JOINT TRANSPORTATION
RESEARCH PROGRAM
INDIANA DEPARTMENT OF TRANSPORTATION
AND PURDUE UNIVERSITY

Evaluation of Current Technologies for Training, Web Apps, and New Technologies

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SPR-4424 • Report Number: FHWA/IN/JTRP-2021/15 • DOI: 10.5703/1288284317317

RECOMMENDED CITATION

Iyer, A. V., Dunlop, S. R., Thakkar, D. J., Mishra, S., Banerjee, A., Gokhale, A., Shah, K., Faiz, A., Arora, A., Awasthi, P., & Gebbie, M. (2021). *Evaluation of current technologies for training, web apps, and new technologies* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2021/15). West Lafayette, IN: Purdue University. https://doi.org/10.5703/1288284317317

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JOINT TRANSPORTATION RESEARCH PROGRAM

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Published reports of the Joint Transportation Research Program are available at http://docs.lib.purdue.edu/jtrp/.

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COVER IMAGE

Supertramp, A. (n.d.). *Training webinar e-learning skills business internet technology concept* [Image]. Shutterstock. https://www.shutterstock.com/image-photo/training-webinar-elearning-skills-business-internet-1135204490

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.
FHWA/IN/JTRP-2021/15

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
Evaluation of Current Technologies for Training, Web Apps, and New Technologies

5. Report Date
March, 2021

6. Performing Organization Code

7. Author(s)
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

8. Performing Organization Report No.
FHWA/IN/JTRP-2021/15

9. Performing Organization Name and Address
Joint Transportation Research Program
Hall for Discovery and Learning Research (DLR), Suite 204
207 S. Martin Jischke Drive
West Lafayette, IN 47907

10. Work Unit No.

11. Contract or Grant No.
SPR-4424

12. Sponsoring Agency Name and Address
Indiana Department of Transportation (SPR)
State Office Building
100 North Senate Avenue
Indianapolis, IN 46204

13. Type of Report and Period Covered
Final Report

14. Sponsoring Agency Code

15. Supplementary Notes
Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. 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. The project was divided in three phases, and the following are our four key takeaways.

(1) *Quality of Safety Training:* Benchmarking training practices provided strong evidence that participative programs, such as role plays, demonstrations of safety devices, and risk mapping are some of the best practices. Additionally, training engineers on work zone design, auditing, and recording safe work zones can influence project attributes, such as the length and duration of work zone. Including all these aspects during the project planning phase has a greater chance of influencing work zone safety.

(2) *Effectiveness of New Technology Tools:* Our vendor outreach project phase allowed us to determine the different attributes in training course development and customer experience using new technology tools. Established research studies provided significant support to our hypothesis that new technology tools are more effective and interactive compared to traditional learning.

(3) *Risk-Based Approach to Training:* Analyzing the risk index for work zone attributes indicate the degree of risk that a worker faces while performing a task characterizing those attributes. We concluded that implementation of new technology tools should be planned based on this risk index and optimization model. This will ensure better worker performance and perception of the course content in alignment with the severity of that work attribute.

(4) *Optimizing Selection of Training Tools for Tasks:* We provide an optimization model to choose the optimal mix of training tools to attain the desired level of risk reduction. The tool is spreadsheet-based and shows the benefit of using a portfolio of modules across training tools, each targeted at attaining the desired risk reduction by attribute for a task. By using the risk reduction due to training tools from the literature, the cost data from vendors and task characteristics, this tool can enable INDOT managers to manage risk cost efficiently.

17. Key Words
work zone safety, risk reduction, safety training, augmented reality, virtual reality, computer simulation, learning management system based gamification, traffic control, long-term retention, road construction

18. Distribution Statement
No restrictions. This document is available through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report)
Unclassified

20. Security Classif. (of this page)
Unclassified

21. No. of Pages
34 including appendices

22. Price

EXECUTIVE SUMMARY

Introduction

Work zone safety has been a top concern for INDOT. This report outlines and explores technological opportunities surrounding INDOT's safety training. It focuses on some key aspects of improving safety training—what areas of a work zone affect safety, safety teaching practices currently in place, a quantified model of risks associated with works, and a cost-benefit analysis of training technologies.

This report first outlines a benchmarking process to understand the components of work zone safety by comparing states with similar accident rates to those in Indiana. Next, it breaks down the different components into attributes and defines a risk-attribute framework. In parallel, the report also explores the technological tools available that can help INDOT develop a better training model. To do this, this report provides a cost and attribute analysis of different tools—gamification, simulation, AR, and VR. This report also creates storyboard and training modules to use with the technological tools, which cover several training modules required by OSHA guidelines in 12 categories.

Finally, this report explores how these technological tools can best be distributed in different work zones to minimize cost while attaining risk reduction. To provide this final risk optimization, the report presents an optimization model that provides a suitable mix of training tools for different training modules.

Findings

- *Benchmarking:* The initial analysis of this report focuses on the benchmarking of INDOT's safety statistics with that of other state departments of transportation. The analysis suggests that five states share similar statistics with Indiana—Colorado, Delaware, California, Texas, and North Dakota. This provides a basis for understanding what parameters affect the safety of work zones at different DOTs.
- *Training Technologies:* The next part of this report focuses on different training technologies. The four different technologies focused on are gamification, simulation, AR, and VR. This phase of the project focused on extensive market research and reaching out to vendors. A holistic approach was taken to gather different cost components of these technologies. As a general bias, cost of training technologies grows with technological complexities; however, the findings suggest that, depending on training heads and the capital investment, risk may be significantly distributed to incur a reduced training cost per person for selected high-tech training tools.
- *Risk Attribute:* Another focus of this report is to find the attributes concerning the risk of a work zone. This analysis suggests that a work zone may have one or multiple attributes (e.g., working near an active roadway or working with power tools). A detailed analysis of the risk attributes is mentioned in this report. The analysis suggests that with valid data and supporting research papers, the risk of a work zone can be quantified. This leads to our findings and recommendations on how to customize the mix of training tools.
- *Storyboard:* The report also focuses on OSHA guidelines about what components should be considered in safety training. Several training modules were explored, and a set of modules created.

