No Boundaries Synthesis

Maintenance Training with Virtual Reality Technologies

CTC & Associates LLC
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Executive Summary

Maintenance managers in state transportation agencies strive to ensure maintenance staff are well-trained in safety, skills, procedures and processes. Technological advances have expanded options for potential training tools. Members of the No Boundaries Transportation Maintenance Innovations pooled fund study were interested in exploring the use of virtual reality (VR) technologies, including simulators, for maintenance training purposes.

Using a national survey of state departments of transportation (DOTs) and a search of publicly available domestic literature and in-progress research, this synthesis sought to:

- Assess current DOT use or interest in using VR for maintenance training.
- Discover the benefits of using VR technologies for training maintenance staff.
- Explore general indications of cost, perceived barriers, or other organizational or operational requirements to use VR.

Responses were received from 22 state DOTs, including 15 of the 20 No Boundaries member states and 22 of the 39 Clear Roads members. In addition to survey responses, several states have sponsored research that examines the use of VR technologies for maintenance training. Summaries of these efforts are incorporated into the survey findings and presented as related resources.

The full report that follows this executive summary details specific states' experiences or interest in VR technologies for training, including the benefits and challenges perceived or encountered. Included are four case studies that provide more detail on selected states' experiences using these advanced training tools, with "points of practice" summarizing strategies or findings of particular interest.

Current Uses of Virtual Reality Technology for Maintenance Training

Nearly half of responding states reported having some experience using VR for training staff and described the training purposes, benefits realized and challenges encountered:

- ***Common uses***. While some respondents reported using VR simulators for commercial driver's license (CDL) or other heavy equipment training, the majority of state DOT experiences relate to snowplow simulators.
- ***Benefits***. Several respondents described simulators as a useful training tool for employees who don't have real-world experience with a snowplow or other equipment, lessening the risk of harmful or costly mistakes and reducing wear and tear on the equipment. Some respondents pointed to the realistic scenarios created by the simulators as good practice for staff, particularly those situations that mimic snow and other weather conditions, equipment issues and even driver fatigue.
- ***Challenges.*** Most respondents cite cost as the main disadvantage of VR technology. Other challenges include the lack of adequate VR equipment or time to train all staff. Lastly, some simulator trainees complain of motion sickness.

Since the early 2000s, several states have sponsored research on the use of VR technologies for maintenance training. A January 2023 Indiana DOT report considering the use of this technology for agency training provides a concise historical perspective on this decades-long period of research.

Case studies in this synthesis include additional details of the experiences of four states:

- ***California (Caltrans)***. A 2021 research study examined the possible use of heavy equipment simulators to support Caltrans training efforts at the Maintenance Equipment Training Academy (META) located in the agency's Sacramento headquarters. The heavy equipment simulators provided by Caterpillar and John Deere for use on a trial basis assessed the benefits to Caltrans staff and were considered for use as stationary units maintained at the META or mobile units that could be transported across the state.

  Key project findings include the following:

  - Both simulator models (Caterpillar and John Deere) are useful in exposing new employees and other trainees to heavy equipment in a safe environment.
  - Training with simulators can be evaluated using trainee and trainer surveys. Trainees' performance on the simulators can also be assessed with built-in metrics while performing tasks on the simulators.
  - Up to five simulators can be comfortably mounted in an existing 48-foot trailer to transport the simulators across the state.
  - Cost–benefit analyses found that:
    - Simulator training has much lower ownership and operating costs when compared to training on actual heavy equipment.
    - Training at the META with stationary simulators has the lowest cost per student if the students are local.

  To date, Caltrans has not funded follow-on research to optimize training on the heavy equipment simulators.

- ***Indiana***. Multiple research efforts sponsored by Indiana DOT date back to 2020 and consider the use of VR and other training formats to provide different types of training for agency employees:

  - *Snowplow operator training.* Recently published research is preparing Indiana DOT to implement snowplow driving simulators that will also be used to support the agency's new CDL training program. The second phase of this research began in the fall of 2023. The ongoing research effort includes the purchase of two simulators, development of an Indiana DOT snowplow training curriculum, evaluation of the effectiveness of simulator training and an examination of the logistics for a potential partnership with the Indiana Local Technical Assistance Program.
  - *Workforce development training*. Researchers compared the efficacy of training methods that included traditional classroom training; learning management systems (gamification); computer simulation; VR (completely virtual world); and augmented reality (AR), which inserts additional computer-generated information into the user's view of a real-world scene. Findings indicate that AR leads to the highest level of learning retention. VR and gamification, respectively, are the next two best methods of training for knowledge retention, with computer virtual simulations having the least amount of knowledge retained over baseline training methods.
  - *Crack sealing training*. Researchers developing a VR crack sealing training process found it difficult to recreate a VR environment that was sufficiently realistic in simulating the crack sealing work to be completed while also including all of the variables found in a real-world environment.

  - *Bridge inspection training*. A July 2023 research report documents researchers' efforts to develop a VR-based testbed to measure and analyze the "variability among inspectors in examination and documentation practices in steel and concrete bridges in Indiana." The new VR application includes eight inspection tools and can be used to take screenshots for written reports and automatically generate statistical analyses.

- ***Ohio***. In 2018, Ohio DOT began investigating the potential use of simulation-based training for its snowplow operators. The multiphase research effort continues with a study in progress expected to conclude in August 2024.

  At the end of the initial phase of this research, Ohio DOT purchased the Doron SP660 snowplow simulator. This unit is larger than other simulators—it is similar in size to an actual plow truck's cabin—and includes controls to simulate operation of certain elements of a plow truck, such as the plow blade or wing blade. The simulator is housed inside a trailer to allow for transporting it to locations around the state. Also housed in the trailer are the computers that run the simulator's hardware and software, and a computer workstation for the trainer to set up the training scenarios and observe the training session.

  The second phase of the agency's research effort focused on confirming the simulator setup to prepare Ohio DOT for regular use of the simulator and developing simulator scenarios and related training materials. Researchers developed exercises to test or demonstrate snowplow operator skills and guidebooks for use by the trainee drivers and instructors that describe exercises that are based on the simulator's scenarios. The research team also trained Ohio DOT training staff on simulator usage and operations, and updated Ohio DOT's current snow and ice training materials to include content related to the simulator.

- ***Utah***. Utah DOT started exploring training snowplow operators with simulators two decades ago and now uses simulators for a variety of maintenance training:

  - *Heavy equipment training*. The agency's three Vortex desktop simulators are used for staff training on excavators, snowplows, backhoes, skid steers, motor graders, front end loaders and cranes. Each Utah DOT region houses the simulators for a set time period and manages how the training occurs based on needs.

  - *Equipment inspection training*. A technician can virtually walk around a piece of equipment and will be prompted to inspect equipment components and describe the potential impacts if that equipment element is not properly maintained. Benefits of this type of simulator-based training include quicker field training on real equipment and less wear and tear on the actual equipment.

  The agency also contracts with L3Harris Technologies, Inc., for use of a snowplow simulator. Transportation technicians are given approximately 1.5 hours of training time in the simulator per year due to cost.

Agencies Considering Using Virtual Reality Technologies for Maintenance Training

Eight of the 22 responding states reported interest in using VR technologies for maintenance training and are primarily in the research phases of exploration. Like states with VR experience, those interested in exploring the use cited cost as a primary barrier. Some indicated a keen interest in learning what other states are doing with VR technologies in their maintenance programs and how they have overcome common barriers.

Agencies Not Currently Considering Virtual Reality Technologies for Maintenance Training

Three responding DOTs reported their agencies are not currently using nor considering using simulators for maintenance training. As with most other respondents, the cost of VR equipment is a primary barrier, along with the logistics of making the equipment available agencywide and ensuring staff are available and prepared to do the training.

Findings from the Literature

Publications and other relevant resources are provided throughout this synthesis report to supplement descriptions of current agency practices, particularly for the four case studies appearing in Chapter 2 and highlighted on pages 2 and 3 of this executive summary. More resources are provided in Chapter 3 of this report, which presents the results of a search of publicly available domestic resources to supplement survey findings. Selected findings from the publications and other resources cited in Chapter 3 are presented below.

- *National guidance*. Resources published in 2023 describe VR training systems for first responders and the use of VR to simulate the traffic and other hazards that maintenance workers are likely to encounter in work zones to "enhance worker preparedness for hazards." An April 2019 Federal Highway Administration report describes AR-based software applications that can be used as inspection tools for bridges and bridge management.
- *State practices*. The case studies presented in Chapter 2 were preceded by a historical perspective describing the simulator-based training experiences of six states over more than two decades. Citations for the studies conducted by Arizona and Illinois DOTs, referenced in Chapter 2, are presented in this section of Chapter 3. Also included are a research report from Missouri DOT that describes immersive work zone inspection training using VR and a Texas DOT report highlighting the agency's "attempt to explore VR training for the largest segment of our workforce using a topic of critical importance to transportation safety"—work zone traffic control.
- *Related resources*. A 2022 journal article describes the use of group-based VR training for highway construction workers. A performance review appearing in a January 2021 journal article assessed a safety training module using VR technology for workers in the precast/prestressed concrete industry. The analysis found that the VR training was more engaging and provided a good understanding of safety protocols and real-life experience of the precast/prestressed concrete plant.
- *Simulator vendors*. Websites for selected simulator vendors, including those used by the agencies highlighted in this synthesis report, are presented for the following:
    - Caterpillar
    - cmlabs
    - Doron Precision Systems, Inc.
    - FAAC Incorporated
    - John Deere, Deere and Company
    - L3Harris Technologies, Inc.
    - Simformotion, LLC
    - Virage Simulation Inc.

1 Introduction

1.1 Background

Participants at the fall 2023 No Boundaries Transportation Maintenance Innovations peer exchange in Suffolk, Virginia, discussed the potential for using virtual reality (VR) technologies to provide training to maintenance staff performing a range of functions. VR technologies include driving simulators, headsets and desktop computer applications that agencies may use to ensure maintenance staff members have the skills and knowledge they need to safely and effectively operate snowplows and other heavy equipment, or conduct maintenance tasks in the field.

This synthesis gathered information to address No Boundaries members' interest in exploring VR technologies for training in safety, skill-building and other maintenance functions. Additionally, general indications concerning costs, perceived barriers, and other organizational or operational considerations are summarized.

1.2 Project Description

CTC & Associates employed a two-part strategy to gather information for this project:

- *Survey of state transportation agencies.* A survey of all 50 states and the District of Columbia gathered anecdotal evidence to assess the current state of practice regarding the use of VR technologies for maintenance training.
- *Literature search*. An examination of publicly available domestic resources and in-progress research supplemented survey findings.

While the survey received responses from almost half of the state transportation agencies, the conclusions cannot be generalized to all state departments of transportation (DOTs). However, the information presented can inform agency practices and interest in using VR technologies for maintenance training.

2 Survey Findings

2.1 Background

CTC & Associates gathered information from state transportation agencies through an online survey of No Boundaries and Clear Roads member state transportation agencies and select members of the American Association of State Highway and Transportation Officials (AASHTO) Committee on Maintenance and Committee on Research and Innovation. The survey received 26 complete or mostly complete responses from 22 state transportation agencies, including 15 of the 20 No Boundaries member states and 22 of the 39 Clear Roads members.

- Alaska
- California (Caltrans)
- Colorado
- Connecticut
- Idaho
- Illinois
- Indiana
- Iowa
- Kansas
- Maine
- Maryland
- Massachusetts
- Michigan
- Missouri
- Montana
- Nebraska
- New Hampshire
- New York
- North Dakota
- Ohio
- Texas
- Utah

Survey questions are provided in Appendix A. The full text of survey responses, including respondent contact information, has been provided to No Boundaries separately as a supplement to this report. The survey findings highlighted below are supplemented by findings from the literature, as noted. Additional publications and related resources appear in Chapter 3.

Four topic areas are examined in this chapter:

- Agencies using VR technologies for maintenance training.
- Case studies describing the use of VR technologies for maintenance training.
- Agencies considering the use of VR technologies.
- Agencies not currently considering the use of VR technologies.

