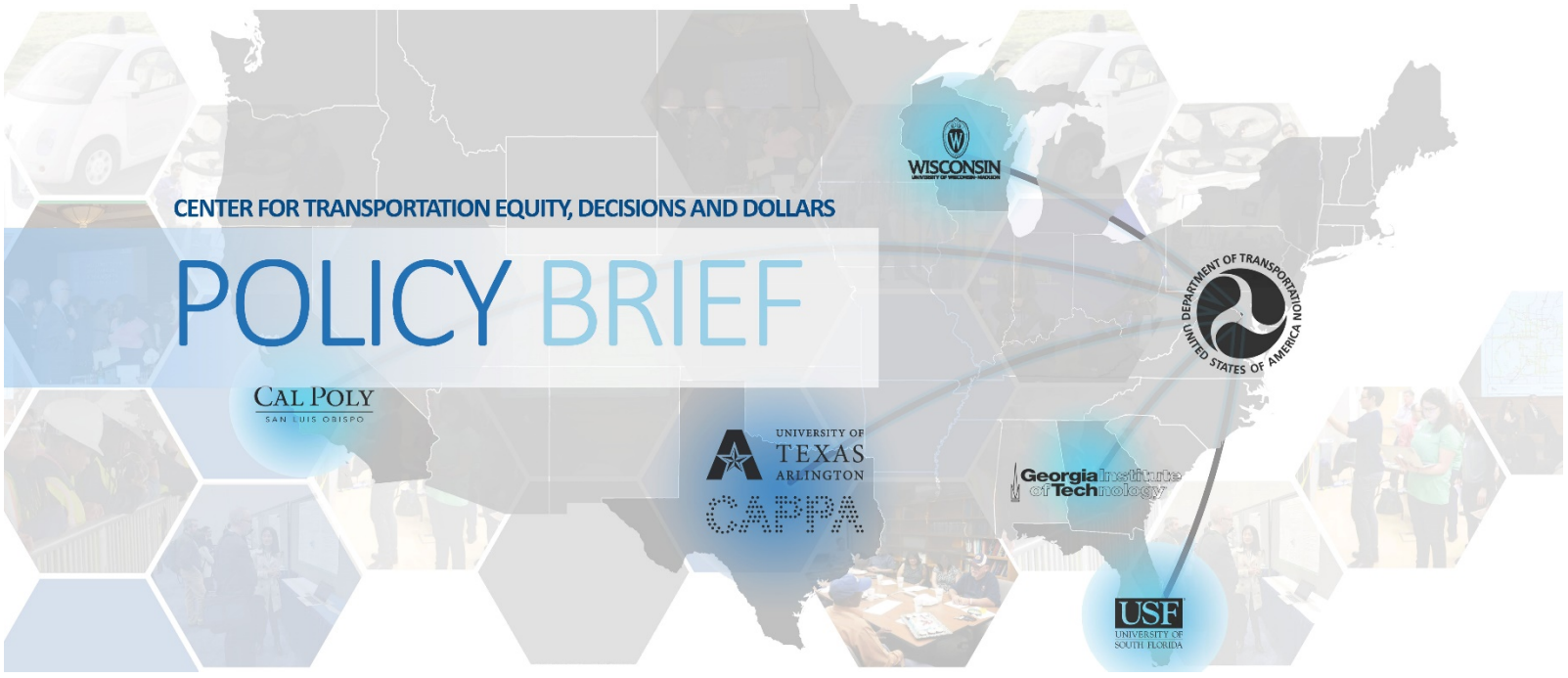

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Development of an Immersive Training Platform for Roadway Construction Workers using Virtual Reality Technologies

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Executive Summary:

Workforce education is crucial to ensuring the safety and equality of the work environment. Immersive virtual reality (VR) training is revolutionizing workforce education, providing practical on-the-job training within a safe simulated environment. The project aimed to develop an immersive training platform using state-of-the-art VR technologies and code proper work zone training scenarios on the VR platform as a demonstration. The research team developed the training platform based on Meta Quest Pro and Unity3D engine to achieve the research objectives. The platform consists of an immersive module and an assessment module. The interactive mechanism allows trainees to "learn by doing" and "learn from mistakes." Flagger operations were coded on the VR platform. The VR flagger training scenarios are coded to include multiple training modules to instruct basic flagger operations, such as stop, release, and slow traffic. Additionally, they are designed to assess trainee performance at pre-defined checkpoints. An internal test was conducted to preliminarily evaluate the VR platform's training effectiveness. Nine volunteers without work zone experience participated in the internal test. These participants took VR or traditional training, followed by a field test and a post-training survey. The research team compared two participants' training performance before and after the VR training. Participants' feedback, opinions, and recommendations on the VR training were also summarized. The internal test results indicated that VR training is an attractive solution to enhance work zone training. The research findings suggest that VR training is more effective than traditional training, with an effectiveness rate of 89% compared to 82%. VR training can serve as a supplemental module integrated into current work zone training programs. This approach allows trainees to practice their skills in various scenarios, unrestricted by spatial and temporal limitations. The research team is improving the current VR platform based on participants' feedback and expanding the applications of VR training to encompass work zone inspection, Road Safety Audits (RSA), and railway operations.

