Virtual Reality in Active Transportation

Planning, Policy, Research & Education

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ABOUT

This report was developed by the New Jersey Bicycle and Pedestrian Resource Center within the Alan M. Voorhees Transportation Center (VTC) at Rutgers, The State University of New Jersey. The research team included Charles T. Brown, MPA, Principal Investigator, Aashna Jain, Lisa Cintron, Wenshu Lin, Kendra Nelson, and Aishwarya Shrestha.

The Alan M. Voorhees Transportation Center (VTC) is a national leader in the research and development of innovative transportation policy. Located within the Edward J. Bloustein School of Planning and Public Policy at Rutgers University, VTC has the full array of resources from a major research university on transportation issues of regional and national significance.

The New Jersey Bicycle and Pedestrian Resource Center (BPRC) assists public officials, transportation and health professionals, and the public in creating a safer and more accessible walking and bicycling environment through primary research, education and dissemination of information about best practices in policy and design. The Center is supported by the New Jersey Department of Transportation through funds provided by the Federal Highway Administration.

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Executive Summary

In the past decade, Virtual Reality has gained momentum, becoming an asset in both recreation and research. Virtual Reality (VR) allows users to immerse themselves in numerous lifelike or fictional landscapes through wearable and sensory technologies. Utilizing VR technology provides researchers with the opportunity to educate and test out various scenarios, while minimizing possible economic and health risks. By monitoring the user's actions, researchers can gain valuable knowledge on human behavior in different circumstances. Public engagement, an essential aspect of planning, can also be assisted through the use of VR, which can provide public and private entities with fun, yet effective alternatives to interact with the public. Recent developments in virtual and augmented reality have arisen, demonstrating the flexibility of the technology itself and the diversity of issues it may aid. These issues range from improving on the age old issue of designing efficient wayfinding systems to creating safe and efficient road work training conditions for bridge repairmen.

The purpose of this white paper is to explore ways in which VR can be used to advance active-transportation research, education, and practice. Through case studies and examples, this study highlights key applications of VR in transportation. Its findings indicate that VR can be extremely useful for interacting with people, visualizing designs, understanding user behavior, and education and training purposes. It can be incorporated into a number of existing New Jersey Bicycle and Pedestrian Resource Center (NJBPRC) and Safe Routes to School (SRTS) initiatives including regional complete streets training workshops, safe routes to school, bicycle and pedestrian planning, public outreach and engagement, senior mobility workshops, etc.

This white paper is organized into three sections. The first section explores VR technology, its characteristics, and advantages, along with the diversity of methods used to experience VR. Using case studies and examples, the second section highlights how VR can be applied to four major areas in transportation, namely, public outreach and engagement, transportation behavioral research, wayfinding and signage design, and safety education and training. Lastly, the third section discusses how VR can be used to benefit NJBPRC and SRTS in research, outreach and engagement, and education and training.

Introduction to Virtual Reality

This section explores the VR technology – its characteristics, and advantages, along with the diversity of methods used to experience VR. It also includes a brief introduction to VR market solutions.

What is Virtual Reality?

Virtual Reality (VR) is a computer-generated real-time virtual environment where users can experience an environment in three dimensions without being physically present in the scene. Immersion and virtual interactivity are two main features of VR. They are accomplished by capturing the user's hand, eye and body movements, and adjusting the immersive virtual environment accordingly.

How to Experience Virtual Reality?

There are different methods of experiencing Virtual Reality. One of the most popular methods is to use a VR headset, which is normally comprised of a stereoscopic head-mounted display (HMD), stereo sound, and head motion tracking sensors. It enables users to explore the virtual environment by moving their heads and eyes, and interact with the environment through a console.

Several VR accessories can be used to enhance the immersive experience by allowing the user to further interact with the virtual environment. For instance, VR motion capture devices can be combined with VR headsets to create a mixed-reality system in which users can interact with the virtual environment by moving their body parts. A typical example of a motion capture device is a VR glove, which is basically a wearable Hand Machine Interface (HMI) that allows users to move their virtual hands in the environment by moving them in reality. Other examples of VR motion capture devices include VR suits, VR fitness equipment, VR motion chairs, and so on. The technology is mainly applied to gaming, entertainment, fitness, and physical therapy. Additionally, VR treadmills allow the users to move their whole body in the virtual environment. They are used in VR training simulators designed for surgery practice, military training, and driving.