2.2 Agencies Using Virtual Reality Technologies for Maintenance Training

State DOT maintenance programs manage a diverse range of functions, from keeping roads and highways clear of snow and ice to constructing roads and keeping machinery operating. Staff safety and the efficiency and effectiveness of completing these functions are priorities supported by various training methods.

While VR is a relatively new technology, state DOTs have used simulators for many years, primarily to train snowplow drivers. No survey respondents reported knowing of any other agency uses of VR or simulators outside maintenance programs.

Eleven state DOT respondents currently use or have tested VR technologies in their maintenance programs. Case studies delve more deeply into the experiences of four agencies—Caltrans and Indiana, Ohio and Utah DOTs—responding to the survey.

See page 13 for historical perspective and case studies describing simulator-based training for heavy equipment and snowplow operators at Caltrans and Indiana, Ohio and Utah DOTs.

Experiences of the remaining seven agencies—Idaho Transportation Department (ITD) and Colorado, Connecticut, Iowa, Montana, Nebraska and Texas—are summarized below. Practices, benefits and challenges are noted for each, along with comments on agency buy-in and future plans provided by some respondents. In some cases, additional insight derived from agency research or other publications is provided. Themes emerging from the survey data include the benefits and challenges summarized below:

- *Benefits*. Several respondents noted advantages of snowplow simulators for new employees who may not have any experience with the equipment (*Colorado*, *Connecticut*, *Idaho* and *Nebraska*). Respondents also highlighted the importance of reducing wear on the equipment (*Iowa*) and creating real-world scenarios without the risk (*Connecticut*, *Iowa* and *Texas*).
- *Challenges*. Most DOTs recognized cost as the main disadvantage of simulator technology (*Connecticut*, *Idaho*, *Montana*, *Nebraska* and *Texas*). While some respondents cited real-world scenarios as a benefit, others said aspects of these technologies are not realistic enough (*Nebraska* and *Texas*). Time to train all operators can be a challenge (*Colorado* and *Iowa*), and motion sickness can be a common complaint when using simulators (*Iowa* and *Texas*).

Point of Practice Getting the Most from Simulator-Based Training

Agencies are realizing various advantages of using simulators to train employees to operate heavy equipment:

- *Reduces risk*. Colorado DOT reports the risk of equipment operation failures is removed, and new hires with little to no experience can become familiar with the equipment.
- *Creates realistic scenarios*. ITD's simulator can create real-world situations such as night driving, fog, flat tires and even driver fatigue, so students can safely learn how to respond.
- *Reduces equipment wear and tear*. Iowa DOT appreciates offering realistic training for operators without putting additional miles and hours on actual equipment**.**
- *Simulates environmental conditions*. Texas DOT can train snowplow operators in the absence of snow and winter events so that operators are ready when these events occur.

Colorado Department of Transportation

Practice: Uses a mobile simulation lab for snowplow training, front-end loader operations and entry level driver training.

Benefits: Works well as a training tool for both new and veteran employees. New hires receive the bulk of the simulator training to reinforce classroom instruction and introduce them to equipment they may have little to no experience using. Simulators also remove the risk of equipment operation failures.

Challenges: Takes time for everyone to go through the curriculum, and scenario-based training necessitates small training groups.

Connecticut Department of Transportation

Practice:	Uses simulators for commercial driver's license (CDL) training, including pretrip inspections and setting sign patterns. Also explored VR and simulators for safety and repair.
Benefits:	Develops real-world situations, especially for plowing snow. Can offer more hours of training to provide familiarity to operators.
Challenges:	Is very expensive. The agency wants to employ a portable unit to expand use in the field and is striving to find the right options to fit its needs.
Future Plans:	Plans to purchase a stationary unit to be permanently housed at agency headquarters that will be used for CDL and snowplow operator training.

Idaho Transportation Department

ITD has used a snowplow simulator to train snowplow operators in agency districts around the state since the mid-2000s. After touring the state for two years with the simulator housed on a trailer, the ITD snowplow simulator was tested by members of the Treasure Valley news media in 2009. Heavy snow, stalled cars and tunnels combined with slippery conditions were simulated to give testers a sense of an ITD snowplow operator shift (Figure 1).

Figure 1. News Reporter Testing ITD Snowplow Simulator

(*Source: The Transporter*, 2019.)

The agency has loaned the simulator to other entities, including the Mountain Home Air Force Base (AFB) southeast of Boise (Figure 2). As described in a 2019 ITD *Transporter* article, the simulator was helpful for aviators who come from tropical climates such as Guam or Puerto Rico and may not have encountered snow.

The Mountain Home AFB's representative recounted several benefits:

- Immediate feedback and evaluation after each lesson by the virtual instructor enhanced student learning.
- Many driving situations are presented, including varying traffic levels and visibility, school zones, speed bumps and lane changing, which students could practice repeatedly without distraction.
- Circumstances such as driver fatigue, flat tires and fog were simulated and practiced.

- The training method was cost-effective—crashing or damaging cars and other property in the simulator had no costs—and was environmentally friendly as no fuel was used.

Figure 2. A Trainee at the Mountain Home AFB Using ITD's Snowplow Simulator

(*Source: The Transporter*, 2019.)

Below is the ITD respondent's feedback on the agency's current simulator-related practices and the **Related Resources** informing this summary.

Practice:	Uses snowplow simulators to help train plow drivers.
Benefits:	Helps new employees gain perspective before ever driving a snowplow.
Challenges:	Is expensive.
Agency Buy-In:	Can be difficult to gain employee acceptance. Some staff members "do not take well to virtual reality." A few have concerns with simulators being seen as toys or video games rather than serious training tools. Like other new initiatives, there are concerns whether the benefits are worth the costs.
Future Plans:	Address ongoing questions in the second phase of the agency's simulator study. The respondent provided no further details about this follow-up research effort.

Related Resources

"ITD Using Snowplow Simulator to Train Drivers Despite Dry Conditions," Sarah Jacobsen, CBS 2 Idaho News, January 11, 2019.
https://idahonews.com/news/local/itd-using-snow-plow-simulator-to-train-drivers-despite-dry-conditions
This article and video describe ITD's snowplow simulator operation and a news reporter's experience.

"A Leisurely Winter Drive? Not Behind the Wheel of ITD's Snowplow Simulator," Mel Coulter, *The Transporter*, Idaho Transportation Department, November 13, 2009.
https://apps.itd.idaho.gov/apps/mediamanagermvc/transporter/2009/111309_Trans/111309_SimulatorDrive.html
This article describes a news reporter's experience with ITD's snowplow simulator.

"Plow Simulator Offers Real-World Training to Airmen," Carl Vaughn, *The Transporter*, Idaho Transportation Department, January 4, 2019.
https://apps.itd.idaho.gov/Apps/MediaManagerMVC/transporter/2019/010419_Trans/010419_PlowSimulator.html
This article describes the Mountain Home AFB's use of the ITD snowplow simulator to train airmen from all over the world.

Iowa Department of Transportation

In 2005, Iowa DOT purchased an L-3 Communications snowplow driving simulator to train new and returning snowplow operators. Housed in a 22-foot trailer, the simulator was moved across the state to train staff members at all six agency districts throughout the year. In 2006 and 2007, the agency commissioned a study to "(1) assess the use of this simulator as a training tool and (2) examine personality and other characteristics associated with being an experienced snowplow operator." This research effort produced two reports that are cited on page 11 of this synthesis report.

Over time, the agency determined that this simulator unit was no longer operating optimally. Its aging software could not be updated and the training scenarios no longer reflected the real-life experiences operators could expect to encounter in the field. As a 2019 *Transportation Matters* blog post describes, Iowa DOT elected to contract with L3Harris to provide a simulator and conduct the agency's snowplow operator simulator training. The new simulator included scenarios that matched Iowa's winter weather and roadway conditions and provided for enhanced movement in the simulator seat, which allows trainees to "feel the rumble of driving and have to react to being bounced around in some of the scenarios, like they would in the actual snowplow."

In October and November 2019, Iowa DOT moved its simulator trailer throughout Iowa, spending one week in each of the agency's six districts. A two-hour training session was provided to four employees at a time, with four sessions each day for a week, allowing for the training of 80 employees in each district. The agency has concluded that contracting out the training is more cost-effective than developing and maintaining its own simulator.

Below is feedback from the Iowa DOT respondent about the agency's current simulator-related practices and the **Related Resources** informing this summary.

Practice: Provides a contracted two-hour snowplow operator course and a two-hour tow plow operator course each year before the winter season.

Benefits: Offers realistic training for operators without putting additional miles and hours on actual equipment**.**

Challenges: Accommodate staff needs. Some staff members cannot participate due to motion sickness. It is also difficult to get all seasonal operators through the training due to time and schedule constraints.

Agency Buy-In: Obtain agency support. When simulator use started, management needed to see that the training cost was worth the benefit. Pushback from field staff has gone down significantly since the training program began.

Related Resources

"A Safe Way to Get the Feel for Plowing Snow," Blog Post, *Transportation Matters*, Iowa Department of Transportation, January 17, 2019.
https://www.transportationmatters.iowadot.gov/2019/01/a-safe-way-to-get-the-feel-for-plowing-snow.html
This Iowa DOT blog entry describes training for snowplow operators from a private firm with a snowplow training simulator that traveled to each district to provide training.

"Iowa's Winter Maintenance Technologies Research," Dennis Burkheimer, *Research News*, Bureau of Research and Technology, Iowa Department of Transportation, August 2009.
https://www.iowadot.gov/research/pdf/Research%20News%20August%202009.pdf
This research brief describes Iowa DOT's use of the simulator the agency purchased in 2005.

Evaluation of Virtual Reality Snowplow Simulator Training: Final Report, Christopher M. Masciocchi, Veronica J. Dark and Derrick Parkhurst, Iowa Department of Transportation, January 2007.
https://cdn-wordpress.webspec.cloud/intrans.iastate.edu/uploads/2018/03/snowplow_simulator_final.pdf
From the abstract: Each winter, Iowa Department of Transportation (Iowa DOT) maintenance operators are responsible for plowing snow off federal and state roads in Iowa. Drivers typically work long shifts under treacherous conditions. In addition to properly navigating the vehicle, drivers are required to operate several plowing mechanisms simultaneously, such as plow controls and salt spreaders. There is little opportunity for practicing these skills in real-world situations. A virtual reality training program would provide operators with the opportunity to practice these skills under realistic yet safe conditions, as well as provide basic training to novice or less-experienced operators.

In order to provide such training to snowplow operators in Iowa, the Iowa DOT purchased a snowplow simulator. The Iowa DOT commissioned a study through Iowa State University designed to (1) assess the use of this simulator as a training tool and (2) examine personality and other characteristics associated with being an experienced snowplow operator.

The results of this study suggest that Iowa DOT operators of all ages and levels of experience enjoyed and seemed to benefit from virtual reality snowplow simulator training. Simulator sickness ratings were relatively low, implying that the simulator is appropriate for training a wide range of Iowa DOT operators. Many reported that simulator training was the most useful aspect of training for them.

Evaluation of Virtual Reality Snowplow Simulator Training: A Literature Review, Christopher M. Masciocchi, Veronica J. Dark and Derrick Parkhurst, Iowa Department of Transportation, September 2006.
https://publications.iowa.gov/4466/1/snowplow_simulator.pdf
From the abstract: Recent technological advancements have made driving simulators a desirable training and research tool. This literature review discusses much of the recent research establishing simulator fidelity and espousing its applicability. Additionally, this report provides a summary of behavioral and eye tracking research involving driving simulators. Other research topics include comparisons between novice and expert drivers' behavioral patterns, methods for avoiding cybersickness in virtual

environments, and a synopsis of current personality measures with respect to job performance and driving performance.

This literature review coincides with a study designed to examine the effectiveness of virtual reality snowplow simulator training for current maintenance operators, using the TranSim VS III truck and snowplow simulator recently purchased by the Iowa DOT.