Implementation

The project develops a model that can, with proper data, evaluate what training tools can be deployed for specific training modules. The analysis rests on three basic findings (1) accident data (for this report, data was taken from a research paper on OSHA and NIOSH data), (2) risk framework, and (3) research on technological tools.

The accident data helps deploy a relative frequency for each risk attribute broken down on outcome of the accident. This ultimately measures the total risk index, which helps quantify the risks involved. In parallel, it is also required for a comparison of different training tools based on effectivity and cost. While cost can be obtained from market research, effectivity requires a firm understanding and research on retention rate and other factors. A separate metric was created to evaluate retention rate and compare the tools. It is assumed that training tools' effectiveness directly impacts the risk mitigation as far as mode of training is considered. Also, the effectivity varies for different training attributes.

The risk attributes are then classified according to training module so that a risk index can be attributed to each module, giving the modules a risk index to signify the modules' risk. Once this is done, the focus is to categorize training modules on what technology is best suited.

This formulation, which comes as a recommendation from this project, requires an optimization model involving effectivity and cost of tools for each attribute and type, training attributes involved with each training modules, and risks involved with each training module. The optimization model provides an optimum solution to reduce risk by a defined level ($<25\%$) and provide the mix of training tools.

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1. INTRODUCTION

The final report details the activities conducted during the 10-month phase (Jan 2020–Oct 2020) to assess the feasibility of using new technology tools for safety training. Utilizing established research studies, risk framework 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 potential to reduce work zone risk. The project was divided in three phases, the following showcases details of the project plan.

During Phase 1, the project was initiated by identifying and analyzing the possible causes of work zone incidents, differences in worker injuries across various states and selecting states for benchmarking. Recognized training practices and their characteristics were also explored in the project, that helped in understanding the application of new technology tools in a coherent manner.

During Phase 2, vendor discussions were initiated to understand training course development costs and product development timeline. Additionally, research studies were analyzed to compare benefits of these training methods. Simultaneously, the team made efforts to develop training course content based on INDOT's *Health and Safety Manual* and OSHA guidelines.

During Phase 3, we utilized a risk-based approach to develop a cost-effective outlook on application of technology tools. Storyboards and gamified presentation tools were developed for the 12 training courses, that were selected based on INDOT's *Health and Safety Manual.* Additionally, we created a prototype for a training module in Virtual Reality based application. Finally, we present an optimization model that enables the choice of an optimal mix of training tools to reduce risk to a desired level while minimizing costs. The model suggests that a mix of tools, targeted at the desired learning objective, would be an optimal choice. Figure 1.1 represents the project's Gantt chart.

2. ACTIVITIES

The team, consisting of Purdue University graduate students, created a detailed project plan and conducted research associated with activities in the project plan. All the activities consisted of researching the experience of other state agencies, estimated costs and potential benefits of the new technology in safety training. The activities are defined in Table 2.1.

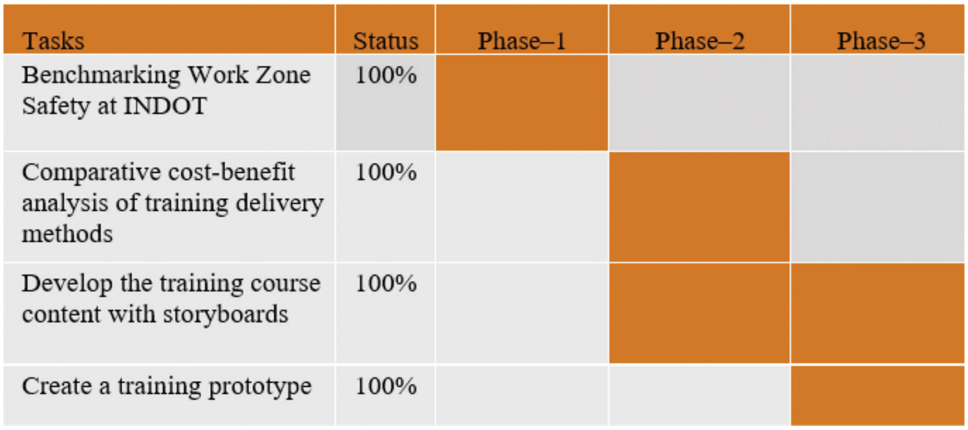
TABLE 2.1
Breakdown of the Activities in the Project

Task	Activities
1	Benchmarking for safety training practices
2	Estimated cost analysis of training technologies
3	Outcome analysis of training technologies
4	Development of risk-based framework
5	Creating training course and prototype

3. BENCHMARKING

Phase 1 of the project defined benchmarking U.S. states for safety training as a starting point for the research in available training technologies. Additionally, we also looked at causes of on-site incidents to ascertain the type of training needed to reduce worker injuries/fatalities in work zone. First, federal-level statistics were used, with various parameters, to identify the states for benchmarking. Second, root cause analysis was employed to identify the leading causes of worker fatalities throughout the U.S. This information can be seen in Figure 3.1 (U.S. Bureau of Labor Statistics, 2020b).

It was observed that the largest cause for occupational deaths is transportation incidents, while the second highest are due to contacts with objects or equipment. The federal level data does not provide an accurate distribution of statistics across states; however, due to the skewed nature of the plot towards "transportation incidents," it is safe to say that the same is true on a state level as well.



Tasks	Status	Phase–1	Phase–2	Phase–3
Benchmarking Work Zone Safety at INDOT	100%	🟧		
Comparative cost-benefit analysis of training delivery methods	100%		🟧	
Develop the training course content with storyboards	100%		🟧	🟧
Create a training prototype	100%			🟧

Figure 1.1 Project Gantt chart.