Another method to experience VR is known as the Cave Automatic Virtual Environment (CAVE). It includes a cube-shaped room with projections on its walls along with sensor-equipped 3D glasses for the user. In the CAVE, the sensors constantly monitor the user's movements and adjust the virtual environment accordingly, enabling the user to interact with the environment through physical movements such as walking and sitting.

The Advantages of Virtual Reality

Virtual Reality presents an interactive and immersive medium when compared to traditional methods. It enables better performances in facets involving research, education, safety and workforce training.

VR environments are extremely effective for training purposes due to their ability to be perceived as a reality as well as their ability to stay in the user's memory as a true experience. In a recent cognitive-psychological study, Schöne et al. (2017) assessed the immersive qualities of VR by comparing performances in a memory task two days after participants' 360° VR or 2D video experience of a motorcycle ride.[1] Results revealed that VR experience was more of a participation-based memory ("autobiographical memory"), while video experience was transformed into observation-based memory ("episodic memory"), which suggested that VR could realize functions of true reality in terms of memory.

VR is more effective for transportation safety education and trainings, compared with conventional computer or television-based strategies. Schwebel et al. (2014) conducted randomized controlled trials to evaluate the efficacy of different pedestrian safety training methods among 231 seven and eight-year-old children. The participants were randomly assigned to 4 groups: A no-contact control group, training using VR, individualized streetside training, and computer-based video/websites training group. Results revealed that children in the VR training and individualized field training group performed better on pedestrian safety than those in the computer-based training and the control group.

Immersive VR environments are helpful in engaging and motivating users, generating curiosity, and gathering feedback. In this context, Bakr et al. (2018) used CAVE, a room-based immersive VR system, to demonstrate two architectural designs to seven kindergarteners to incorporate their responses and feedbacks into the design.[2] Results showed that the children were highly engaged and fully immersed in the virtual environment. They interacted positively with the VR environment as they touched the screen several times, played on the virtual grass on the floor, and used other body languages to interact with the environment.

Besides cognitive training, transportation researchers employ VR to replace unsafe, difficult and costly experiments with indoor VR experiments. Tapiro et al. (2018) examined the difficulties pedestrians face while crossing an intersection as they are subjected to environmental distractions.[3] Results indicated that pedestrians picked shorter crosswalks and took more time to initiate a crossing when subjected to environmental distractions. Visual distractions had a higher influence on people's crossing behaviors than auditory distractions, and the impact of distractions on kids was more prominent compared to adults. Planning for such an experiment in the real world would have been extremely dangerous, but with VR, researchers are able to simulate risky scenarios and study user behavior in such situations.

VR systems further provide seamless interaction with the virtual environment, allowing experimental researchers to observe and analyze user behavior. Participants in VR experiments can be exposed to specific situations and asked to complete a task, while their natural reaction to the situations is recorded. For example, in Rogé's study, elderly drivers' ability to detect pedestrians and two-wheelers was tested using a car-driving simulator.[4] Participants were asked to flash the headlights as soon as they see a pedestrian or a two-wheeler in the virtual road environment.

1 Experiences in Virtual Reality: a Window to Autobiographical Memory. https://link.springer.com/content/pdf/10.1007%2Fs12144-017-9648-y.pdf

2 Virtual reality as a tool for children's participation in kindergarten design process. https://www.sciencedirect.com/science/article/pii/S1110016818301790

3 The effect of environmental distractions on child pedestrian's crossing behavior. https://www.sciencedirect.com/science/article/pii/S0925753517312821

4 Useful visual field training: A way to improve elderly car drivers' ability to detect vulnerable road users. https://www.sciencedirect.com/science/article/pii/S1369847814001223

Because of their programmability, VR also enables the researchers to precisely control and replicate the environment of an experiment. For instance, in one of the environment distraction conditions in Tapiro et al.'s study, a continuous loud noise of 75 dB was added to the environment.

Additionally, with pre-programmed virtual environments, portable VR hardware, and accessible user interfaces, VR systems that require minimal staff support are made possible for schools, enterprises and other agencies with training demands. Johnsen et al. (2014) developed a movable and self-sufficient mixed-reality virtual game for children in a summer camp to increase their physical activity.[6] The system required the researchers to be on-site for support only during the initial orientation and during the end surveys for the product.

Market Study (technology and service providers for research and trainings)

VR Headsets

Leading companies that have commercialized VR hardware products include Oculus, HTC, Samsung, and Sony. VR headsets are one of the most popular VR devices, widely used in research work to adjust the virtual environment as per the user's movements. Headsets such as Oculus Rift and HTC Vive are particularly common for these purposes as they work well with personal computers, unlike other products that are designed for smartphones (e.g. Google Daydream View and Samsung Gear VR) and special environments (e.g. Sony PlayStation VR).