Point of Practice Getting Simulators Out to the Districts

Transportation departments have different practices for making simulator training accessible across an agency.

- *Colorado DOT* conducts the bulk of its simulator training at the central Training Academy, with the simulator lab trailer traveling during summer months upon request.
- *Idaho Transportation Department* moves its simulator to districts around the state as well as loaning it out to other entities such as the U.S. Air Force.
- *Iowa DOT* contractors take a simulator around the state, spending one week to train up to 80 employees in each district.
- *Nebraska DOT* plans to start with a simulator housed at its Maintenance Academy and would like to eventually purchase a second mobile simulator.

Montana Department of Transportation

Practice: Uses a simulator to provide plow training for about 50 maintenance technicians.

Benefits: Receives a positive response to the training from technicians.

Challenges: Has concern about the costs of contracting for simulator training or purchasing a simulator.

Nebraska Department of Transportation

Practice: Hopes to provide snowplow operator and motor grader training.

Benefits: Exposes new operators to equipment controls and situations.

Challenges: Is expensive. Also, simulation may not build skill as well as operating the actual equipment with an experienced operator riding along to provide instruction and guidance. Time between simulator training and actual experience could be too great for content to be adequately retained.

Future Plans: Seeks to purchase a heavy equipment simulator for new hires at the Maintenance Academy, and a VR simulator for road construction safety training. The agency is exploring Simformotion and other vendors, and beginning a formal bidding process. Future plans include the purchase of a mobile simulator to share around the state.

Related Resources

"Snowplow Simulator Prepares Workers for Winter Conditions," Sara Wilder, KNOP News 2, October 26, 2016.
https://www.knopnews2.com/content/news/Preparing-workers-for-driving-in-snow-conditions--398775041.html
This article describes the Nebraska Department of Roads' (which became the Nebraska DOT in 2017) use of a snowplow simulator to train drivers.

Texas Department of Transportation

Practice: Uses snowplow simulators to help train plow drivers.

Benefits: Because snowfall and opportunities to train during winter events are limited, helps operators know what they might encounter.

Challenges: Can be difficult to gain employee acceptance. Some students experience motion sickness using the simulators, and costs are substantial, which may divert funds from other projects. Additionally, while simulator training seems effective for staff with little or no real-world experience, some more experienced operators feel simulators are not "real life," and seat time during an actual event is the only training needed.

> *The use of the snowplow simulator was better for those who had little to no real-world experience.*
>
> — Clear Roads Texas DOT member

2.3 Case Studies: Using Virtual Reality Technologies for Maintenance Training

Historical Perspective

Researchers who recently evaluated the use of simulator technology to train Indiana DOT snowplow operators began their investigation with a deep dive into the history of state transportation agency use of simulators for this training purpose. (This January 2023 Indiana DOT report is cited on page 23.)

As the authors of the Indiana DOT report noted, "Our results help support INDOT in defining to use or not simulators in their snowplow driver training events by identifying relevant factors from previous and current state DOT experiences and academic literature. Furthermore, our findings provide information about the current state of the practice in the use of driving simulators for snowplow driver training for all American state DOTs." Below is a brief summary of the previous research the Indiana DOT researchers describe in more detail in their report.

All but one of the publications highlighted below are cited within this synthesis report, either within the case studies appearing later in this chapter or in Chapter 3, Findings from the Literature.

- *Pennsylvania* (2002). This is the earliest of the state DOT simulator experiences that were documented in a final report. (This report does not appear to be publicly available online.) The project involved a motion-based Pennsylvania State University simulator unit used for research. Researchers were optimistic about the potential of simulators but "cautioned PennDOT about the potential costs, and recommended that any action towards using a simulator for training be based on careful planning."
- *Utah* (2004). In this study commissioned by Utah DOT, results "provide a baseline for other state DOTs considering the use of driving simulators for snowplow driver training." Researchers noted challenges with data reporting and interpretation that make it difficult to assess simulator training impacts on accidents, maintenance and fuel management.
- *Arizona* (2006/2007). Two studies commissioned by Arizona DOT included a literature review and a qualitative and quantitative evaluation of two years of simulator snowplow training in the state. Researchers presented 14 short-term recommendations that included increasing seat time for novice drivers, using more scenarios that are specific to drivers' needs and experience, and conducting separate training for novices and experienced drivers. Six long-term recommendations included improving simulator realism to address local issues and establishing consistent training among the agency's districts.

  A second project evaluated the potential benefits associated with fuel and maintenance when using driving simulators to train snowplow drivers. Researchers' recommendations included:

  - Improving data collection and reliability related to fuel and maintenance costs.
  - Improving gear shifting training.
  - Improving training for automatic transmission techniques for fuel economy.
  - Considering simulator downtime and maintenance.
- *Iowa* (2006/2007). Two studies commissioned by Iowa DOT addressed the use of driving simulators for snowplow training. The first project reviewed literature and included an evaluation of findings from the 2004 Utah DOT study. The second project "discusses the experimental findings related to the deployment of snowplow training that included a driving simulator in Iowa."
- *Illinois* (2011). In addition to also evaluating previous state DOT reports on the use of simulators for snowplow training, this report "aimed to evaluate the effectiveness of the simulator training in two phases—(1) right after the training program and (2) end-of-snow-season follow-up evaluation." The researcher recommended using the simulator as a complement to—not a replacement for—behind-the-wheel training.
- *Ohio* (2022). Like other researchers examining the use of driving simulators to train snowplow operators, Ohio DOT researchers conducted a two-phase effort. The first portion of the research summarized the results of a literature review and assessed Ohio DOT's snowplow operator training needs. In Phase II of the project, a simulator located at the University of Cincinnati was used to develop customized plow routes; a training curriculum that included five modules for snowplow operator training was also developed. Researchers cautioned that use of simulators comes with some risks, including cybersickness and possible malfunctioning of the hardware and software. Researchers also recommended that Ohio DOT track the performance of drivers using the simulator and their trainers using typical training protocols. The agency's latest research effort is highlighted in the **Point of Practice** below.

Point of Practice Research in Progress: Ohio DOT's Research Continues

A research project expected to conclude in August 2024 will "complete the development of a customized simulator training program" for Ohio DOT. As the research team notes, "The intent of this project is to develop customized simulation that can mimic truck operations, actual Ohio roads, and influences from snow and ice on both the truck and the plow. This will allow drivers to hone their skills before taking a plow onto a busy Ohio highway/interstate during a snow event."

Find out more about the Ohio DOT snowplow simulator project on page 24 of this synthesis report.

The Indiana DOT report also identified factors agencies might consider when selecting a driving simulator to deliver snowplow training (see Table 3.1 on page 15 of the report). Below is a brief summary of these factors:

- Hardware
  - Enhanced realism (high refresh rate, motion-based platform, high-fidelity graphic and haptic feedback).

Note: *Haptic feedback* is described by the Indiana DOT research team as sensory feedback through touch. In this research effort, the haptic feedback provided to trainees includes "vibrations mimicking real-world conditions."

  - Increase driver engagement.
  - Reduce cybersickness.
- Software
  - Adaptability.
  - Collection of training data.
  - Reality cues.
  - Variable road design scenarios for improved decision-making.
- Training
  - Time on simulator.
  - Cost of training.
- Potential long-term impacts
  - Reduced operation costs (increased fuel efficiency).
  - Increase in fleet reliability (decrease in maintenance costs).
  - Accident reduction (increased public safety).
  - Assessing effectiveness of simulator training (collecting and validating data).

Agency Case Studies

The case studies below summarize simulator experience to train heavy equipment and snowplow operators at four transportation agencies: Caltrans, and Indiana, Ohio and Utah DOTs. Survey findings supplemented by a review of agency-specific research and related publications informed the case studies.

Caltrans

Caltrans launched a research effort in 2021 to evaluate the use of a simulator to train heavy equipment operators. The publications highlighted in this case study appear in **Related Resources** beginning on page 18.

Simulator-Based Heavy Equipment Operator Training

To better train its maintenance personnel, Caltrans sponsored a 2021 research study that "evaluated the applicability and benefits of state-of-the-art heavy equipment simulators to support training efforts at the Maintenance Equipment Training Academy (META) and in Caltrans districts." META training is available to all Caltrans maintenance employees and focuses on preparing Caltrans maintenance workers and heavy equipment operators to safely operate trucks, snowplows and other motorized equipment. Researchers considered whether the simulators should be stationary, maintained at the META in the agency's Sacramento headquarters, or mobile, which would allow the agency to train personnel across the state, including more remote rural areas.

Research Findings

Researchers procured heavy equipment simulators provided by Caterpillar and John Deere for use on a trial basis to assess benefits to Caltrans staff (Figure 3). The simulators were installed at the META. Researchers conducted three primary tasks:

- Develop training plans (how much training is needed and for how long).
- Analyze simulator mobility for possible transport of the simulators across the state.
- Develop and analyze traveling scenarios to transport the simulators to determine feasibility and cost-effectiveness.

Key project findings include the following:

- Both simulator models (Caterpillar and John Deere) are useful in exposing new employees and other trainees to heavy equipment in a safe environment.
- Training with simulators can be evaluated using trainee and trainer surveys. Trainees' performance on the simulators can also be assessed with built-in metrics while performing tasks on the simulators.
- Up to five simulators can be comfortably mounted in an existing 48-foot trailer to transport the simulators across the state.

Figure 3. Simulators Installed at Caltrans' META Facility

(*Source*: Caltrans, December 2022.)

- A cost–benefit analysis that compared simulator use to training on actual heavy equipment showed much lower ownership and operating costs for the simulators. Worksheets were developed for comparing costs and training effectiveness ratios.

- A cost–benefit analysis of a stationary simulator as compared to a mobile unit indicated that training at the META with stationary simulators has the lowest cost per student if the students are local. Researchers noted that training some local students with traveling simulators is "still very cost-effective even for training in higher per diem counties, such as San Diego County." Table 1, an excerpt from Table 5.9 appearing on page 33 of the Caltrans report, highlights a selection of specific costs based on student location and travel.

Table 1. Total and Per Student Costs for Selected Stationary and Traveling Training Scenarios

(*Source*: Caltrans, December 2022.)

Scenario	Scenario description	Total costs ($)	Costs per student ($)
Scenario 1: Students Visit META for Training from Sacramento (SAC)	Lowest possible cost scenario; only train students less than 50 miles from META (18 students total, 3 trainers)	36,480	2,027
Scenario 2: Students Visit META for Training from Close to SAC	Students need to be compensated for their drive to META, but do not require per diem (18 students total, 3 trainers)	41,621	2,312
Scenario 4: Trainers Drive to HMS Close to SAC	Trainers drive the simulator truck to a Highway Maintenance Station [HMS] close to META and park it there for 2 weeks; they then drive to and from the local HMS via car (12 students total, 2 trainers)	25,531	2,128
Scenario 5: Trainers Drive to Redding	Trainers drive the simulator truck to Redding [and] stay for 2 weeks (12 students total, 2 trainers)	28,866	2,405
Scenario 6: Trainers Drive to San Diego	Trainers drive the simulator truck to San Diego [and] stay for 2 weeks (12 students total, 2 trainers)	31,335	2,611

Two training plans were developed for excavator and grader training: novice and advanced training. The novice training plan, which includes initial Caltrans safety instructions and introductory exposure to motor grader and excavator use, includes a self-guided version that can be provided as a handout for students to follow on their own. The advanced training is a weeklong program focusing on specific equipment and includes both simulator and real equipment training. Both simulator models record performance metrics that can be used to assess trainee performance in each training session.

Researchers recommended the following to enhance future simulator deployment:

- One or more dedicated Caltrans support staff members for simulator maintenance and troubleshooting.
- Sufficient spacing around the simulators for trainer and trainee observation.
- Acquisition of a customized trailer if the simulators are to be transported for training.
- Integration of the simulators into the Caltrans intranet.

Future research recommended by researchers includes:

- Advanced training plans with varying depth and training time on the simulators.
- Exploration of regular use of VR goggles.

- Quantification of simulator training benefits by comparing student groups with and without simulator exposure and related training times on real equipment.
- Generation of more training material.