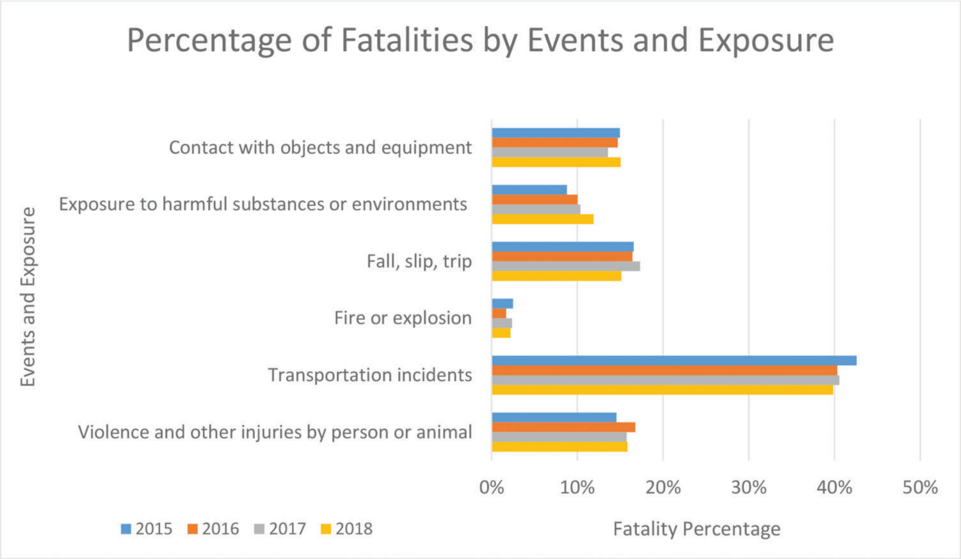


Figure 3.1 Root-cause analysis of federal level occupational injuries.

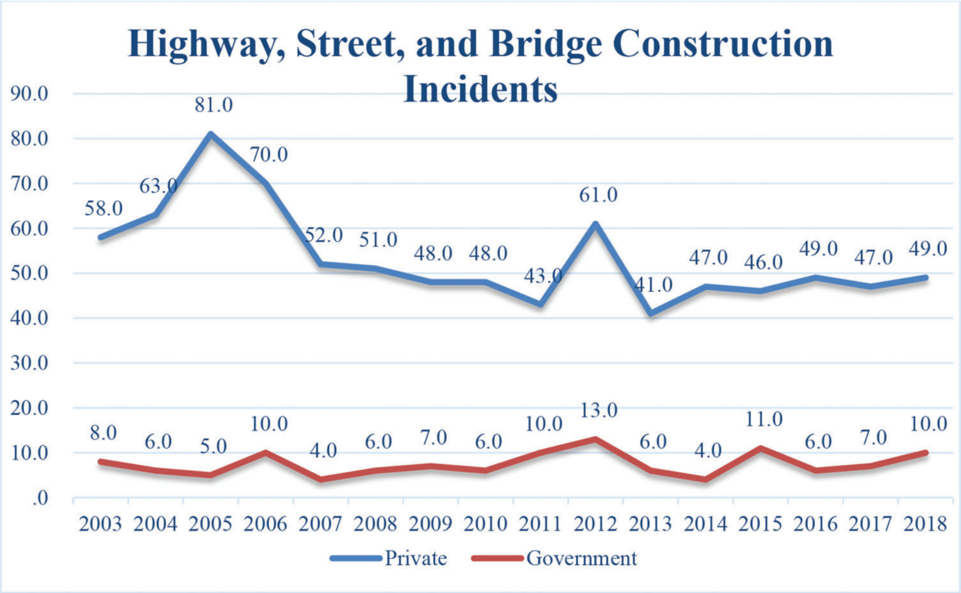


Figure 3.2 Fatal work-zone occupational injuries for private vs. government contractors (U.S. Bureau of Labor Statistics, n.d.).

Additionally, it was important to make a distinction between fatalities at road construction sites operated by private contractors, versus those operated by state government personnel.

Figure 3.2 shows a positive correlation between private and government contract work in work-zone occupational injuries. Furthermore, the number of incidents under private contractors were far higher, year on year. This may arise because private contractors perform more jobs a year as compared to government personnel or that private contractors may tend to compromise on safety procedures to meet deadlines.

INDOT has a plethora of practices that are currently employed to ensure work zone safety. These have been considered in the benchmarking analysis. Among them is the *INDOT Traffic Management Strategic Deployment Plan* (Wuertz, 2008). This plan consists of the following verticals.

- ITS (Intelligent Transportation System) Deployment: Responsible for design, maintenance, and operation of ITS devices.
- Traffic Management Centers (TMC): All activities associated with INDOT's two TMCs situated at Indianapolis and Gary.
- Traffic Control Systems: Maximizing traffic signal efficiency.

- Public Safety Operations: Incident management in coordination with law enforcement and emergency services (IN.gov, n.d.b). Additionally, INDOT requires the following regulations to be met (INDOT, 2015).
- Each contractor is required to identify a certified Work Zone Traffic Supervisor for each project.
- INDOT Maintenance Staff is required to receive work zone flagging and traffic control training, which can be obtained from District Safety Directors.
- The Public Safety Operations Division provides periodically updated incident management awareness training.
- INDOT University provides a Certified Training Program (CTP) to increase the number of people able to carry out contract inspections (IN.gov, n.d.a). In order to further solidify the benchmarking process to find innovative solutions to the work zone safety issues faced by INDOT, it was decided to undertake a benchmarking approach across different states, the details of which are enumerated in the upcoming subsection.