In a study on the usage of VR for pedestrian safety, researchers developed an effective pedestrian simulator using the HTC Vive VR headset, as it has a motion tracking system that can work over a comparatively larger area, enabling the user to move freely across a bigger space. Comparatively, Oculus Rift requires an additional motion tracking system, but has a lower price with easier setup. Both headsets use stereoscopic 3D imaging to display an immersive virtual environment that appears to have depth.

Figure 1. HTC Re Vive (left) and Oculus Rift (right) VR headsets in use (Source: U.S. Air Force photo by Senior Airman Alexa Culbert and Maurizio Pesce, Flickr)

As evident from the above-mentioned experiment, VR headsets can be conjoined with other hardware to create pedestrian, driving or cycling simulators. Birenboim et al. (2019) used Oculus Rift and an electromagnetic trainer to develop a cycling simulator to study cyclists' environmental preferences.[7] Besides the headset and the trainer, a standard bicycle and a computer were also a part of the simulator.

Both HTC Vive and Oculus Rift also offer commercialized or tailored VR solutions for enterprises and professional users. HTC Vive provides VR solutions combining HMD devices with controllers, base stations and room-scale stages at different pricing levels, ranging from $499 to $1,599. Oculus Rift S, the latest PC-powered headset costs $399, while Oculus also provides VR solutions that can be combined with a $130 controller to run on smartphones.

5 Mixed Reality Virtual Pets to Reduce Childhood Obesity. https://www.researchgate.net/publication/260996197

6 Efficacy of virtual reality in pedestrian safety research. https://www.sciencedirect.com/science/article/pii/S0003687017300662

7 The utilization of immersive virtual environments for the investigation of environmental preferences. https://www.sciencedirect.com/science/article/pii/S0169204618312350

CAVE / Projection VR

Cave Automatic Virtual Environment (CAVE) solutions for certain room sizes and customized solutions developed to fit given room configurations are also available. For instance, Mechdyne company, a CAVE hardware provider, offers a system of projection walls, stereos and projectors, while another CAVE provider, VisCube, provides CAVE systems for different room sizes.[8]

Software/Virtual Environment

The software used to create the virtual environment in VR systems is mostly developed by external service providers such as Unity and Vizard, both of which are widely used for VR content development in a variety of fields, such as games, films and animation, transportation, manufacturing, healthcare, architecture, engineering, and construction. In transportation research experiments, Unity has been extensively used by researchers to simulate a variety of street-crossing and driving scenarios,[9] while Vizard has also been used by researchers to develop a pedestrian simulator.[10]

Unity offers subscription plans ranging from $0 to $125 per month for individuals, hobbyists, professionals, and studios, with some eligibility requirements. In addition, the company also promotes tailored plans for enterprises and free Unity licenses for education purposes.

WorldViz, the parent company of Vizard, offers VR solutions ranging from a single software program to integrated systems comprised of both hardware and software.[11] Their hardware devices include backpack VR units, projection displays, tracking systems, and basic headsets. The company has provided integrated VR solutions building comprehensive VR labs for Stanford University as well as Georgia State University.

Virtual Reality Applications

VR provides an interesting and effective alternative that can address a variety of transportation issues, ranging from designing complex infrastructure/facilities to improving the safety of transportation users. Using case studies and examples, this section highlights how VR can be applied to four major areas in transportation, namely, public outreach and engagement, transportation behavioral research, wayfinding and signage design, and safety education and training.

Public Outreach and Engagement

Public engagement is the process of incorporating stakeholder/community feedback and participation in a planning project. It serves the goal of promoting transparency, receiving feedback, and being inclusive in the development and realization of planning projects. The process provides a platform for stakeholders and local communities to voice their preferences and needs, while planners and designers get the opportunity to determine how well a certain project responds to the needs and wishes of the community.