A proposal for a follow-on research project to optimize training on the heavy equipment simulators is not included in the fiscal year 2023/2024 research plan approved by the Caltrans Division of Research, Innovation and System Information.

Assessing Simulator Use

The Caltrans survey respondent reported the following benefits of using simulators to conduct heavy equipment operator training:

- Reduced downtime on equipment due to damage.
- No fuel costs.
- No maintenance.
- Elimination of land impacts that would be incurred by trainees practicing with real equipment.
- Lower carbon footprint.
- Accessibility. Training can be done anytime of the year and is not affected by weather.

The Caltrans respondent also reported occasional challenges, such as unanticipated malfunctioning of the simulators, periodic software issues and VR headsets that failed to interface with the Caterpillar simulator. Space limitations preclude the agency from retaining as many simulator units as desired in-house.

Leadership supports the use of simulators and staff enjoys using them. While agency leaders are open to considering the purchase of additional simulators, unit costs are high, and Caltrans' ability to purchase additional units is limited by budget constraints.

Related Resources

Evaluation of Heavy Equipment Simulator Systems, B. S. Linke, W. A. White, K. Yen, W. Watson, F. Fashanu, J. Rodriguez and I. Garretson, California Department of Transportation, December 2022.
https://ahmct.ucdavis.edu/sites/g/files/dgvnsk8581/files/inline-files/Final_report_Task%203833.pdf
From the abstract: The California Department of Transportation (Caltrans) needs to provide the best available training to its Maintenance personnel, particularly those operating heavy equipment. This research study evaluated the applicability and benefits of state-of-the-art heavy equipment simulators to support training efforts at the Maintenance Equipment Training Academy (META) and in Caltrans districts. Initial trainings showed that the simulators can be integrated easily into training efforts and were received positively by trainers and users. Training plan proposals were developed. The cost benefits of simulator use over real equipment were estimated. Simulators can be transported in a trailer from district to district, which was evaluated in a cost–benefit analysis as well as discussed with trailer layouts and logistics.

"Evaluation of Heavy Equipment Simulator Systems," *Research Results*, California Department of Transportation, February 2023.
https://dot.ca.gov/-/media/dot-media/programs/research-innovation-system-information/documents/research-results/task3833-rrs-02-23-a11y.pdf
This research brief summarizes the completed research cited above.

Indiana Department of Transportation

Indiana DOT has sponsored multiple research efforts dating back to 2020 that consider the use of VR and other training formats to provide different types of training for agency employees. The VR application garnering the most significant level of ongoing interest is the use of driving simulators to provide snowplow operator training. The publications highlighted in this case study appear in **Related Resources** beginning on page 22.

Simulator-Based Snowplow Operator Training

Indiana DOT requires a wide range of positions to carry a CDL and participate in snow removal during major snow events. These employees are referred to as *transfer drivers*. For many of these employees, operating a snowplow during a snowstorm is the only time they will drive a truck all year. A snowplow simulator provides an additional tool to train new snowplow drivers, and especially transfer drivers, increasing their seat time and enhancing their skills to be better prepared when they are asked to step in and plow snow.

Research Findings and In-Progress Research

Recently published research is preparing Indiana DOT to implement snowplow driving simulators that will also be used to support the agency's new CDL training program. The recently concluded project examined other state DOT use of simulators for snowplow operator training and available technology.

See page 13 for a discussion of the Indiana DOT researchers' examination of other state DOTs' use of simulators for snowplow operator training.

The project's survey of state DOTs using or contemplating the use of a snowplow simulator identified the top four decision-making factors when purchasing a snowplow driving simulator:

- Perceived long-term effects on public safety.
- Cost of simulator-based training.
- Ease of simulator training.
- Ability to replicate vehicle dynamics and characteristics.

Simulator costs identified by one of the four driving simulator manufacturers that researchers surveyed ranged from a low of $110,000 to a high of $300,000 per simulator.

The simulator modules used in study simulator tests included wing, rear and tow plow configurations employed under a range of winter weather road conditions (dry, wet, snow and black ice); daytime and nighttime conditions; and various traffic levels.

Point of Practice Keeping It Real

As noted in a March 2023 Indiana DOT blog post, "The simulators can match INDOT's truck controls and feedback so that it responds like an actual truck. When simulator users lower a blade, make a turn or encounter new conditions, they feel it in the steering wheel. The seat platform is mounted to move and adjust so the driver feels like they are in a truck cab."

Read more about the agency's snowplow simulator testing in the *INDOT Insider* blog entry INDOT Tests Snowplow Simulator.

Researchers recommended beginning simulator implementation with a pilot "focused on the best adoption practices for INDOT." After the pilot, the agency was advised to consider how the simulator might be used for other training purposes. Other recommendations included:

- Reviewing snowplow-related accident reporting to track risky situations and trouble locations to inform training recommendations.
- Further research to explore the effect of experience, work assignment (full time or transfer snowplow drivers) and simulator seat time, and a better understanding of the effectiveness of simulator training for snowplow driving.

The second phase of this research began in the fall of 2023. The ongoing research effort includes the purchase of two simulators, development of an Indiana DOT snowplow training curriculum, evaluation of the effectiveness of simulator training and an examination of the logistics for a potential partnership with the Indiana Local Technical Assistance Program (LTAP).

The Indiana LTAP center at Purdue University expanded its physical and online spaces in fiscal year 2022 to house and support a Virage driving simulator used in snowplow and new driver CDL training for local transportation agencies. This training program includes some truck inspection modules. In the ongoing research, Indiana DOT is considering an option for LTAP and Indiana DOT to house simulators at Indiana DOT facilities and provide standardized training to both state and local transportation agency drivers. This approach would allow LTAP to meet its goal of having a simulator within an hour of every local transportation agency partner in the state. Figure 4 shows two examples of snowplow driving simulators.

Figure 4. Snowplow Driving Simulator Installations from Virage (left) and L3Harris (right)

(*Source*: Indiana DOT, January 2023).

Assessing Simulator Use

Benefits of the driving simulators for snowplow operator and CDL training are still being defined as the current phase of research moves toward simulator implementation. Researchers faced initial challenges in determining the best curriculum and length of training. Staff reluctance to use the simulators for training has been limited, though a small number of employees experience motion sickness when operating the simulator. A more limited concern is the perception that simulators are "toys" or video games and not effective training tools.

Phase I of the research effort indicated that when the agency purchases training simulators, it should experience a positive return on investment (ROI) through accident reduction. Training snowplow operators without having both a driver and an instructor on the road is also expected to provide savings in time, fuel and equipment wear. Any ongoing concerns with regard to whether simulator training is worth its cost are expected to be addressed through the findings of the Phase II research now underway.

Limiting factors in establishing a simulator-based training program for snowplow operators include space and access. Truck/plow simulators require adequate space for a stationary setup at a single location and then require trainees, who may come from across the state, to travel to use it. A mobile trailer that houses the simulator solves the access issue but creates additional up-front costs and presents equipment maintenance issues. When providing the simulator training in-house rather than contracting it out, agencies must also train the trainers.

Other Uses of Virtual Reality for Training

Indiana DOT has explored other uses of VR for training, beginning with a 2021 study that explored various training formats, including VR and augmented reality (AR).

Workforce Development Training

Partnering with Purdue University, Indiana DOT assessed the "feasibility of using new technology tools for safety training." Researchers compared the attributes of the following training methods:

- Traditional training (classroom and presentations).
- Learning management systems (gamification).
- Computer simulation.
- VR (completely virtual world).
- AR (technology that inserts additional information generated by a computer into the user's view of a real-world scene).

Researchers identified five key takeaways of the research:

- Participative programs such as role-plays, demonstrations of safety devices and risk mapping are some of the best practices.
- Established research studies provided significant support to the researchers' hypothesis that new technology tools are more effective and interactive compared to traditional learning.
- Implementation of new technology tools should be planned based on a defined risk index and optimization model to "ensure better worker performance and perception of the course content in alignment with the severity of that work attribute."
- A spreadsheet-based optimization model was developed to choose the optimal mix of training tools to attain the desired level of risk reduction. This tool "can enable INDOT managers to manage risk cost-efficiently."
- AR leads to the highest level of learning retention. VR and gamification, respectively, are the next two best methods of training for knowledge retention, with computer virtual simulations having the least amount of knowledge retained over baseline training methods.

Research results indicate the following anticipated benefits:

- Improved training program development.
- Higher interactivity and long-term retention.
- Opportunity to reduce work zone risk.

As the survey respondent noted, the number of trainees who must participate to make it cost-effective to develop in-house VR programming is fairly high, particularly for a single state. Therefore, it is difficult to justify the ROI for VR-based training if the programming needed must be created from the ground up. The respondent further noted that this training study was one of the factors that led Indiana DOT to focus on driving simulators as the agency's point of entry into VR-based training. Also factoring into the decision to move forward with snowplow operator simulator training was the ready availability of commercial options and the driving simulator's capacity to meet the training needs of a large number of employees.

Crack Sealing Training

In another research effort, Indiana DOT sought to apply the lessons learned through the examination of training formats described above. Indiana DOT, in partnership with Purdue University, created a VR crack sealing training process. Researchers found it difficult to recreate a VR environment that was sufficiently realistic in simulating the crack sealing work to be completed while also including all of the variables found in a real-world environment. Other concerns related to the purchase and maintenance of enough VR headsets and hand controllers across multiple locations to allow for widespread training opportunities within the agency.

The final report describing this research project does not appear to be publicly available online.

Bridge Inspection Training

A July 2023 research report documents researchers' efforts to develop a VR-based testbed to measure and analyze the "variability among inspectors in examination and documentation practices in steel and concrete bridges in Indiana." Researchers modeled nine types of defects, among them efflorescence, cracking, corrosion, spalling and delamination. Eight inspection tools were "recreated in the VR scene, such as chain drag, hammer, scratch or wire brush, flashlight and tape measure." Inspectors can also use the VR application to take screenshots that complement a written report or to automatically generate a statistical analysis that provides for greater consistency among inspectors.

Assessing Other Uses of Virtual Reality for Training

The Indiana DOT survey respondent noted that building virtual environments for roadway maintenance and other asset management-based practices will require industrywide investment to offset the high development cost. He commented further that curves, elevation changes, slopes on rights of way, rip-rap, creeks/streams, under- and overpasses, culverts, trees, tall grass and traffic all present variables not found in less complex simulation environments such as the construction of commercial buildings.

Related Resources

Investigating Consistency Among Bridge Inspectors Using Simulated Virtual Reality Testbed, Mohammad Jahanshahi, Shirley J. Dyke, Luis David Fernandez Vasquez, Nikkhil Vijaya Sankar and Yu-Ting Huang, Indiana Department of Transportation, July 2023.
https://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=3397&context=jtrp
From the abstract: The current condition of U.S. infrastructure requires a data-driven, risk-based approach to asset management. In the case of bridges, inspectors in every state visit these structures and collect data, and based on the information they report, state departments evaluate bridge conditions, predict deterioration, and make repair and retrofit decisions. However, the capacity of inspectors for defect detection might vary due to several factors, such as the inspectors' experience or eyesight, which results in differences when reporting their results. Through the development of a virtual reality (VR)-based testbed, the variability among inspectors in examination and documentation practices

in steel and concrete bridges in Indiana will be measured and analyzed. As a result, training programs could be enhanced according to the outcome analyses of the VR system.

"INDOT Tests Snowplow Simulator," Blog Post, *INDOT Insider*, Indiana Department of Transportation, March 2023.
https://www.in.gov/indot/about-indot/Blog/indot-tests-snowplow-simulator/
This blog post describes select employees' feedback "for the research project in conjunction with the Indiana Local Technical Assistance Program, Purdue University and Joint Transportation Research Program. If successful, the simulators could provide training for new drivers, saving time, fuel and equipment maintenance."