3.1 Selection of U.S. States

To consider similarities in external factors such as traffic volume, population, etc. that could affect worker conditions on-site, a smaller set of U.S. states were selected to be benchmarked for their safety practices. As shown in Figure 3.3, U.S. states were selected that compared with Indiana based on the VMT/capita and road fatalities/capita (2010–2018) (Policy and Governmental Affairs, n.d.; U.S. Bureau of Labor Statistics, 2020a). Additionally, the selection was refined to enable learning best practices by considering states that have observed a high reduction in worker fatalities over the same period (ARTBA, n.d.).

Based on the analysis, details provided in supplement, the following states and their respective DOTs were selected.

- Colorado: Colorado Department of Transportation (CDOT)
- Delaware: Delaware Department of Transportation (DELDOT)
- California: California Department of Transportation (Caltrans)
- Texas: Texas Department of Transportation (TxDOT)
- North Dakota: North Dakota Department of Transportation (NDDOT)

3.2 Overview of Benchmarked U.S. States

3.2.1 Colorado

Based on the research, CDOT (Federal Highway Administration, 2012) leads the way in using risk management as a safety training tool to ensure compliance, with a plan of action concerning loss of life or property, and prevention and control of bodily injury to employees and public, private, or contractor property damage. It covers three basic areas from insurance, medical provider, and reduced workers' compensation insurance premiums to ensure safety training is provided to all contract workers (CDOT, 2020).

CDOT also focuses on Traffic Control Plans (CDOT, 2020), detailed checklists and videotaping work zone setups to document all aspects of work and traffic. These videos could be used in training to convey learning lessons. It also implements training topics based on level of responsibility, so that project personnel at different management levels have relevant training.

3.2.2 Delaware

Based on the research, DelDOT (Delaware.gov, n.d.) focuses its efforts in utilizing project specific temporary traffic control measures to ensure work zone safety. DelDOT was a pioneer in experimenting a full road closure as part of its traffic management plan (FHWA, 2004). These efforts resulted in various benefits like 75% reduction in exposure time for workers and travelers and improved worker safety.

DelDOT also uses contractor selection as a tool to ensure safety training is provided to every contracted

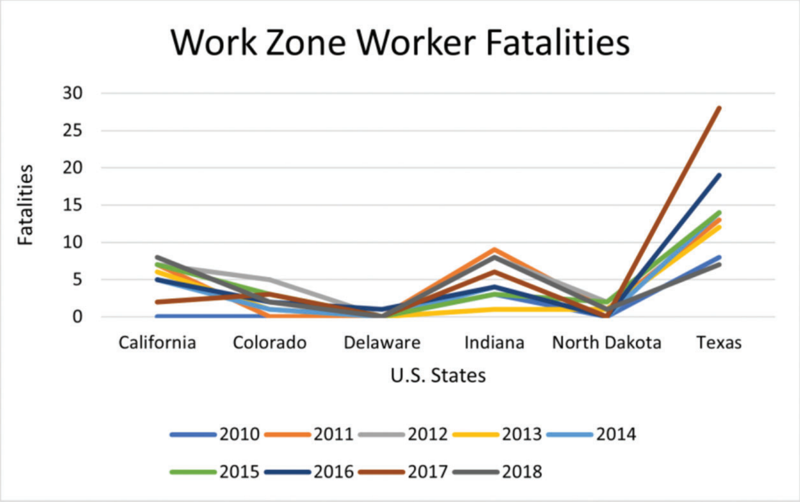


Figure 3.3 Worker fatalities across benchmarked states.

worker. By meeting DelDOT's requirements on safety management and training, contractors can utilize reduced insurance premiums for its workers.

In summary, DelDOT focuses most of its efforts in traffic management and control plans. Additionally, it also utilizes ATSSA (American Traffic Safety Services Association)-based safety training involving education materials and exam for seeking qualified workers (DelDOT, n.d.).

3.2.3 California

Caltrans (2014) focuses its efforts on traffic management plans as well as project specific safety training to ensure worker safety. Caltrans was a pioneer in developing and implementing the concept of traffic management plan, wherein according to different point of contact between workers and drivers, placement of speed limit signs, speed feedback signs, and barriers was decided upon (FHWA, 2020).

Caltrans (2014) also enforces training through handouts, presentations, case studies, quiz, and training certificates—the following are some examples.

- Certified flagger
- Safety quality control manager
- Traffic control supervisor
- Traffic control technician

It has also collaborated with UC-Berkeley for customized training courses for project engineers, technicians, inspectors, and work crews (Berkeley Institute of Transportation Studies, n.d.).

3.2.4 Texas

TxDOT focuses on providing a training catalog of online and instructor-led training courses for all employees. It also enforces on-the-job training for all types of employees including supervisors, technicians, and skilled craft workers.

TxDOT has also implemented new technologies that can assist workers and flaggers on-site. The following are some examples of such technologies (TxDOT, n.d.).

- Equip the flagger with audible warning system, to warn the workers.
- Audible warning tech on the body of the worker that acts as a personal alarm.

3.2.5 North Dakota

NDDOT (n.d.) uses project-based analysis to implement safety practices such as continuous work zone assessment, monthly vehicle assessment (based on project budget), vehicular traffic, and population size affected (North Dakota Safety Council, n.d.). Continuous work zone assessments include measurement of Level of Service and Vehicle delay to implement specific traffic management tools and change project plans.

NDDOT utilizes certifications and inspections as a tool to ensure work zone safety (NDDOT, n.d.). The following are some of the certifications that are used to ensure on-site worker safety and help in inspections.

- Review of Traffic Control Plan (TCP) design–Traffic Control Design (ATSSA) and advanced work zone management and design (NHI) certified specialists.
- Project Manager or Engineers–Traffic Control Supervisor (ATSSA) certification.
- Construction Inspectors or Technicians–Traffic Control Technician (ATSSA) certification.
- Maintenance Section Supervisor–ATSSA certification in lane closure, mobile, mowing and truck-mounted attenuator operations.