Public engagement can take on a variety of forms ranging from conducting anonymous surveys to public outreach and public in-person meetings. While anonymous surveys provide an excellent means to gather public feedback, public engagement is an interactive process that includes involving the community in shaping or creating a vision for a particular project. In one of North Jersey Transportation Planning Authority (NJTPA)'s projects, VTC's Public Engagement and Outreach Team (POET) designed a faux radio booth to add some fun to the process of collecting community feedback on transportation and planning issues.[12] Creative outreach such as the radio booth provides an

8 Visbox VisCube Models. http://www.visbox.com/VisCube-models.pdf

9 Efficacy of virtual reality in pedestrian safety research. https://www.sciencedirect.com/science/article/pii/S0003687017300662; The effect of environmental distractions on child pedestrian's crossing behavior. https://www.sciencedirect.com/science/article/pii/S0925753517312821; Useful visual field training: A way to improve elderly car drivers' ability to detect vulnerable road users. https://www.sciencedirect.com/science/article/pii/S1369847814001223

10 Examining how different measurement approaches impact safety outcomes in child pedestrian research: Implications for research and prevention. https://www.sciencedirect.com/science/article/pii/S0001457517302142

11 WorldViz - VIRTUAL REALITY SOLUTIONS. https://www.worldviz.com/virtual-reality-solutions

12 POET – Public Outreach and Engagement Team. http://vtc.rutgers.edu/poet/

excellent opportunity to collect a variety of feedback as you are able to reach audiences that may not otherwise be interested in participating in the planning process.

It can be rewarding as well as fun to engage with the public, but it is also immensely important for conceptualizing, developing, and implementing a project. Without it, a project can create bigger problems for a local community or come up against unsurmountable backlash. Because of the ease of visualization that VR warrantees, it can make it easier and much more fun to interact and communicate with the public.

Public Engagement Using Virtual Reality

The values of VR could help planners in communicating their ideas and engaging with the public during project demonstrations. Compared to traditional methods such as 2D drawings, renderings and 360˚ images, users can find it much easier to experience and explore a design, compare alternatives, brainstorm ideas, or point out specific elements of a project through an immersive virtual experience. Researchers have also found that compared to 2D plans on paper or 360˚ images on a computer screen, VR can increase civic participation in offering feedback on designing public spaces.[13] In a general sense, Howard and Gaborit (2007) demonstrated that VR can enhance public participation in the planning process, by analyzing and comparing the results of one group that engaged in an urban planning simulation survey with another group that took part in a traditional general public survey.[14]

Figure 2. I-74 Bridge prior to improvements (left) and an artist's rendering of the new bridge on the right (Source: Wikimedia Commons, Before and Artist's Rendering)

Case Study: I-74 Mississippi River Bridge Replacement VR Demonstration

The Iowa Department of Transportation (IDOT) collaborated with Iowa State University to develop a VR demonstration of the I-74 Mississippi River Bridge replacement project, attracting a number of citizens to observe, advise, and provide feedback on the project. The project demonstrations were also uploaded on social media websites such as YouTube where concerned locals could also comment. For example, one user asked why the toll booths on the old I-74 bridge were included in the new design, and IDOT was able to respond with a clarification pointing out that the old toll booths held historical significance and were included as "a fun piece of history."[15]

According to Annette Jeffers, the automation engineer of IDOT, the development of the 3D fully-immersive environment of the I-74 Mississippi River Bridge replacement project cost less than $50,000. The 3D model of the bridge was developed by a consultant, while other 3D content for the simulation was designed by IDOT's Office of Bridges and Structures and Iowa State University.[16] The demonstration allowed the users to experience the new design in different ways. For instance, one could drive or fly through the bridge, walk along its pedestrian path, or observe the view from its scenic deck.

13 Using Virtual Reality to Increase Civic Participation in Designing Public Spaces. https://urbanux.nl/wp-content/uploads/2018/10/2018_ECDG.pdf

14 Using Virtual Environment Technology to Improve Public Participation in Urban Planning Process. https://ascelibrary.org/doi/full/10.1061/%28ASCE%290733-9488%282007%29133%3A4%28233%29

15 I-74 Mississippi River Bridge Virtual Reality Experience. https://www.youtube.com/watch?v=mtobPt9f51k

16 Get A Great View Of The New I-74 Bridge At Rock Island Public Library. https://www.quadcities.com/articles/local/get-a-great-view-of-the-new-i-74-bridge-at-rock-island-public-library/

17 I-74 Mississippi River Bridge - Outreach. https://i74riverbridge.com/outreach/meetings.aspx

The VR demonstration was available at multiple places across the city and was supplemented by public meetings and presentations.[17] Additionally, IDOT brought it to the 2018 Transportation Research Board meeting where it was complimented for the presentation of the structural details.

Transportation Behavioral Research

Transportation researchers often believe that understanding people's behavior is the key to encouraging safe behaviors and dissuading unsafe road etiquette among users. Their studies are often related to understanding unsafe driving behaviors (such as speeding and not wearing a seat belt), and bicyclist and pedestrian street crossing behaviors, with a special focus on specific age groups (such as kids, young adults and older adults) that are commonly overrepresented in traffic fatalities/injuries. A better or more in-depth understanding of such issues could help researchers in developing countermeasures encouraging safe road behaviors and decreasing traffic fatalities/injuries due to human errors.