Synthesis Study on Employing Snowplow Driving Simulators in Training, Luciana Debs, Yanchao Zheng, Jesutoba Ademiloye, Yunfeng Chen and Jiansong Zhang, Indiana Department of Transportation, January 2023.
https://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=3373&context=jtrp
From the abstract: The present study synthesizes information from previous literature, revises current information from INDOT, and surveys other state DOTs to identify the benefits and challenges of driving simulators for snowplow driver training. … Based on the findings, the researchers recommend that INDOT continues to explore the use of driving simulators for training purposes in addition to the yearly snowplow driver training, due [to] the ability to reinforce learning in a safe environment. Moreover, the research team suggests the following areas for further research: evaluating optimal simulator "seat time," peer learning in simulator training, and the impact of experience level and work assignment in the perception of driving simulator training effectiveness.

Evaluation of Current Technologies for Training, Web Apps and New Technologies, Ananth V. Iyer, Steven R. Dunlop, Dutt J. Thakkar, Sayak Mishra, Apoorva Banerjee, Apurwa Gokhale, Karan Shah, Ali Faiz, Aman Arora, Preeti Awasthi and Matthew Gebbie, Indiana Department of Transportation, March 2021.
https://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=3295&context=jtrp
From the abstract: This report details the activities conducted to assess the feasibility of using new technology tools for safety training. Utilizing established research studies, risk frameworks and vendor quotations, we compared the different attributes of training methods such as Traditional Training (classroom/presentations), LMS (Learning Management System) based gamification, Computer Simulation, Virtual Reality (VR) and Augmented Reality (AR). The anticipated benefits include improved training program development, higher interactivity and long-term retention, and the chance to reduce work zone risk.

Related Resources:

> **"Evaluation of Current Technologies for Training, Web Apps and New Technologies,"** Ananth V. Iyer, Steven R. Dunlop, Dutt J. Thakkar, Sayak Mishra, Apoorva Banerjee, Apurwa Gokhale, Karan Shah, Ali Faiz, Aman Arora, Preeti Awasthi and Matthew Gebbie, Technical Summary, Joint Transportation Research Program, 2021.
> https://docs.lib.purdue.edu/cgi/viewcontent.cgi?filename=5&article=3295&context=jtrp&type=additional
> This two-page brief provides highlights of the research project cited above.

Optimization Model, Joint Transportation Research Program, 2021.
https://docs.lib.purdue.edu/cgi/viewcontent.cgi?filename=1&article=3295&context=jtrp&type=additional
This Excel workbook presents the optimization model "that provides a suitable mix of training tools for different training modules."

Driving Innovation Forward: 2023 Performance Assessment Report, Local Aid Support, Federal Highway Administration, undated.
https://www.fhwa.dot.gov/clas/pdfs/Driving_Innovation_Forward_LAS_Performance_Assessment_Rpt.pdf
From page 11 of the report (page 13 of the PDF):

> The LTAP center is at Purdue University and in FY 2022 had a monumental year, expanding their physical and online spaces. Their main offices were relocated to a larger space to hold their expanding training opportunities and the classrooms house a driving simulator for use in snowplow and CDL training. As CDL requirements have changed, this simulator will help locals in the training of their employees.

Ohio Department of Transportation

In 2018, Ohio DOT began investigating the potential use of simulation-based training for its snowplow operators. The multiphase research effort continues with a study in progress expected to conclude in August 2024. The publications highlighted in this case study appear in **Related Resources** beginning on page 26.

Simulator-Based Snowplow Operator Training

After examining the potential benefits to Ohio DOT of the use of simulators as part of an overall training program for snowplow operators, researchers considered various simulators available from multiple vendors and conducted driver behavior experiments with the agency's plow drivers.

Research Findings and In-Progress Research

At the end of the initial phase of this research, Ohio DOT purchased the Doron SP660 snowplow simulator. This unit is larger than other simulators—it is similar in size to an actual plow truck's cabin—and includes controls to simulate operation of certain elements of a plow truck, such as the plow blade or wing blade.

> *By allowing drivers to gain experience with a snowplow's operation in a safe and controlled setting before going out onto the road, it is believed [the] safety of both drivers and the motoring public will be improved. Additionally, the further practice will lead to more efficient plowing operations.*
>
> — Ohio DOT *Research Summary*

The simulator sits on a motion base described as "a platform supported by hydraulic cylinders on which the cab rests, and it moves to simulate acceleration, the dropping of the plow blade, etc." The simulator's cab is surrounded by four screens that provide a 240 [degree] view of the outside environment and is outfitted with joystick controls for the trainee to operate the plow blade and other plow components (Figure 5). The simulator is housed inside a trailer to allow for transporting it to

locations around the state (Figure 6). Also housed in the trailer are the computers that run the simulator's hardware and software and a computer workstation for the trainer to set up the training scenarios and observe the training session (Figure 7).

Figure 5. Doron SP660 Snowplow Simulator

(*Source*: Ohio DOT, February 2022.)

Figure 6. Trailer Housing Ohio DOT's Doron Simulator and Its Components

(*Source*: Ohio DOT, February 2022.)

Figure 7. Inside View of Trailer Housing Ohio DOT's Doron Simulator with Trainer Workstation

(*Source*: Ohio DOT, February 2022.)

The second phase of the agency's research effort focused on confirming the simulator setup to prepare Ohio DOT for regular use of the simulator, and developing simulator scenarios and related training materials. Developing the simulator scenarios involved creating virtual maps of 70 miles of Ohio DOT routes using 3D modeling software. These scenarios were based on maps and photos of real-world facilities in three Ohio DOT districts, which allows trainees to hone their skills driving routes that are similar to those they will drive when behind the wheel of a real snowplow. Feedback from snowplow drivers in each district used for the scenarios allowed the research team to enhance the quality of each scenario.

Researchers also developed exercises to test or demonstrate snowplow operator skills. Built-in training scenarios that were accepted for the final training program were supplemented by custom scenarios developed by the research team that allow trainees to practice plowing an intersection or an interstate highway with a narrow median. The research team also developed guidebooks for use by the trainee drivers and instructors that describe exercises that are based on the simulator's scenarios. The research team also trained Ohio DOT training staff on simulator usage and operations, and updated Ohio DOT's current snow and ice training materials to include content related to the simulator.

Assessing Simulator Use

A research project expected to conclude in August 2024 will "complete the development of a customized simulator training program." As the Ohio DOT respondent noted, "We are in the development stages with hopes of having a simulator online within a few months." The respondent also noted simulators could be useful for mowing and paving training.

Related Resources

Research in Progress: Enhancing Current Snow and Ice Training Practices by Incorporating the Use of a Customized Snow and Ice Simulator, Ohio Department of Transportation, start date: August 2022; expected end date: August 2024.
Project description available at https://trid.trb.org/view/1994580
From the project description: Winter maintenance operations are the Ohio Department of Transportation's (ODOT) premier service. ODOT strives to set a standard of excellence through comprehensive planning that includes equipment readiness, truck routing, material inventory control

and training. Over the past few years, staffing at government agencies has been decreasing. As this trend continues ODOT is experiencing a loss of seasoned full-time drivers who have made the "snow warriors" of the past. Much of the replacement[s] are auxiliary and seasonal drivers with little training. The intent of this project is to develop customized simulation that can mimic truck operations, actual Ohio roads and influences from snow and ice on both the truck and the plow. This will allow drivers to hone their skills before taking a plow onto a busy Ohio highway/interstate during a snow event. This research is needed to complete the development of a customized simulator training program.

Evaluate Opportunities to Provide Training Simulation for ODOT Snow and Ice Drivers—Phase 2, John E. Ash, Jiaqi Ma, Mehdi Norouzi, Ming Tang and Xuefu Zhou, Ohio Department of Transportation, February 2022.
https://www.dot.state.oh.us/Divisions/Planning/SPR/Research/reportsandplans/Reports/Final%20Reports/135776%20-%20Final%20Report_2_1_22.pdf
From the abstract: Winter maintenance poses great concerns both during and after the snow and ice season. During winter, snowplow drivers must use equipment (i.e., plow trucks), each valuing up to $200,000, sometimes in severe snowstorms and unfavorable traffic conditions. This poses great safety concerns to both the plow operators and the road users. The complexity of and dangers attached to plowing operations during winter makes it important to ensure plow drivers are equipped with adequate skills to navigate in their environment and be effective while on the job. Recently, the Ohio Department of Transportation (ODOT) noted a desire to enhance the current training offered to snowplow drivers by integrating driving simulation into the overall curriculum. As such, ODOT purchased a snowplow driving simulator to use for this purpose. In this project, the research team helped ODOT set up the simulator, developed and implemented custom training environments and scenarios, and developed training materials to be used in snow and ice driver education training programs by both drivers and instructors. Virtual environments were modeled directly after actual ODOT facilities in order to allow drivers to gain familiarity with the details of their future work environment. Training scenarios were created to allow for teaching and evaluation of specific skills under varying environments in the simulator (e.g., how to plow an intersection). It is the hope of this project that the use of the simulator and developed materials can help ODOT drivers gain more experience before going out onto the road, thus improving their efficiency, as well as safety for both themselves and the motoring public.

Related Resources:

> **"Evaluate Opportunities to Provide Training Simulation for ODOT Snow and Ice Drivers—Phase II**," Research Summary, Ohio Department of Transportation, undated.
> https://www.dot.state.oh.us/Divisions/Planning/SPR/Research/reportsandplans/Reports/Final%20Reports/135776-Final_fact_sheet_2_1_22.pdf
> Below are findings and recommendations from the research summary published as a companion to the final report:
>
> > Based upon the work conducted in the Phase 2 portion of this project, the research team believes that the SP660 driving simulator is a tool of potential value for use in ODOT's snow and ice driver training program.
> >
> > The simulator system is ready for implementation and use in training programs throughout the state and is believed to lead to numerous benefits as discussed above. The research team also recommends an evaluation of snowplow driver performance in the future to assess the effectiveness of the simulator system.

"Evaluating Opportunities to Provide Training Simulation for Snow and Ice Plow Drivers," Adekunle Adebisi, Jiaqi Ma and Ming Tang, *Ohio Transportation Engineering Conference*, October 2019. https://www.otec.transportation.ohio.gov/static/presentations/2019/42/Snowplow_Presentation_OTEC_2019_v2.pdf
This PowerPoint presentation highlights the Ohio DOT research effort, including:

- State-of-the-practice review focusing on state transportation agencies in Arizona, Illinois, Iowa, Minnesota, Texas and Utah.
- Effectiveness of driving simulator training, including cost and operation.
- Driving simulator training alternatives: in-house capability and contractor training.
- Cost–benefit analysis.

Utah Department of Transportation

Utah DOT started exploring training snowplow operators with simulators over two decades ago and now uses simulators for a variety of maintenance training. The publications highlighted in this case study appear in **Related Resources** beginning on page 30.

Simulator-Based Snowplow Operator Training

In 2004, recognizing the safety improvements from using high-fidelity simulators in commercial aviation, Utah DOT sponsored a collaborative study with the University of Utah and General Electric Driver Development (GEDD) to explore simulator use for snowplow drivers. (Researchers completing the 2004 study noted in their report that GEDD, the company developing the Mark II Motion-Based and the TranSim VS III simulators, was acquired by L-3 Communications during the study.) The research included customizing software to model snowplow dynamics, creating scenarios based on Utah DOT needs and developing a training program.

Research Findings

After training 40 snowplow operators with the simulators developed by GEDD (Figures 8 and 9), researchers monitored operators' driving behavior over six months and compared it to drivers who had not received the training. Measures relating to safety, fuel management and maintenance illustrated operators who had simulator training experienced diminished odds of getting in an accident and higher fuel efficiency. Operators reported the training to be realistic and worthwhile.

Figure 8. Mark II Motion-Based Simulator Used in Utah DOT Study

(*Source*: Utah DOT, November 2004.)

Figure 9. TranSim VS Simulator Used in Utah DOT Study
(*Source*: Utah DOT, November 2004.)