To summarize, most of the above certifications rely upon classroom and video-based (in some cases, without instructor) training methods to ensure work zone safety.

3.3 Qualitative Research

Our research regarding improving safety performance of construction workers, different characteristics that training sessions should include can be summarized as follows.

1. Content and delivery method should be customized based on worker skill levels, technical experience, language skills, flatter learning curve (Hussain, 2018).
2. Using qualified academic trainers is always necessary to be compliant with OSHA mandate.
3. Use of abstract situations for an andragogical learning style wherein workers are taking the initiative to learn safety concepts ("learning by doing" technique) (Dudley, 2010).
4. Use of visual aids like 4D (cost) and 5D (cost, time) visualization tools (Miller et al., 2012) helps in gaining knowledge and experimenting with traffic management and project management plans.
5. Participatory training programs such as risk maps, role plays, demonstrations, games, etc.
6. Employees' past-experience could create biased perception towards the severity of certain hazards. Employees with more site/on-the-job experience likely apply their prior experience and safety knowledge to form reliable perceptions towards a given hazard (Yu et al., 2019). Therefore, distribution of training resources based on worker experience, hazard occurrence and severity is necessary.

The following summarizes management-level practices that can motivate workers to get more involved in safe practices.

1. Commitment by middle management to safety training results (O'Toole, 2002).
2. Worker recognition on completion of no-incident reporting.
3. Annual training evaluation audits that observe employee reaction on-the-job, review training objectives during training and performance metrics.

4. OUTCOME ANALYSIS OF TRAINING TECHNOLOGIES

Established research studies were analyzed to compare interactivity and effectiveness of training methods. Many of these studies relied upon user surveys, user testing results across range of demographics involving students to professionals in various industries.

A range of testing results comparing user performance across different combinations of the five training technology tools were summarized into 11 interactivity attributes and five outcome-based attributes. Figure 4.1 and Figure 4.2 provide the usability analysis based on 11 attributes.

Appendix A provides comparative summary of the conclusions and comments across these five research studies (Abdel et al., 2018; Martin et al., 2013; Seaborn & Fels, 2015; Tsay, 2018; Wolff, 2017), that was subsequently utilized to compare the usability of these technology tools. Analysis of these research studies provides higher interactivity and user experience of the new tools compared to traditional learning. Figure 4.3 provides the learning outcome analysis across five attributes.

Appendix B provides comparative summary of the conclusions and comments across these four research studies (Abdel et al., 2018; Borsci et al., 2016; Martín-Gutiérrez et al., 2013; Wang et al., 2020), that was subsequently utilized to compare the learning outcomes of these technology tools. Analysis of these research studies suggests relatively higher long-term retention and better understanding of the concepts using new tools compared to traditional learning.

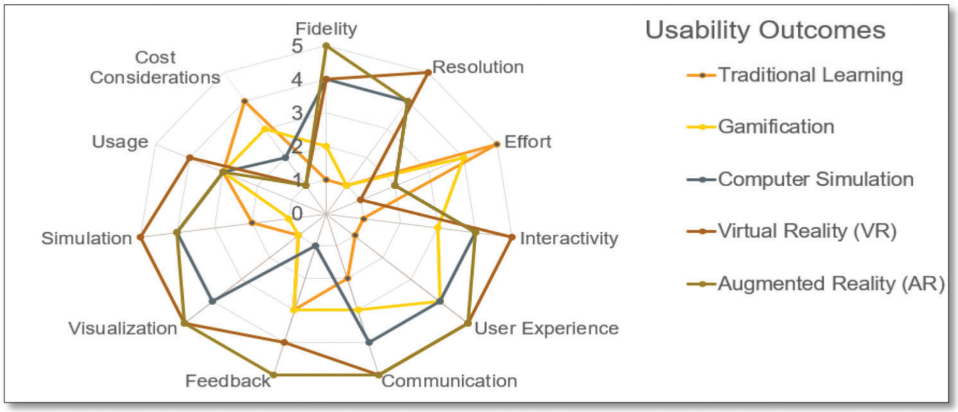


Figure 4.1 Usability-based outcomes for five technology tools (Abdel et al., 2018; Martin et al., 2013; Seaborn & Fels, 2015; Tsay, 2018; Wolff, 2017).

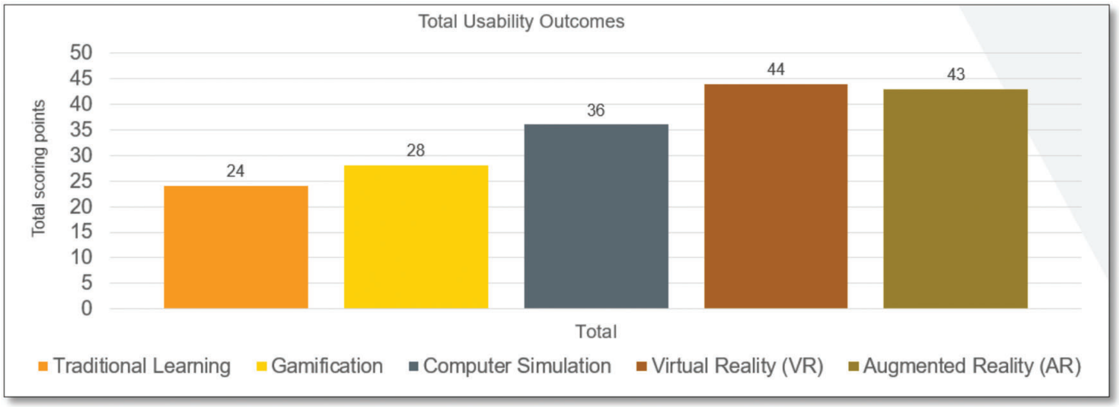


Figure 4.2 Total usability-based outcomes for five technology tools (Abdel et al., 2018; Martin et al., 2013; Seaborn & Fels, 2015; Tsay, 2018; Wolff, 2017).