In the past, behavioral studies have been carried out using research methodologies such as personal interviews, intercept interviews/surveys, direct observation, and focus groups. However, studies have to rely on self-reported data with most of these techniques, especially while studying risky behaviors because carrying out planned experiments for them in the real world could be dangerous. VR creates new opportunities in transportation research by allowing the researchers to study user behavior in any real world scenario through direct observation and without the added danger of moving vehicles.

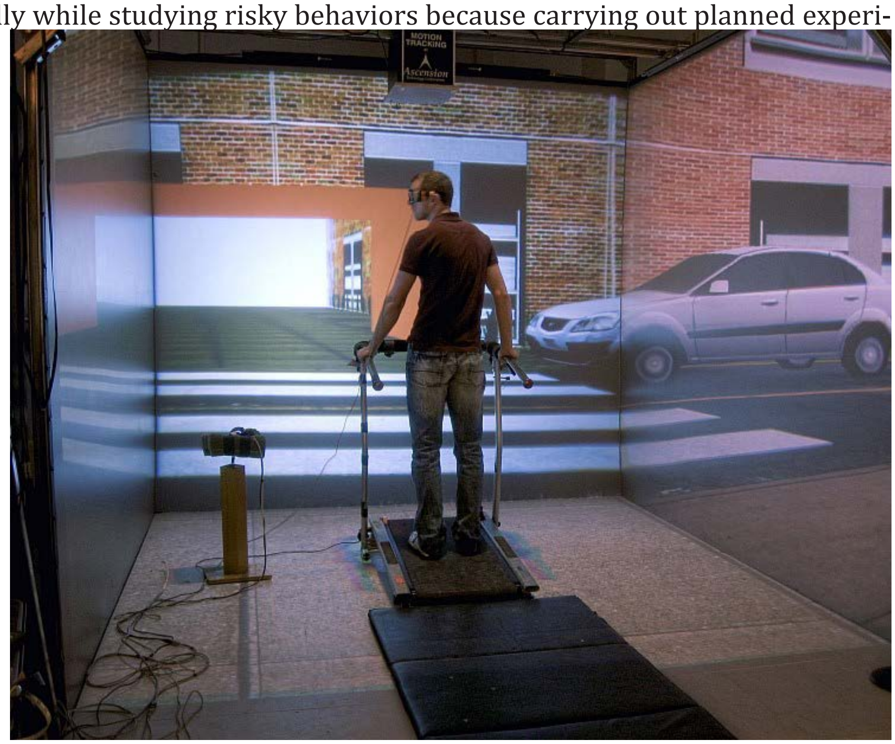

Figure 3. Pedestrian Safety Crossing Virtual Reality CAVE Environment at Beckman Institute, University of Illinois at Urbana-Champaign. (Source: Illinois Simulator Laboratory, University of Illinois)

VR and the Study of User Behavior

Using VR, transportation researchers are able to conduct precisely controlled experiments studying risky behaviors that can lead to dangerous traffic conditions. The technology allows researchers to put people in tricky situations, and observe their reactions. For example, Plumert et al. (2014) explored youth bicyclists' behavior as they rode through six "traffic-filled" unsignalized intersections.[18] In another study, researchers asked kids to complete two tasks in a given time, studying their crossing behavior (not using the crosswalks or running across the road) while they were in a hurry.[19]

VR also allows the researchers to study age or health-related difficulties faced by people navigating through a street.[20] For instance, Meir et al. (2015) explored children's ability to identify potentially dangerous traffic situations such as obstructed field of views due to parked vehicles, and curving roads.[21] The study was used to inform training programs designed to educate children about pedestrian road safety. Such experiments would not have been possible in reality, but with VR, new opportunities for

18 Children's Perception of Gap Affordances: Bicycling across Traffic-Filled Intersections in an Immersive Virtual Environment. https://psychology.uiowa.edu/sites/psychology.uiowa.edu/files/groups/plumert/files/PlumertGapAffordances04.pdf

19 Do child pedestrians deliberately take risks when they are in a hurry? An experimental study on a simulator. https://www.sciencedirect.com/science/article/pii/S1369847812000666

20 Towards an explanation of age-related difficulties in crossing a two-way street. https://www.sciencedirect.com/science/article/pii/S0001457515300798

21 Are child-pedestrians able to identify hazardous traffic situations? Measuring their abilities in a virtual reality environment. https://www.sciencedirect.com/science/article/pii/S092575351500171X

researchers to study user behavior and draw up recommendation for increasing traffic safety have arisen.

