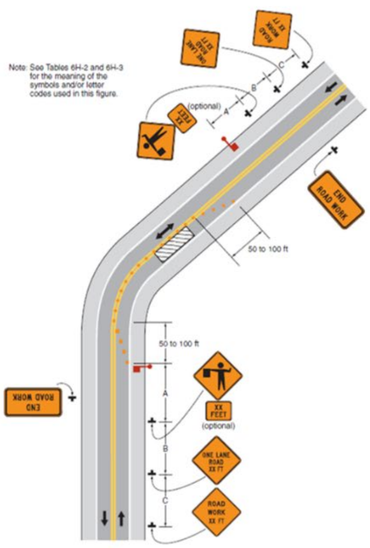
- Teleporting can move your avatar from point A to point B instantly.



- When you press the trackpad, there are two areas: you can move to any place in the blue area, but the yellow area (beyond the center line) is not accessible.



- Use the teleport arc to help you reach where you want to go.



Collaborative Training – Scenario

- Typical Application 10 - Lane Closure on Two Lane Highways Using Flaggers

VR Module

Warm up session – 5 mins
(practice to teleport and turn the STOP/SLOW paddle)

Stop the approaching vehicle while your coworker sets up the taper.

Release the traffic

Stop the approaching traffic

Wait the other flagger release traffic

Release the traffic

Appendix C: Participant Test Questionnaire – TA-10

Name:____

Job Title:____

[ ] Pre- VR

[ ] Post - VR

1. What are the signs included in MoDOT's TA-10 typical sign package? (select all that apply)

   a. Road Work Ahead   b. Road Work Next 2 Miles

   c. Stop Ahead   d. Flagger Sign

   e. One Lane Road Ahead

2. According to the EPG TA-10, which flagger sign should be used?

a. 

b. 

3. According to the EPG TA-10, arrow boards shall be used on the shoulder.

   a. True

   b. False

4. Flaggers should never face oncoming traffic?

   a. True

   b. False

5. According to the EPG TA-10, a protective vehicle with a TMA and flashing arrow board should be used while work is in progress. Which display mode should the truck mounted arrow board use?

   a. Four Corner

   b. Straight Line Caution

   c. Sequential Arrow

   d. Flashing Arrow (Left, Right, or Both)

Appendix D: MoDOT Advanced Work Zone VR Module Survey

Thank you for participating in the Virtual Reality (VR) module. Please complete the following questionnaire to help us improve the module in the future.

Q1 Which MoDOT District do you work in?

- ◯ Central District
- ◯ Kansas City District
- ◯ Northeast District
- ◯ Northwest District
- ◯ Southeast District
- ◯ Southwest District
- ◯ St. Louis District

Q2 What is your gender?

- ◯ Male
- ◯ Female

Q3 What is your age?

- ◯ 18 - 24
- ◯ 25 - 34
- ◯ 35 - 44
- ◯ 45 - 54
- ◯ 55 - 64
- ◯ 65 or older

Q4 How long have you been with MoDOT?

____

Q5 How many years of work zone experience do you have?

____

Q6 Have you used VR before yesterday's module?

- ◯ No, I have never used VR
- ◯ Yes, I have used VR a few times
- ◯ Yes, I use VR often

Q7 Please indicate the extent to which you agree with the following statements.

	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
I believe the virtual reality module provided a realistic representation of an actual work zone.	○	○	○	○	○
I was comfortable wearing the virtual reality headset.	○	○	○	○	○
I was able to distinguish between good and bad signage in the work zone.	○	○	○	○	○
I did not find the virtual reality module to be challenging.	○	○	○	○	○
I had enough time to read the work zone signage.	○	○	○	○	○
I did not feel nauseated while using the virtual reality headset.	○	○	○	○	○
I had sufficient time to notice any concerns in the work zone.	○	○	○	○	○
I was able to recall the related typical application (TA) during the virtual drive through.	○	○	○	○	○
Overall, I believe that the virtual reality module is useful for training staff that inspect work zones.	○	○	○	○	○

Q8 Please indicate the extent to which you agree with the following statements.

	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
The VR module helped me focus more on the overall Advanced Work Zone training.	○	○	○	○	○
The VR module allowed me to interact more with my colleagues during training.	○	○	○	○	○
The VR module made me feel more positive about the overall training experience.	○	○	○	○	○

Q9 Please enter any additional suggestions and comments you may have regarding the VR training.

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Appendix E: MoDOT Flagger Training VR Module Survey

Thank you for participating in the Virtual Reality (VR) module. Please complete the following questionnaire that will help us improve the module in the future.

Q1 Which MoDOT District do you work in?

- ○ Central District
- ○ Kansas City District
- ○ Northeast District
- ○ Northwest District
- ○ Southeast District
- ○ Southwest District
- ○ St. Louis District

Q2 What is your job title or primary job duties?

- ○ ____

Q3 What is your gender?

- ○ Male
- ○ Female

Q4 What is your age?

○ 18 - 24

○ 25 - 34

○ 35 - 44

○ 45 - 54

○ 55 - 64

○ 65 or older

Q5 How long have you been with MoDOT?

○ ____

Q6 How many years of work zone experience do you have?

○ ____

Q7 Have you tried virtual reality (VR) before today?

○ No, I have never tried VR

○ Yes, I have tried VR a few times

○ Yes, I use VR often

Q8 Please indicate the extent to which you agree with the following statements regarding today's VR training module.

	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
I would like for the VR module to be included in future flagger training.	○	○	○	○	○
I found the VR module unnecessarily complex.	○	○	○	○	○
I thought the VR module was easy to use.	○	○	○	○	○
I think that I would need the support of a technical person to be able to use the VR module.	○	○	○	○	○
I found the various functions in the VR module were well integrated.	○	○	○	○	○
I thought there was too much inconsistency in the VR module.	○	○	○	○	○
I would imagine that most people would learn to use the VR module very quickly.	○	○	○	○	○
I found the VR module very cumbersome to use.	○	○	○	○	○
I felt very confident using the VR module.	○	○	○	○	○
I needed to learn a lot of things before I could get going with the VR module.	○	○	○	○	○

Q9 Please indicate the extent to which you agree with the following statements.

	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
The VR module helped me focus more on the overall advance work zone training.	○	○	○	○	○
The VR module allowed me to interact more with my colleagues during training.	○	○	○	○	○
The VR module made me feel more positive about the overall training experience.	○	○	○	○	○

Q10 Please enter any additional suggestions and comments you may have regarding the VR training.

____

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Appendix F: Work Zone VR Training Survey

Thank you for participating in the Virtual Reality (VR) training module. Please complete the following questionnaire to help us improve the module in the future.

Q1. Please indicate the extent to which you agree with the following statements.

	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
I believe the VR module provided a realistic representation of an actual work zone.	○	○	○	○	○
I thought the VR module was easy to use.	○	○	○	○	○
I believe that the virtual reality module is useful for training staff.	○	○	○	○	○
I would like to include the virtual reality module in future training at my agency.	○	○	○	○	○

Q2. Please enter any suggestions or comments to improve the VR training module.

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