Scope of Problem:

Maintenance and construction activities are fundamental for maintaining the current roadway infrastructure's functionality and upgrading it to meet future transportation needs. Work zones are critical elements for maintaining and upgrading roadway systems. In the United States (U.S.), 20% of the nation's roadway system is under construction, with more than 3,000 work zones during peak construction season and 12 billion vehicle miles traveling through active work zones yearly. Roadway construction workers are often directly exposed to traffic and experience a significant number of fatalities and injuries in their working environment. In 2021, road construction sites reported 108 worker fatalities. Of these fatalities, 45.3% involved workers on foot struck by vehicles, 29.4% were workers driving or riding in motor vehicles, and 25% resulted from falls, slips, trips, being struck-by struck by objects or equipment, caught between objects or equipment, or electrocutions collectively.

Workforce education is crucial to ensuring the safety and equality of the work environment. Through training, workers can understand the risks in their working environment, obey the operation rules, and increase their skills to respond to potential hazards. In recent decades, state DOTs, non-profit NGOs, and the private sector have developed and implemented various work zone training programs and applications. These traditional training methods have several drawbacks and limit their effectiveness in work zone training, including high costs, fixed schedules, lack of practice in a risk-free environment, and lack of personalized training.

Policy Alternatives:

With the rapid progress of virtual reality (VR) technologies, scenario-based immersive learning methods have become an attractive training solution for high-risk environments (i.e., work zones). Immersive training places trainees in a synthetic environment nearly identical to the real world. Trainees in the virtual environment have a sense of self within the scenario by perceiving visual or auditory information from the virtual environment and interacting with the objects via selection, manipulation, and locomotion. Immersion, interaction, and measurable assessment are traits of immersive training.

The project developed a VR-based immersive training platform based on the Meta Quest Pro and the Unity3D engine. The platform consists of an immersive module and an assessment module. Using a VR headset, trainees perceive virtual work zone scenarios and take actions in response to task commands. The assessment module analyzes trainees' tracking data and provides feedback to trainees in real time. The interactive mechanism allows trainees to "learn by doing" and "learn from mistakes."

Flagger operations at a rural two-lane work zone were coded on the VR platform because flagger operations are the fundamental work zone training topic and involve interactions with the virtual environment. Four training scenarios were developed to teach basic flagger operation skills (stop, release, and slow traffic) with step-by-step instructions. A summary report is automatically provided to assess trainees' performance at pre-defined checkpoints.

Policy Recommendations:

VR training is an attractive solution to enhance work zone training. The emerging technology delivers performance comparable to, and sometimes surpasses, traditional in-person training methods. Trainees report increased confidence after completing VR training sessions, where they engage in flagger operations within an immersive environment. Field tests and post-survey data indicate that participants effectively acquired essential knowledge and skills related to flagger operations through VR training.

VR training is suitable as a practice module embedded in existing work zone training programs. VR training can simulate various scenarios, including high-risk situations such as encounters with high-speed vehicles or vehicles approaching flaggers). Trainees can practice their skills across multiple scenarios without space and temporal limitations. The comparison conducted before and after VR training demonstrated the effective enhancement of trainees' skills.

The current VR experience needs to be improved. The existing VR platform presents limitations, including hand tracking, virtual paddle operations, simulating speeding vehicles, and user interface design. Participants expect more immersive VR experiences, explicit instructions and feedback, and straightforward VR operations. Upon completing this study, the research team will continue to improve the current VR platform based on participants' feedback. With the updated platform in place, a more comprehensive test is planned to obtain more accurate and reliable evaluations of VR training. The research team intends to incorporate additional flagger operation scenarios into the VR training programs, such as urban work zone sites and risky situations other than speeding vehicles. The research team will also expand the application of VR training, such as work zone inspection, Road Safety Audits (RSA), and railway operations.

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