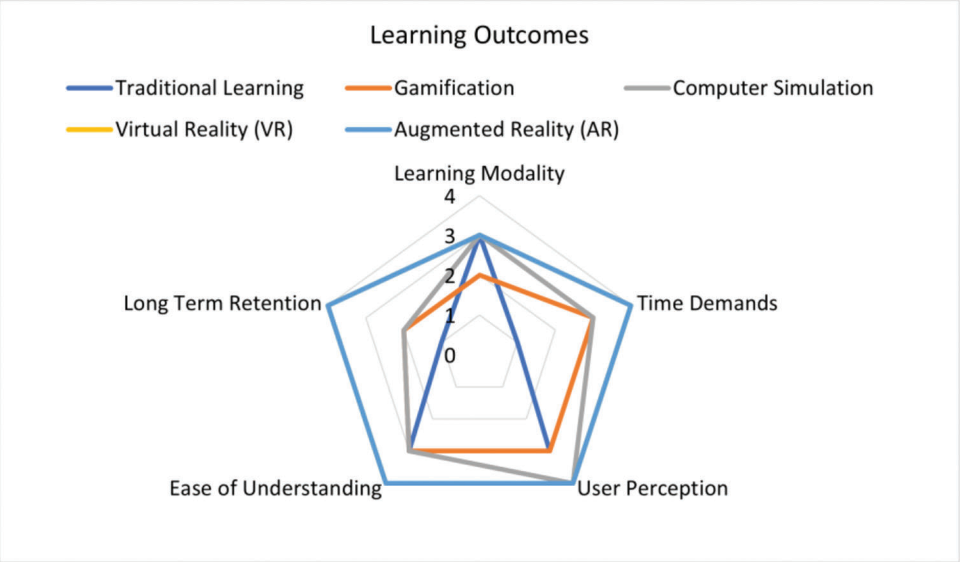


Figure 4.3 Learning outcomes for five technology tools (Abdel et al., 2018; Martin et al., 2013; Seaborn & Fels, 2015; Tsay, 2018; Wolff, 2017).

5. RISK ATTRIBUTE ANALYSIS

Introduction: The analysis conducted on benchmarking of technologies and training tools followed the unique aspect of understanding the risk of a work zone. A major focus of this project has been to understand what risk constitutes any work zone. To understand this in more detail, focus was made at a granular level. In this regard, risk attribute turns out to be a great way to achieve such understanding. To start with, a risk attribute is a cause or something of causal nature for an accident. For example, consider ongoing work on a highway involving a nail gun; thus, working with a nail gun is a risk attribute. The report focuses on attributes for highway and street construction (group 1611) and bridge, tunnel, and elevated highway construction (group 1622) (Esmaeili, 2015). All the data obtained were from OSHA and NIOSH database and are federal in nature.

The framework classifies each group (which can be expanded to fit the requirement of INDOT) in two ways—type of injury and risk attribute.

Analysis: The goal is to categorize risks by attributes or activities performed in a work zone and then recommend, depending on the risk factor, how advanced training is required. Several papers define risk as sumproduct of severity score, work hour, and probability of occurrence. Hallowell and Gambatese (2009) define severity factors for five major accident outcomes—first aid, medical case, lost work time, permanent disablement, and fatality.

The weightage provided to each of these outcomes are mentioned in Table 5.1 (Esmaeili, 2012). It should be noted that these weightage are assigned to understand the risk nature of an accident outcome and do not relate only to monetary loss but both to monetary loss and the intangible loss that follow an accident outcome.

TABLE 5.1
Weightage for Accident Outcomes

Type of Injury	Score
First aid	48
Medical case	128
Lost work time	256
Permanent disablement	1,024
Fatality	26,214

The attributes associated with a work zone are classified according to how the analysis is conducted or in which area the analysis is conducted. In this analysis, focus is on a total of 22 attributes that were major concerns on the set of accident reports researched. It should be noted that these attributes are subject to change according to the specific data set that is used. The risk attributes shall be consistent across all SIC groups.

INDOT may have certain SIC groups that are more prevalent. A partial dataset of the cases in Indiana under SIC 1611 is provided in Figure 5.1. In absence of data specific to INDOT, the analysis focused on drawing results from federal data.

The goal of this analysis is to create a severity risk index to classify a work zone. Risk attributes are associated with every work zone. A sample snapshot of how risk index of fatality can vary for different attributes is provided in Figure 5.1 (Esmaeili, 2012).

Total Risk Framework: The framework comes with a formulation of the different factors regarded in the analysis. The weightage has already been provided in the previous sections. The next part is to find the relative frequency of attributes. Relative frequency is the number of times an attribute is cited as a cause for