Case Study: Effects of Cell Phone Distraction on Pedestrian Street-Crossing Behaviors

Researchers at the University of Illinois, Urbana-Champaign conducted a study to explore the effects of cell phone distraction on adults' (18-30 years old) street crossing behaviors.[22] The study used Beckman Institutes's Virtual Reality CAVE environment to model an unsignalized intersection between a two-way road and an alleyway. The environment performed the following three major functions: displaying the virtual environment, tracking user motions, and synchronizing the virtual environment accordingly. The setup included three-walls (about 10 feet X 9 feet in size) and a floor CAVE system along with a LifeGear Walkease manual treadmill to track the pedestrian's movements and adjust the virtual environment accordingly. The virtual environment was used to control all the characteristics of the intersection including the traffic density and speed of oncoming vehicles on the road.

The research involved 36 university students as participants, each of whom was asked to cross through the intersection under three distraction conditions: no distraction; listening to music through headphones; and conversing on a cell phone. The trials were structured in a balanced and random manner across the three scenarios and all the participants. The results were used to compare the street-crossing performance of the adults across the three scenarios.

The results indicated that adults talking on a phone take more time to initiate and complete a crossing compared to when they are listening to music or undistracted. Hence, individuals on phones took more time to safely cross the intersection, on average. Other than that, the study did not suggest that crossing the modeled intersection while talking on a phone is extremely dangerous. In the discussion, the research team pointed out that their results are consistent with past research that showed slower walking by people talking on phones.

Wayfinding and Signage Design

Wayfinding is fundamental to transportation planning and circulation in indoor and outdoor spaces. It refers to a system of resources that helps people navigate through physical spaces such as roads/intersections and building hallways. GPS and directional signage are two wayfinding tools that are commonly used by designers to guide people through a space.

It is often challenging for people to quickly and successfully navigate through complex indoor environments, atypical road intersections, and unknown places. Signage in buildings is often out of people's line of sight, unclear and confusing, because of which users require extra assistance in getting accurate directions. At roads and intersections, their placement is occasionally untimely, while they are also often obstructed by other objects such as shrubs and trees.

Additionally, it can be really tricky and time-consuming to use navigation tools such as GPS in foreign places with unknown routes and layouts. One challenge that individuals routinely face while using GPS is user orientation. Even users familiar with map reading have issues with orientation and can find themselves walking several blocks in the wrong direction. VR in wayfinding brings forth new ways to tackle these issues and come up with an efficient wayfinding system that saves time, and improves safety and movement of people across a space.

Testing Infrastructure Plans and Designs through VR

Designers coming up with wayfinding plans for indoor and outdoor spaces have found it extremely useful to visualize their designs and test them for inefficiencies and grey areas using VR. The technology allows them to experience their designs in real-time and validate whether their signage is clear and effectively placed. Through VR, designers can also gather objective feedback from other people who are unfamiliar with a design. They can ask these people to navigate to given destinations in the virtual environment and use their performance to identify potential issues with the design and revise them accordingly.

Using these techniques, designers can come up with more efficient wayfinding systems that improve vehicle and passenger flow in physical environments. It can be extremely useful while designing indoor structures such as transport terminals as wayfinding is one of the main functions of these building. Most recently, this technology was used in the expansion of the Admiralty Station in Hong Kong for designing and validating its 970 signs.[23]

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22 Pedestrians, vehicles, and cell phones. https://www.sciencedirect.com/science/article/pii/S0001457509002681

23 Testing the signage and wayfinding system before the station is built. https://www.arup.com/projects/admiralty-station-3d-wayfinding

In outdoor environments, the technology was recently used by Traffic Operations and Safety (TOPS) Laboratory at the University of Wisconsin-Madison to virtually drive through a road interchange in Wisconsin to audit the placement of traffic signs and signals at the interchange.24 The following case study assesses the efficacy of horizontal versus vertical signage in an indoor environment through VR. It also highlights potential applications of the study findings using augmented reality.