Current Simulator-Based Maintenance Training

Snowplow and Other Heavy Equipment Training

As reported by the Utah DOT respondent, the agency currently owns three Vortex desktop simulators for staff training on excavators, snowplows, backhoes, skid steers, motor graders, front end loaders and cranes. Each Utah DOT region houses the simulators for a set time period and manages how the training occurs based on needs, such as when a shed obtains a new piece of equipment and must train crews to use it. The agency also contracts with L3Harris for use of a snowplow simulator. Transportation technicians are given approximately 1.5 hours of training time in the simulator per year due to cost.

Benefits of using simulators for heavy equipment training were noted by the respondent:

- "Gets nerves out" before real equipment is operated.
- Speeds up hands-on training in the field.
- Actual equipment is not always available for training.
- Simulators are cheaper to run than actual equipment.
- Wear and tear on equipment is avoided, and fuel costs are saved.

The agency's primary challenge has been securing upper management buy-in to purchase the simulators due to the high initial cost. However, as the respondent stated, "The cost–benefit ratio was analyzed and [it was] determined that the simulator would actually save money in the long run." The ongoing information technology support needed over the course of many years can become a barrier as the simulator computers need frequent software updates. As the computers are housed in a trailer without internet access, the trailer housing the simulators must be parked near Wi-Fi or a hotspot to receive software updates.

The Utah DOT respondent reported that some transportation technicians experience motion sickness in the simulators, while others prefer to have the haptic or tactile feedback—such as vibrations or the moving chair—that real equipment or a more advanced simulator offer. While younger staff seems to be

very enthusiastic about using the simulators, some older staff and trainers prefer learning and teaching using actual equipment.

Equipment Inspection Training

The respondent reported that simulators used to train equipment inspectors are expected to provide a basic understanding of what to look for before operating equipment. A technician can virtually walk around a piece of equipment and will be prompted to inspect equipment components and describe the potential impacts if that equipment element is not properly maintained.

Benefits of this type of simulator-based training include:

- Quicker field training on real equipment because operators are already familiar with basic items and issues to inspect.
- Less wear and tear on the equipment since an operator has basic knowledge of operations before using it in the field.
- Fuel consumption and wear and tear are covered in the simulator, which helps trainees understand how their operation is affecting the life span and overall health of the equipment.

As the respondent noted, "We've not had a single piece of equipment damaged at our yearly Transportation Technician Academy since buying the simulators." The respondent also reported the following challenges:

- The simulator equipment isn't always the exact same piece of equipment that will be at the trainee's maintenance station.
- Some have said the feel of the seat and controls is different from the real equipment.
- The supply of simulators doesn't always keep up with demand. Spring and fall are the best training times, but demand is high.

Overall consensus is that simulators DO save money in the long run due to saving on fuel, equipment damage and underground asset damage.

— No Boundaries Utah DOT member

Related Resources

The Development and Evaluation of a High-Fidelity Simulator Training Program for Snowplow Operators, David L. Strayer, Frank A. Drews and Stan Burns, Utah Department of Transportation, November 2004.
https://collections.lib.utah.edu/dl_files/c5/1b/c51b51a61d7de72148a0a247b6a4ca29a6502e8c.pdf
From the abstract: A customized training program incorporating high-fidelity simulation was developed for snowplow operators in a collaborative research project with the Utah Department of Transportation, the University of Utah, and General Electric Driver Development. Ratings of user acceptance of the training were very high, with drivers of all levels of experience indicating that the training helped them prepare for several issues critical to the safe and efficient operation of a snowplow. In the [six]-month period following training, the odds of getting in an accident were lower for the group of drivers who received training compared with a matched control group who did not receive training, and the estimated cost associated with each accident was also lower for the drivers who received training. In

addition, the data indicate that fuel efficiency was greater for the trained drivers than for the control group.

UDOT's Snowplow Drivers Utilize High-Tech Simulators to Improve Skills, University of Utah, Utah DOT, and GE Driver Development Joint News Release, November 17, 2003.
https://archive.unews.utah.edu/news_releases/udot039s-snowplow-drivers-utilize-high-tech-simulators-to-improve-skills/
This news release describes the (then) in-progress snowplow simulator training study.

2.4 Agencies Considering the Use of Virtual Reality Technologies

Transportation agencies in eight states have plans for or interest in using VR technologies for maintenance training in the future: Alaska, Illinois, Maryland, Massachusetts, Missouri, New Hampshire, New York and North Dakota. Comments are summarized below regarding potential uses, barriers and needs, and any concrete actions reported by respondents from these agencies.

More than half of these survey respondents cited cost as a primary barrier to the use of VR technologies (*Alaska*, *Maryland*, *Missouri*, *New York* and *North Dakota*). The Missouri DOT respondent, while reporting the agency's interest in learning more about the technology and how other states have been using it, also questioned what other states see as the ROI associated with VR technology.

> *Cost and implementation are always the difficult parts.*
>
> — No Boundaries North Dakota DOT member

Alaska Department of Transportation and Public Facilities

Potential Training Use: Train equipment operators to support skill building.

Potential Barriers: In addition to cost, the location of simulators can be challenging due to the large land area of Alaska—one-fifth the size of the lower 48 states—which makes it difficult to provide statewide employee access to the simulators. Also, if internet access is required for VR or simulators, slow internet speeds can also be a challenge.

Illinois Department of Transportation

Potential Training Use: Enhance current training processes for traffic incident management and highway maintenance.

Potential Barriers: No leadership or organizational concerns were noted, only that the necessary tools for virtual training are needed.

Maryland Department of Transportation

Potential Training Use: Train truck and equipment operators, and teach plowing and salting skills during the summer season. Could also demonstrate to employees how to identify and prioritize needs when driving a route and testing inspection accuracy for things such as guardrail, lighting and sight distance.

Potential Barriers: Primarily cost. Some staff members feel simulators are fake, and time is being wasted "playing games." Simulation training would need to be incorporated into standard operating procedures or guidelines, but would not take the place of hands-on training.

Concrete Actions: Seeking to set up a tour in New Jersey to view some newer VR or simulator technologies.

Missouri Department of Transportation

Potential Training Use: Could help snowplow and other heavy duty truck drivers identify strengths and weaknesses before getting on the road, and assist in preparing for the CDL exam.

Potential Barriers: In addition to cost, potential challenges include:

- Uncertainties over simulator training effectiveness, its realism and whether different makes and models of trucks are simulated.
- Motion sickness concerns for some staff.
- Training approximately 3,000 employees, one-third of which will be new.
- Logistics of simulator access for seven districts across the state.

Concrete Actions: Researching simulator training vendors.

New Hampshire Department of Transportation

Potential Training Use: Train snowplow operators.

New York State Department of Transportation

Potential Training Use: Provide excavator, snow and ice, truck and other equipment training.

Potential Barriers: Cost is the main barrier. Also, concerns with transportation logistics for sharing the simulator around the state.

North Dakota Department of Transportation

The agency currently provides formal in-person, hands-on training twice a year (spring and fall) to prepare maintenance staff to use equipment in the field. This training has been successful and well-received by maintenance staff. The respondent notes little intra-agency interest in using simulators for training.

Budget constraints preclude investment in simulators and VR technology. A cost–benefit analysis is needed to determine if simulator training provides an equal degree of training and experience for maintenance staff as compared to training with actual equipment.

Potential Training Use: Provide snowplow operation with and without a tow plow, excavator, skid steer and motor grader training.

Potential Barriers: Cost of implementation and need for simulator trainers to train maintenance staff.

2.5 Agencies Not Currently Considering the Use of Virtual Reality Technologies

Respondents from Kansas, Maine and Michigan DOTs reported their agencies are not currently using nor considering using simulators for maintenance training. As with other agencies already using the technology or interested in using it, cost is a primary barrier. The Michigan DOT respondent also noted there is some concern within the agency that simulators don't accurately represent real-world situations. Feedback from the Kansas, Maine and Michigan DOTs respondents is summarized below.

- *Kansas.* Though not aware of specific agency concerns with using VR technologies for maintenance training or other agency purposes, the survey respondent reported the agency is not seeking to use these technologies at this time due to cost and resources, including staff to operate and transport the equipment.
- *Maine.* The survey respondent personally believes using VR technology for maintenance training or other purposes would be beneficial. While the respondent doesn't anticipate leadership or organizational concerns, he is unsure about staff response. The primary barrier is cost. The agency would also need to ensure trainers are available and understand the options for different equipment types.
- *Michigan.* The survey respondent reported several agency concerns with using VR technology for maintenance training, including that the simulation doesn't accurately represent real situations. Other concerns were cost, in the context of ensuring access for enough employees and being able to offer training in needed locations, and availability of staff to conduct the training.

3 Findings from the Literature

To supplement survey findings, a literature search of publicly available domestic resources identified the publications and other resources presented below in the following topic areas:

- National guidance.
- State practices.
- Related resources.
- Simulator vendors.

3.1 National Guidance

"Virtual Reality Simulation Training at the 102nd Transportation Research Board Annual Meeting," Innovation Corner, *Public Roads*, Vol. 87, No. 2, Summer 2023.
https://highways.dot.gov/public-roads/summer-2023/innovation
From the article: The Federal Highway Administration's (FHWA) National Highway Institute (NHI) provides transportation training that cultivates innovation to enhance the learning experience. NHI demonstrated such innovation in January 2023 at the 102nd Transportation Research Board (TRB) Annual Meeting in Washington, D.C., by offering participants VR simulation experiences at its TRB exhibit hall booth:

- **Virtual Reality bridge inspection (VR VBI):** Participants learned how to inspect a bridge using various tools.
- **Rivers and floodplains:** Participants discovered river interactions and processes.

A video highlighting both VR simulations was displayed for TRB participants as they waited in line to take part in this experience.
….

By using advanced technology, FHWA effectively promotes knowledge and understanding of river functions and processes critical to highway planning and design. FHWA worked with consultants to develop a VR site visit of the Elwha River in Washington [s]tate. A diorama of the site leads participants through a series of locations along the river, including the former location of Glines Canyon Dam, the U.S. 101 bridge crossing and the river's confluence with the Strait of Juan de Fuca.

Virtual Reality Training Systems for First Responders, *TechNote*, National Urban Security Technology Laboratory, June 2023.
https://www.dhs.gov/sites/default/files/2023-06/Virtual%20Reality%20Training%20Systems%20for%20First%20Responders%20TechNote.pdf
This two-page brief examines hardware and infrastructure requirements; experiences, benefits and challenges; cybersecurity considerations; and standards and regulations applicable to AR/VR technology.

Work Zone Safety: Virtual Reality-Based Traffic Co-Simulation Platform for Workforce Training and Pedestrian Behavior Analysis, Semiha Ergan, Kaan Ozbay, Suzana Duran Bernardes, Juan Guerrero, Sushmita Kadarla, Hanna Lee and Fan Zuo, Federal Highway Administration, May 2023.
https://cip.tandoncsmart.com/uploads/1689086146320-Ergan_WorkZoneSafety_2023.pdf
From the executive summary: Work zones pose risks due to exposure to traffic and the potential desensitization of workers to hazards over time. To improve safety awareness, innovative intrusion alarm systems with wearables and other devices are being considered. Virtual [r]eality (VR) offers realistic simulations without exposing workers to real-world dangers, such as speeding cars or work zone intrusion. This report consists of three main parts. First, an assessment was conducted to evaluate the

suitability of VR in replicating reality and to compare worker behaviors in real-world and virtual environments. Second, an existing VR-based traffic co-simulation platform was enhanced by incorporating realistic worker and pedestrian behavior. This improvement allows for more accurate simulations of movement, including restrictions, tasks and random movements. The platform also enables users to modify variables to adjust worker behavior. Finally, VR-based training modules were implemented and evaluated against traditional methods to enhance worker preparedness for hazards.

"**Virtual and Augmented Reality in Transportation**," Executive Briefing, FHWA ITS Deployment Evaluation Program, 2022.
https://www.itskrs.its.dot.gov/sites/default/files/doc/05_VRAR%20in%20Transportation_Final%20508_01_25_22.pdf
AR and VR technologies are discussed for a range of transportation uses, including to "improve driver performance, help with accessible trip planning, improve the transit passenger experience, assist with highway construction and better protect vulnerable road users. … Managers may also be able to use these technologies for training, certification, inspection and stakeholder outreach." Costs, benefits and best practices are also presented along with a case study of Utah DOT's use of a handheld AR mobile device to develop 3D models for highway infrastructure asset planning, design, implementation and management.