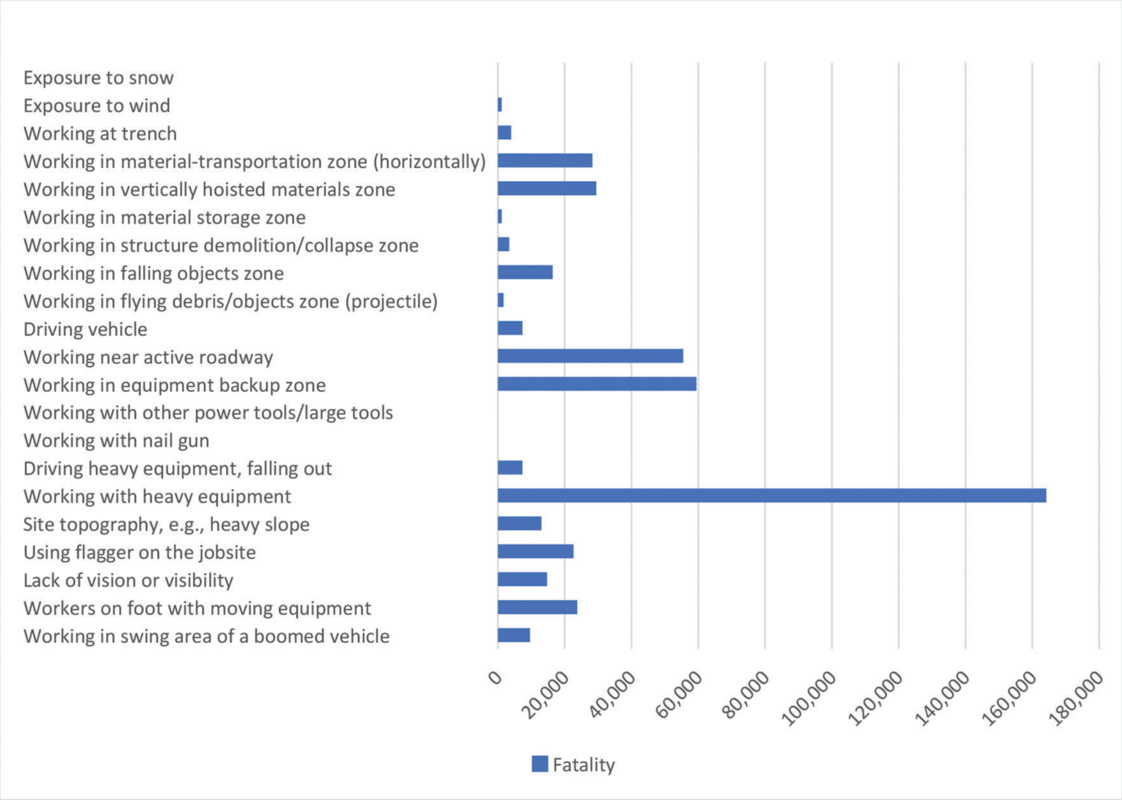


Figure 5.1 Risk index for fatality cases within SIC 1611.

TABLE 5.2
Relative Frequency of Sample Calculations 1

	First Aid	Lost Work Time	Fatality
Lack of vision or visibility	10	15	10
Site topography, e.g., heavy slope	5	7	30
Driving vehicle	4	8	20

TABLE 5.3
Relative Frequency of Sample Calculations 2

	First Aid	Lost Work Time	Fatality
Lack of vision or visibility	0.1	0.15	0.1
Site topography, e.g., heavy slope	0.05	0.07	0.3
Driving vehicle	0.04	0.08	0.2

accident divided by the total number of cases in the SIC group. Assume that in any SIC group there are 100 cases. Next, the number of cases related to attributes chosen for the analysis is determined. A sample is mentioned in Table 5.2 (Esmaeili, 2012) as a reference to show the calculation of relative frequency.

Consider that first aid occurred for lack of vision 10 times, for driving vehicle 4 times; lost work time occurred for lack of vision 15 times, for driving vehicle 8 times. The relative frequency in each of these cases will thus be 0.1, 0.04, 0.15, and 0.08 respectively. This is represented in Table 5.3 (Esmaeili, 2012).

Another important thing to consider is what happens when there are multiple attributes for a particular outcome. Consider that 25 cases of first aid occurred and the probable attributes are “lack of vision,” “site topography,” and “drivin vehicle.” Now, if some cases are contributed by multiple attributes, cases will be counted for each attribute. This means that if a case is contributed for lack of vision and driving vehicle both, the case will be considered for both lack of vision and driving vehicle individually.

This will result in the relative frequency for each attribute and accident outcome. A list of relative fre-

TABLE 5.4

Relative Frequency for Attributes and Accidents Outcome (Esmaeili, 2012)

	First Aid	Medical Case	Lost Work Time	Permanent Disablement	Fatality
Working in swing area of a boomed vehicle	0.00	0.43	0.43	0.43	3.67
Workers on foot with moving equipment	0.00	1.08	1.30	0.43	9.07
Lack of vision or visibility	0.00	0.22	0.86	0.43	5.62
Using flagger on the jobsite	0.22	0.65	1.30	0.86	8.64
Site topography, e.g., heavy slope	0.22	1.30	0.43	0.65	4.97
Working with heavy equipment	2.81	3.67	9.29	2.38	62.63
Driving heavy equipment, falling out	0.00	0.22	0.43	0.00	2.81
Working with nail gun	0.00	0.00	0.00	0.00	0.00
Working with other power tools/large tools	0.00	0.00	0.00	0.00	0.00
Working in equipment backup zone	0.22	0.65	1.94	0.65	22.68
Working near active roadway	1.08	1.08	3.67	1.51	21.17
Driving vehicle	0.43	0.43	1.08	0.43	2.81
Working in flying debris/objects zone (projectile)	0.00	0.00	0.43	0.00	0.65
Working in falling objects zone	0.22	0.22	1.73	0.43	6.26
Working in structure demolition/collapse zone	0.00	0.00	0.43	0.00	1.30
Working in material storage zone	0.00	0.00	0.86	0.00	0.43
Working in vertically hoisted materials zone	0.43	0.43	1.73	0.00	11.23
Working in material-transportation zone (horizontally)	0.22	0.65	3.24	0.43	10.80
Working at trench	0.22	0.00	0.00	0.00	1.51
Exposure to wind	0.00	0.00	0.00	0.00	0.43
Exposure to snow	0.00	0.00	0.00	0.00	0.00
Extreme temperature, freezing or above 27°C	0.00	0.00	0.00	0.00	0.22

quency for each attribute classified according to outcome is mentioned in Table 5.4 for SIC 1611 (the data used here are at federal level and not specific to INDOT).

Once the relative frequency is evaluated, the risk factor can be estimated using the below formula.

$$Risk_{ij} = S_j * F_{ij} * W_i$$

$$Total\ Risk = Sum\ total\ of\ Risk_j\ for\ all\ outcomes$$

Where $Risk_{ij}$ is the risk index for attribute i and accident outcome j.