Case Study: Evaluating Indoor Wayfinding Performance of Horizontal and Vertical Signage

A team studying at the Technical University of Lisbon in Portugal assessed the efficacy of vertical and horizontal signage designs in a virtual indoor environment.[25] Even though the experiment is conducted for an "indoor" environment, much of the same thought-process applies to outdoor wayfinding. Vertical signage in the study refers to what most would consider a traditional sign in which destinations are sequentially listed along with arrows directing the people in their respective directions. Horizontal signage in the study refers to a color coded list of destinations complemented by colored strips on the floor guiding the user to the respective locations. Fifty-four participants were randomly distributed between the three scenarios – one with horizontal signage, one with vertical signage, and a third scenario without any signage.

The researchers compared the wayfinding performance of the participants in the three scenarios and found horizontal signage to be the most efficient, while the control scenario (no signage) was found to be the least efficient. Their findings indicated that participants assigned to the horizontal signage scenario took the least time, traveled the shortest distance, and took the least number of pauses to reach their destination compared to the other two scenarios.

Augmented reality (AR), an off-shoot of VR where computer-generated images are projected onto real images, has been used for wayfinding using horizontal signage. The technology is leveraged by 22 Miles, a digital wayfinding and signage company that used an augmented reality wayfinding mobile app to guide the attendees at the 2018 Digital Signage Expo.[26] The app used the phone's camera to virtually superimpose a guiding line with arrows on the real world in real-time, directing people to their destinations.

Figure 4. Example of Augmented Reality (Source: Wikimedia Commons)

The above case studies show how virtual and augmented reality have been used to address signage designs and navigational orientation issues in wayfinding. Although the case studies focused on wayfinding in indoor environment, the same can be applied to outdoor settings as well.

Safety Education and Training

Educating pedestrians, bicyclists and drivers in proper road etiquette is essential in creating a safe multi-modal transportation environment. Many safety education and training programs are in place to teach users how to act on roads, handle conflicts, and create a safe road environment for all modes.

First-time driver's license applicants in New Jersey are required to receive driving education and pass a knowledge test before obtaining a learner's permit. Additionally, safe driving training courses such as defensive driving and distracted driving are also routinely offered for motor vehicle drivers. Drivers learn to handle tricky situations

24 Virtual Road Safety Audit of the Watertown Plank Road Interchange. https://topslab.wisc.edu/research/tse/virtual-road-safety-audit-of-the-watertown-plank-road-interchange/

25 Indoor Human Wayfinding Performance Using Verticaland Horizontal Signage in Virtual Reality. http://areas.fmh.ulisboa.pt/~pnoriega/vrdesign/files/08.pdf

26 Wayfinding enters the world of augmented, virtual reality. https://www.digitalsignagefederation.org/wayfinding-enters-the-world-of-augmented-virtual-reality/#.XjHIZPZFzcs

and avoid conflict through these courses, which is also valued by the car insurance companies for their safety implications. While users do not need a mandatory training to practice other modes of transportation such as walking and bicycling, people teach their kids how to safely cross street intersections and bike on streets at an early age. Currently, the Voorhees Transportation Center (VTC) assists with bicycle rodeos, an event aimed to educate children in safe biking practices.[27] Having pedestrians, bicyclists and drivers learn how to act on roads assists in reducing the likelihood of traffic collisions in the future. The programs also help in realizing complete streets and multi-modal streets where multiple modes of transportation can safely co-exist with each other.

Figure 5. Example of VR Driving Simulation (Source: Nan Palmero, Flickr)

Additionally, training safety personnel such as traffic policemen and roadside maintenance crews is also crucial for the safety of road users. The personnel learn to handle normal as well as complicated transportation situations and weather conditions to keep the roads safe and functioning. As an imaginative and immersive medium, VR has huge implications in improving the effectiveness of such programs and producing long-lasting results.

VR as a Medium for Education and Training

VR could be utilized to help enhance training beneficial to all road users and traffic safety/maintenance personnel. The technology provides users the opportunity to virtually witness a traffic situation in real-time without risking any individual's wellbeing in reality. The technology replaces expensive driving simulators that are frequently used while training commercial drivers and pilots, lowering costs and increasing safety.[28]

While educating drivers, pedestrians, bicyclists and other micro-mobility users, VR allows learners to experience and traverse a number of scenarios and weather conditions. Having experienced the situation in real-time, users not only understand better but also retain the learnings much better compared to learning through safety manuals and in-class presentations.

While training safety staff, the technology can recreate challenges that the workers might face in the real world, and allow them to experience it as well as test their performance. The following case study explores Rutgers Center for Advanced Infrastructure and Transportation's project to provide job training to roadside crews using VR.