Virtual Reality and Augmented Reality for Hazardous Work Training, National Safety Council, 2020.
https://www.nsc.org/getmedia/e2bb071c-e134-4c8e-b0b3-be74b46066eb/report-virtual-training.pdf
This report reviews VR and AR uses in hazardous work training in the commercial, industrial and civil government sectors. It reviews the identified and proposed benefits of these technologies, the limitations and risks associated with adoption, the VR/AR market and available tools.

"Leveraging Augmented Reality for Highway Construction," Jaganath Mallela, Kevin Gilson, Paul Goodrum and Jennifer Steen, FHWA Office of Infrastructure Research and Development, November 2020.
https://www.fhwa.dot.gov/publications/research/infrastructure/pavements/20038/20038.pdf
From the abstract: Challenges in highway construction management and field operations include the lack of real-time and integrated information, gaps between planned solutions and practical implementations, quality assurance and effective project communications. Three-dimensional (3D) model-based design and construction workflows are becoming more common on highway projects, and the Federal Highway Administration (FHWA) is promoting these and other innovations through its Every Day Counts program and Building Information Modeling efforts. This increased use of 3D model-based workflows and rapid advancement in computer interface design and hardware make augmented reality a tool for overcoming these challenges.

Augmented Reality Enhancing the Inspections of Transportation Infrastructure: Research, Education and Industry Implementation, Fernando Moreu, Chris Lippitt, Dilendra Maharjan, Marlon Aguero and Xinxing Yuan, U.S. Department of Transportation Research and Innovative Technology Administration, April 2019.
https://rosap.ntl.bts.gov/view/dot/62556/dot_62556_DS1.pdf
From the abstract: Transportation infrastructure needs continuous monitoring that is conducted by field inspectors regularly in the field. Currently, infrastructure inspectors climb, measure and photograph structures annually to inform repair needs and prioritize decisions. In order to promote and accelerate early learner's expertise in decision-making capabilities during infrastructure inspections, this research project developed various software applications using augmented reality (AR) as an inspection tool for bridges and bridge management, more specifically. By objectively quantifying infrastructure field

inspections, inspectors can make more accurate field assessments and managers can make better-informed decisions. This project collaborated with stakeholders, national laboratories, DOT agencies such as NCHRP and NMDOT [New Mexico DOT], and local owners like the City of Albuquerque, to inform the needs of AR for field inspections. The results of this study summarized the current limitations of visual inspections from the perspective of the various owners, as well as pilot developments of AR applications and their benchmarked accuracy in comparison with visual methods. The education and training aspect of this project included teaching and exposing AR to high school students, community college students, undergraduate students, and graduate students, as well as industry (bridge inspectors). This research project's outcome includes a webinar free to access in the NCHRP national website on this topic. The conclusion of this research is that AR can be an effective tool and that industry is interested in specific programming of AR software that matches their bridge management needs.

3.2 State Practices

Multiple States

"Can Augmented Reality Address Highway Construction Challenges?" Hoda Azari and Keving Gilson, *Public Roads*, Summer 2020.
https://highways.dot.gov/public-roads/public-roads-magazine-summer-2020-edition.
Research conducted by Federal Highway Administration explores handheld and head-mounted AR technologies and applications in construction environments. Examples are presented from California, Florida, Michigan and Utah.

Arizona

Snowplow Simulator Training Evaluation: Potential Fuel and Drivetrain Maintenance Cost Reductions, Mary Kihl, Donald Herring, Peter Wolf, Mike Finn and Peng Yang, Arizona Department of Transportation, December 2007.
https://apps.azdot.gov/ADOTLibrary/publications/project_reports/PDF/AZ635.pdf
From the abstract: The Arizona Department of Transportation (ADOT) introduced simulator-based training in 2004, when maintenance crews in five rural districts received a third-party snowplow safety topics course on the L-3 TranSim VS III simulator. In 2005, a simulator was deployed in the Globe District, initiating a training program for the 60-plus snowplow operators there. Local volunteer trainers, all experienced plow operators, went through a "Train the Trainer" course from L-3 staff. On that basis, in early 2006, all of the district's drivers took a Fuel Management Driving Techniques (FMDT) course on proper shifting techniques for better fuel economy.
….

This study used Kirkpatrick's four-level evaluation model to assess if the training improved fuel economy in the Globe District. At the Reaction level, results are positive; crews say the training did increase awareness and change driving behaviors with regard to fuel efficiency. At the Learning level, results show some drivers improved but others did worse in post-testing. At the Performance level, the results are promising: drivers of manual-shift trucks achieved improvements in fuel economy. At the Results level, aggregate fuel economy figures also show a discernable difference in pre-training and post-training fuel efficiency for key winter maintenance tasks.

This study confirmed that operational training can best be measured in quantitative terms, but with challenges. Future ADOT efforts to evaluate simulator training results must first strive to better integrate field data. Training must focus on improved manual gear shifting, and on "best practices" for automatics. The most benefit may come from fully integrating simulators into ADOT's field training program, which

requires strong agency support. Key future requirements are (1) [a] state-level champion who can enhance simulator training, (2) [a] new fuel vs. work effort reporting system, (3) [f]ormal recognition and incentives for the volunteer local training teams.

Snowplow Simulator Training Evaluation, Mary Kihl, Donald Herring, Peter Wolf, Stephanie McVey and Vamshee Kovuru, Arizona Department of Transportation, November 2006.
https://apps.azdot.gov/ADOTLibrary/publications/project_reports/PDF/AZ585.pdf
From the abstract: The Arizona Department of Transportation (ADOT) outsourced simulator training for snowplow operators in rural Arizona in late 2004. A mobile simulator classroom visited five ADOT districts: Globe, Flagstaff, Holbrook, Kingman and Safford, to deliver a half-day introductory course with both classroom and simulator training segments. This Year One (2004-05 winter) trainee group included 149 snowplow drivers. In Winter Two (2005-06), more in-depth training was given on a dedicated driving simulator unit purchased for ADOT's Globe Maintenance District. All 61 of Globe's snowplow drivers took two courses: situational awareness training in the fall, and then fuel management and shifting skills in the spring. All Year Two trainers were experienced ADOT snowplow operators from the Globe District.
….

Based on the Year Two results from Globe and new personnel training needs, ADOT procured two more simulators for Holbrook and Flagstaff [d]istricts in mid-2006. A [w]orking [g]roup was formed of field trainers from the three simulator districts to refine and focus the training courses. A new third-year study will expand on this analysis, with a focus on results of training in proper gear shifting (a control-level skill) to improve fuel efficiency and to reduce repair costs. As the study proceeds, it will continue to evaluate the simulators' effectiveness, providing quantitative documentation to reinforce the qualitative results and to define broader benefits of the driving simulator for heavy equipment operations.

Illinois

Snowplow Simulator Training Study, Thomas O'Rourke, Illinois Department of Transportation, January 2011.
https://rosap.ntl.bts.gov/view/dot/24792
From the abstract: This report evaluates simulation training of Illinois Department of Transportation (IDOT) snowplow operators to improve IDOT snow and ice removal operations. Specifically, it assesses a drivers' evaluation of snowplow simulation training immediately after training in fall 2009 and again after the snow season in spring 2010. The report includes the supervisors' assessment of the simulator training after the snow season and a description of conventional training at the district level. Also included are an estimated cost analysis of the simulation training and the estimated cost of behind-the-wheel training, a review of the accident records of snowplow drivers who participated and who did not participate in the simulation training, and a review of reports from other states on simulator training. Results show favorable driver evaluations after the fall training but less positive evaluations after the snow season. Supervisor evaluation of simulation training was generally favorable. As presently conducted, simulation training appears more costly than conventional training. Finally, and consistent with most of the literature, no conclusive findings on driver performance were found when comparing drivers whose training included simulation to drivers whose training did not include simulation. Multiple reasons for this finding are provided in the report. Suggestions for future study are provided.

Missouri

Immersive Work Zone Inspection Training Using Virtual Reality, Praveen Edara, Carlos Sun, Khaled Aati and Daeyeol Chang, Missouri Department of Transportation, February 2020.
Publication available at https://rosap.ntl.bts.gov/view/dot/62062
From the abstract: Can virtual reality tools be used to train engineers that inspect work zones? In this report, we share the findings of a research project that developed an interactive and immersive training platform using virtual reality to train state department of transportation (DOT) staff [who] inspect[s] work zones for compliance. Virtual reality offers an immersive platform that closely replicates the actual experience of an inspector driving through a work zone, but in a safer, cheaper and quicker way than field visits. The current training practice involves reviewing temporary traffic control procedures and reports, and pictures from previous inspections. The developed platform consists of a learning module and an immersive module. The learning module is founded on the historical knowledge gained by DOT staff from inspections dating back at least five years. This knowledge incorporated representative inspection reports from prior years from all DOT districts including photographs of deficiencies. The synthesized knowledge was converted into a concise, easy-to-consume format for training. The immersive module places the trainee in a vehicle moving through a work zone, thus providing a realistic experience to the engineer prior to inspecting a real work zone. The research team developed and tested two immersive scenarios of a freeway work zone. The training platform was tested by 34 individuals [who] worked for the Missouri Department of Transportation. An overwhelming majority (97%) agreed that virtual reality offered a realistic and effective way to train inspectors. One additional scenario of flagger operations in a two-way one lane work zone was also created for the purposes of training work zone inspectors. The scenario was developed in Unity using drive-through video data, mapping software and motion capture technology for replicating manual flagger movements. The use of flagger scenario in the immersive training module is recommended for staff [who] inspect[s] work zones in rural areas of the state where two-lane roadways are more prevalent.

Texas

Work Zone Traffic Control Refresher Virtual Reality Pilot, Texas Department of Transportation, undated.
https://ftp.dot.state.tx.us/pub/txdot-info/hrd/training/work-zone-traffic-control.pdf
From the report's conclusions and implications: This 2021-2022 project was TxDOT's [Texas DOT's] attempt to explore VR training for the largest segment of our workforce using a topic of critical importance to transportation safety. While 300 participants were directly involved in pilots, a completion record of approximately 2% indicated TxDOT was not prepared for a self-service VR training model, necessitating an intentional change management plan for future VR implementations. The benefits of VR training remain similar to those of other virtual or remote methods, with the added benefit that a VR experience anecdotally appears more realistic and engaging than traditional in-person training or videos. The increasing capabilities of VR devices and the continued support for online VR settings through publicly accessible online platforms like YouTube make VR an option to replace existing static or video content, but does not yet replace the training event that typically houses such content. To that end, this content can also be used as a performance intervention during routine safety meetings, tailgates, and even contract kickoff meetings with any group involved in work zone traffic control in Texas.

Related Resources:

TRF527 Introduction, Lecture and Post-Lecture Information, YouTube Video, Texas Department of Transportation, 2022.
https://youtu.be/GxKFZrzKT6Q

TRF527 Virtual Reality Scenarios, YouTube Video, Texas Department of Transportation, 2022.
https://youtu.be/LAMl5bo8KJk

TRF527 Exam Instructions, YouTube Video, Texas Department of Transportation, 2022.
https://youtu.be/FD9BPbH2qbI

3.3 Related Resources

"Group-Based VR Training to Improve Hazard Recognition, Evaluation and Control for Highway Construction Workers," Nazila Roofigari-Esfahan, Curt Porterfield, Todd Ogle, Tanner Upthegrove, Myounghoon Jeon and Sang Won Lee, *Institute of Electrical and Electronics Engineers Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops*, March 2022.
Citation at https://ieeexplore.ieee.org/document/9757707
From the abstract: The construction industry spends approximately $15 billion [per] year for occupational injuries, and highway sector is the most dangerous. Highway construction workers have to work in close proximity to construction equipment and high-speed traffic, exposing them to an elevated risk of serious injuries/fatalities. Safety training has a direct impact on the prevention of construction accidents. The traditional lecture-based construction training curriculum has not been revisited and is designed to train the workers individually, thus the benefits of collective engagement in worker training is ignored. High-engagement [v]irtual [r]eality (VR) environments offer a more effective learning experience for training workers to identify hazards in the job site. We present a training platform for instructor-in-the-loop, group-based VR training to complement and increase the effectiveness of the current training program for highway workers. We develop a VR platform in which an instructor can create and improvise on work zone scenarios and share the virtual scenario easily with the entire class.

"Implementing Virtual Reality Technology for Safety Training in the Precast/Prestressed Concrete Industry," Sayali Joshi, Michael Hamilton, Robert Warren, Danny Faucett, Wenmeng Tian, Yu Wang and Junfeng Ma, *Applied Ergonomics*, Vol. 90, January 2021.
Citation at https://doi.org/10.1016/j.apergo.2020.103286
This journal article reviews a VR training module for concrete industry workers covering personal protective equipment and safety protocols for two specific concrete processes. The performance of the module was evaluated based on simulation sickness, user experience and system usability. The analysis found that the VR training was more engaging and provided a good understanding of safety protocols and real-life experience of the precast/prestressed concrete plant.

3.4 Simulator Vendors

Presented below are the websites for selected simulator vendors, including those used by the agencies highlighted in this synthesis report:

- Caterpillar
- cmlabs
- Doron Precision Systems, Inc.
- FAAC Incorporated
- John Deere, Deere and Company
- L3Harris Technologies, Inc.
- Simformotion, LLC
- Virage Simulation Inc.

Cat Simulators, Caterpillar, 2024.
https://catsimulators.com/
Tested by Caltrans, Cat Simulator Systems include "simulated machines and worksite applications for construction with environments from city building sites to highways and more." The company also offers Simformotion Operator Skills training. *From the website:*

> Our training specialists will plan with you to create a [one]-day to a weeklong training session for your operators. The training will be based on the skills and techniques you want to address. Our specialist can travel to your location, to a third-party location in your area, or your team can come to our Peoria, Ill., facility for training. Simulators make it easy to be flexible.

Vortex Simulators for Cranes and Heavy Equipment, cmlabs, undated.
https://www.cm-labs.com/en/simulation-solutions/vortex-training-simulators/hardware-features/
This vendor offers a variety of systems, from desktop to full immersion. Utah DOT uses Vortex desktop simulators for heavy equipment training. *From the website:*

> Flexible display options mean you can start small and scale up to full immersion, and swappable controls mean you can use one simulator to train on many equipment types—with the assurance that you can count on your Vortex simulators for years of training, thanks to their rugged, durable construction.

660Truckplus—Truck Driving Simulator, Doron Precision Systems, Inc., 2023.
https://doronprecision.com/truck-cdl-simulator/660truck-2/
Described by Ohio DOT researchers as the Doron SP660, this vendor website describes the current 600 Truckplus simulator model. *From the website*:

> **660Truckplus Driving Simulator**
>
> - High Resolution Visual System/Four (4) 55[-inch] High Definition LED Displays.
> - Newly Updated, True-to-life seamless "Virtual World" driving environment with animated weather and pedestrians.
> - Advanced curriculum of On-The-Road scenarios for Heavy Goods Vehicles, Trucks and Tractor Trailers.
> - Practice CDL and other maneuvers on the Virtual World Driving Range.
> - Microsoft Windows based Scenario Developer allows easy creation of new scenarios.
> - Scenario Developer can also be used to recreate collisions for remedial and regular training.
> - Multiple—malfunction capabilities, selectable objects and student vehicles.
> - Industry-leading update and refresh rate to provide superior image quality.
>
> Doron's 660Truckplus driving simulator replicates the driving compartment of a typical truck and includes essential components found in late model tractor-trailers. The 660Truckplus driving simulator enables efficient and cost-effective truck driver training. Instructors can customize truck driver training by placing virtual cones in the Virtual World driving range to allow for effective CDL training, curriculum enhancement and practicing other challenging maneuvers. Doron's TrueSteer digital servo force feedback steering is unsurpassed for accurate response to road conditions and driver input. The 660Truckplus also promotes fuel-efficient shifting.

Snow Plow Driver Training Simulator, FAAC Incorporated, 2024.
https://www.faac.com/commercial/truck/snowplow-driving-simulator/
From the website:

> **Real-Feel Training Experience**
> The FAAC TT 2000 Truck Driver Training Simulator, coupled with our advanced snowplow simulation, can be used for basic skills development, refresher activities, annual certification and remedial lessons. FAAC sims use real OEM components and gauges so students' experience in our cab can perfectly replicate their experience using your plows to clear your roadways.

Operator Training Simulators, John Deere, Deere and Company, 2019.
https://www.deere.com/assets/pdfs/common/parts-and-service/manuals-training/2019-John-Deere-Simulators-Combined.pdf
Caltrans tested a John Deere heavy equipment simulator to support training plans for excavator and grader training. *From the document*:

> **Bridge the gap between the classroom and worksite**
> John Deere simulators offer cost-effective and efficient operator training in a risk-free environment, all while avoiding wear and tear on equipment. With options for different screen configurations, motion platform, instructor station, and swappable control sets and pedals, John Deere simulators are designed for maximum training flexibility.
>
> **Swappable Control Sets**
> Convert your simulator to a new machine in a matter of minutes with swappable controls. True-to-life control sets are available for these John Deere construction machines:
>
> - Backhoe
> - Crawler Dozer
> - Excavator
> - Wheel Loader
> - Motor Grade

Training and Simulation Systems, L3Harris Technologies, Inc., 2024.
https://www.l3harris.com/all-capabilities/training-and-simulation-systems

Note: This company was formed in 2019 after the merger of L3 Technologies (formerly L-3 Communications) and Harris Corporation.

This vendor provides snowplow simulators for several state DOTs, including Arizona, Iowa and Utah. *From the website*:

> L3Harris offers a selection of highly customizable training services and simulation experiences for varying levels of skill, experience, budget and physical deployment requirements. L3Harris leverages real-world experience to support the effective delivery of content to develop the user community.

Simulation Training Solutions, Simformotion, LLC, 2024.
https://simformotion.com/
This vendor provides heavy equipment simulators, including commercial trucks, forklifts, cranes, and CAT machines. The vendor also offers standard and custom training curriculum, in-person training and train-the-trainer services.

Truck Driving Simulator—VS600M, Virage Simulation Inc., 2024.
https://viragesimulation.com/vs600m-truck-simulator/
Indiana LTAP is using a Virage simulator to offer CDL training for local transportation agencies. *From the website*:

The VS600M truck simulator includes the following key features:

- Real truck parts.
- Full simulation of virtually any type of heavy vehicle, from dump trucks to highway tractor-trailer and semi-trailer applications.
- Automatic and manual transmission, including the simulation of the popular Eaton-Fuller 10-13-15 and 18 speed nonsynchronized transmission with realistic force feedback and vibrations on the shifter.
- 3D sound.
- High fidelity visual scenes with a virtual 360 degree view from the driver's seat (180 degree forward field of view and rear-view mirrors) using the latest LCD high resolution display technology.
- Glass instrumentation approach for maximum flexibility and adaptability, allowing the rapid selection of different truck configurations without changing hardware.
- A high-performance, compact three-axis motion system.
- A multifunction touch display for a wide range of truck driver controls and applications.
- Realistic steering wheel behavior based on actual measurements of the forces acting on the wheel during turning maneuvers.
- Realistic responses from the clutch, gas and brake pedals based on actual vehicle measurements.
- Complete driver training and evaluation package.

Appendix A: Survey Questions

The survey below was provided in an online format to members of No Boundaries and Clear Roads pooled fund studies and selected members of the AASHTO Committee on Maintenance and Committee on Research and Innovation.

Note: The question below determined how respondents were directed through the survey.

(Required) Has your agency tested, or does your agency currently use, simulators or virtual reality technologies in training or for other maintenance functions?

- Yes (Skipped respondents to the following survey sections: **Experience with Simulators or Virtual Reality in Maintenance Programs**, **Issues Associated with Use of Advanced Technologies in Maintenance Programs**, and **Wrap-Up**.)
- No, but we have plans for or interest in using these tools in the future. (Skipped the respondent to the following survey sections: **Potential Use of Simulators or Virtual Reality in Maintenance Programs**, **Issues Associated with Use of Advanced Technologies in Maintenance Programs**, and **Wrap-Up**.)
- No, and we aren't interested in using these tools at this time. (Skipped the respondent to the following survey sections: **Issues Associated with Use of Advanced Technologies in Maintenance Programs** and **Wrap-Up**.)

Experience with Simulators or Virtual Reality in Maintenance Programs

1. Please describe any testing or ongoing use of simulators or virtual reality technologies for maintenance program purposes in the following areas. Your descriptions might address the purpose of the application, how long you've tested or used it, operational requirements, vendors or manufacturers, costs, outcomes, and the participation of external partners or collaborators.

   Training for Staff Safety, Skill-Building or Procedures
   Respondent comments:

   Asset Management
   Respondent comments:

   Equipment Inspection or Maintenance
   Respondent comments:

   Other Program Areas
   Respondent comments:

2. Please describe the benefits realized from any testing or ongoing use of simulators or virtual reality technologies in maintenance programs in the following areas:

   Training for Staff Safety, Skill-Building or Procedures
   Respondent comments:

   Asset Management
   Respondent comments:

   Equipment Inspection or Maintenance
   Respondent comments:

Other Program Areas

Respondent comments:

3. Please describe the challenges encountered in any testing or ongoing use of simulators or virtual reality technologies in maintenance programs in the following areas:

   Training for Staff Safety, Skill-Building or Procedures

   Respondent comments:

   Asset Management

   Respondent comments:

   Equipment Inspection or Maintenance

   Respondent comments:

   Other Program Areas

   Respondent comments:

Potential Use of Simulators or Virtual Reality in Maintenance Programs

1. Please describe your agency's general interest in or specific ideas for using simulators or virtual reality technologies for maintenance staff training or other maintenance purposes.
2. Please indicate the specific technologies or solutions your agency has explored.
3. Please describe any concrete actions your agency has taken to prepare for testing or implementing simulators or virtual reality technologies in your maintenance program.
4. Has your agency worked with any external partners or collaborators in considering the use of simulators or virtual reality technologies in maintenance contexts?
   - No
   - Yes (Please describe the nature of these discussions or collaborations.)
5. What, if any, types of staff training or other maintenance uses could you envision simulators or virtual reality technologies being useful for?
6. To your knowledge, are there other nonmaintenance programs or functions in your agency that currently use simulators or virtual reality technologies?
   - No
   - Yes (Please describe known uses of simulators or virtual reality technologies in other agency programs.)

Issues Associated with Use of Advanced Technologies in Maintenance Programs

1. Are you aware of concerns in your agency with regard to using simulators or virtual reality technologies for maintenance staff training?
   - No
   - Yes (Please describe these concerns.)
2. Are you aware of concerns in your agency with regard to using simulators or virtual reality technologies for maintenance purposes other than training?
   - No
   - Yes (Please describe these concerns.)

3. Please describe barriers, if any, you have experienced or anticipate when using simulators or virtual reality technologies in maintenance programs under each of the topic areas below.

   Cost or Resources

   Respondent comments:

   Staff Reluctance or Other Concerns Regarding Staff

   Respondent comments:

   Leadership Reluctance or Other Organizational Issues

   Respondent comments:

   Operational Limitations

   Respondent comments:

   Other Barriers

   Respondent comments:

4. Please describe any needs your agency addressed—or must address—before using simulators or virtual reality technologies for training maintenance staff or other maintenance purposes.

Wrap-Up

1. If applicable, please provide links to documentation that describes your agency's use or interest in simulators or virtual reality technologies. Send any files not available online to susan.johnson@ctcandassociates.com.
2. Please use this space to provide any comments or additional information about your previous responses.