Case Study: Job Training for Roadside Crews by Center for Advanced Infrastructure and Transportation

Rutgers Center for Advanced Infrastructure and Transportation (CAIT) has developed several VR simulations to provide safe and effective job training to roadside crews.[29] A team haded by Dr. Jie Gong, an associate professor in the Department of Civil and Environmental Engineering, has successfully created two simulation environments: The Stan Musial Veterans Memorial Bridge, which connects St. Clair County, Illinois to St. Louis Missouri, and an in-service pump station. The simulations are operated using the following three instruments – HTC Vive controllers, a headset, and a mobile backpack VR computing system – making it possible for job training facilities to be set up in any location.

Aside from improved safety during training, these simulations allow trainees to experience key scenarios that often occur in reality, but may not occur during training on an actual site. In an environment where every variable can be

27 NJAIM Kicks Off the Summer with Bicycle Rodeos. http://njbikeped.org/njaim-kicks-off-the-summer-with-bicycle-rodeos/

28 How Virtual Reality is driving innovation in transport training. https://absorbreality.com/how-virtual-reality-is-driving-innovation-in-transport-training/; UPS Enhances Driver Safety Training With Virtual Reality. https://www.pressroom.ups.com/pressroom/ContentDetailsViewer.page?ConceptType=PressReleases&id=1560261872163-765; VR for Transportation. https://elitevrtraining.com/transportation/

29 Rutgers CAIT is Using VR to Make Workforce Training Safer and More Efficient. https://cait.rutgers.edu/rutgers-cait-is-using-vr-to-make-workforce-training-safer-and-more-efficient/

controlled – including weather, visibility and "traffic types" like car speed, and driver recklessness – almost no scenario is out of reach. In the bridge scenario, for example, bridge settings can be adjusted to simulate cracks in the bridge for training the users to mark a work zone and inspect the cracks. The users are able to simulate laying down or picking up traffic cones in the environment by using their controller to move forward or simply by walking towards the cone, and then picking it up by extending their hand to the object, pressing a trigger and retracting their hand. They can navigate to any part of the bridge in this way to inspect essential structural components. In addition, users can also interact with other objects such as working vehicles and signs.

One of the primary goals of this project is to offer transportation entities the opportunity to provide a safe means to train their employees for a broad range of scenarios that they may encounter during bridge inspections and work zone setup.

Findings

This white paper explored ways in which Virtual Reality can be used to positively impact transportation planning and policy. Virtual Reality allows users to immerse themselves in and interact with numerous lifelike situations – a quality that can be valuable in numerous NJBPRC and SRTS initiatives. It can be extremely useful for interacting with people, observing user behavior, visualizing/testing designs, and education and training purposes. We believe that Virtual Reality can be incorporated with NJBPRC and SRTS's existing efforts, including regional complete streets workshops, pedestrian safety enforcement and education (PSE), bicycle safety education and enforcement (BSEE), crossing guard training, bicycle rodeos, active-transportation planning, policy and research, as well as classroom trainings and education, to name a few.

Similar to how CAIT's roadside crew training program used Virtual Reality, NJBPRC conducted education and training workshops such as PSE, BSEE, crossing guard training, bicycle rodeos, and regional complete streets workshops, can also benefit from the use of this technology. For instance, with the help of a stationary cycling unit in addition to other hardware, Virtual Reality can be used to conduct bicycle rodeos to teach adults and children how to ride safely in a street environment. The technology can also assist in training children to avoid some of the common threats associated with bicycling on roads. This can similarly be applied to assist drivers to practice sharing roads with micro-mobility users.

The environment in the simulation can be used to train individuals in unfavorable situations such as driving, riding or walking at night, which can also offer VTC with valuable insights on how people behave in certain situations such as in low visibility. Additionally, Virtual Reality can also be used to further advance Safe Routes to School (SRTS), another program at Rutgers that focuses on education and training to improve walking and bicycling environment near schools.

In its simplest form, Virtual Reality can be a useful asset in teaching children how to safely walk or bike on streets, while more advanced versions of Virtual Reality may alter how roadside safety education and training is perceived and conducted.

Additionally, the technology can also benefit regional complete street projects in demonstrating proposed designs and interacting with the local community members and stakeholder. Using a VR headset and a motion tracking system, Virtual reality can allow the local community to experience a remodeled intersection or street segment, and provide feedback and ideas.

This paper indicated that Virtual Reality can be effectively used for outreach and engagement, research, design, and education and training purposes. It can be particularly useful for training children and staff, and studying risky scenarios that cannot be recreated in the real world. The findings warrant further discussion with NJDOT on how this technology can be incorporated to advance VTC initiatives.