S_j is the severity weightage mentioned earlier for different types of outcomes (first aid, lost work time, etc.).

F_{ij} is the relative frequency of attribute i in causing outcome j as obtained after analysis of accident reports classified according to different outcomes.

W_i is the work hour associated with an attribute, or the work hour a crew is expected to be exposed to attribute i.

Total risk factor can then be calculated as total of risk associated with each attribute.

A snapshot of the total risk associated with SIC 1611 is presented in Table 5.5.

TABLE 5.5
Sample of Total Risk Associated with SIC 1611 (Esmaeili, 2012)

	First Aid	Medical Case	Lost Work Time	Permanent Disablement	Fatality
Severity scale	*48*	*128*	*256*	*1,024*	*26,214*
Working in swing area of a boomed vehicle	0	5.504	11.008	44.032	9,620.538
Workers on foot with moving equipment	0	13.824	33.28	44.032	23,776.1
Lack of vision or visibility	0	2.816	22.016	44.032	14,732.27
Using flagger on the jobsite	1.056	8.32	33.28	88.064	22,648.9
Site topography, e.g., heavy slope	1.056	16.64	11.008	66.56	13,028.36
Working with heavy equipment	13.488	46.976	237.824	243.712	16,4178.3
Driving heavy equipment, falling out	0	2.816	11.008	0	7,366.134
Working with nail gun	0	0	0	0	0
Working with other power tools/large tools	0	0	0	0	0
Working in equipment backup zone	1.056	8.32	49.664	66.56	59,453.35
Working near active roadway	5.184	13.824	93.952	154.624	55,495.04
Driving vehicle	2.064	5.504	27.648	44.032	7,366.134
Working in flying debris/objects zone (projectile)	0	0	11.008	0	1,703.91
Working in falling objects zone	1.056	2.816	44.288	44.032	16,409.96
Working in structure demolition/collapse zone	0	0	11.008	0	3,407.82
Working in material storage zone	0	0	22.016	0	1,127.202
Working in vertically hoisted materials zone	2.064	5.504	44.288	0	29,438.32
Working in material-transportation zone (horizontally)	1.056	8.32	82.944	44.032	28,311.12
Working at trench	1.056	0	0	0	3,958.314
Exposure to wind	0	0	0	0	1,127.202
Exposure to snow	0	0	0	0	0
Extreme temperature, freezing or above 27°C	0	0	0	0	576.708

6. VENDOR COST ANALYSIS

With the technologies assessed, we reached out to potential vendors for pricing and content development for the training courses that we provided. The storyboards can be developed using the studied technologies to get a better user experience and hence better content retention to improve the worker safety in the work zone.

6.1 Virtual Reality

Our research suggests that there are significant positive differences in learning, engagement, and retention through VR compared to traditional learning methods (Avveduto et al., 2017) and there are also applications in construction training (Sacks et al., 2013).

Based on our vendor research we identified the vendors which provide VR training solutions for construction work zones and industrial environment. We received a quote for creating a 30-minute VR training model which includes content creation and content deployment for the training. We discovered that some companies offer off-the-shelf content, and the others provide custom made content. The firms shortlisted were the following.

1. EHS Insight
2. Strivr
3. 3M
4. Royal Innovative Solutions
5. 360 Immersive
6. PixoVR
7. Matterport
8. SAP Litmos
9. HoloPundits

One of the highlights of our correspondence with the vendors was their willingness to provide customized content and integration with new/existing LMS platforms. Based on the correspondence, we learned that the total cost depends on scalability, extent of customization and deployment strategy. The suggested ballpark timeline was the following.

1. Content creation: 3 to 4 months.
2. Content rollout: 6 to 12 months.

The cost contains the cost for creating the content, the Learning Management System, server to host the training for multiple users simultaneously and the modules offered. Based on the limited communication received from some of the vendors, comparison between the quotations is given in Table 6.1.

From the comparison, it was evident that Strivr offers competitive pricing for custom made content and SAP Litmos offers competitive pricing for off-the-shelf content.

6.2 Augmented Reality

Augmented Reality (AR) is a technology or an environment where the additional information gener-

TABLE 6.1
Pricing Obtained for Training Content Development in VR

	PixoVR	**SAP Litmos**	**EON**	**Strivr**
Hardware and Subscription Costs	**$17,000** for 10 users for 3 pre-created modules	**$9,000** for 50 users	**$10,000** per user at a time/3 years	Custom content
	$250 per additional user	–	**$149**/user/year to store progress	–
	$500 per headset	–	–	**$500** per headset
	–	–	–	**$15** per location
	$2,200/user/year	**$180/user/year**	**$3,482/user/year**	**$515/user/year**
Content Creation	Content already created	Pre-created content library	Pre-created content	–
	$1,500 per additional pre-created module	–	**$15,000** per experience	–
	$250,000–$500,000	–	–	**$175,000–$200,000**
Details	Content along with OSHA standards, no certification	No VR, 360° video capability	LMS integrable	Content certification with OSHA standards
	–	LMS included	–	LMS integrable
	–	–	–	Offline content

ated by a computer is inserted into the user's view of a real-world scene (Wang & Dunston, 2007). The supremacy of this tool lies in its ability to allow the transfer of digital information into the real world, blending the two worlds together, therefore pre-eminently befitting training curricula aiming at situational awareness (Barsom et al., 2016). We have also found that the use of AR has improved the speed and accuracy of training participants for Emergency Medical Services (EMS) cadets by 10% and 34.5% respectively compared to traditional learning, (Koutitas et al., 2020) but similar studies are yet to be conducted for construction safety training. Lastly, most of the research literature that was studied, indicates that the use of AR technology is more suitable to domains of operation, planning, and maintenance where standardized sequenced tasks are required.

We attempted to contact several AR technology and service vendors and indulged in abstract discussions about the use of AR technology for safety training. Some of the vendors that showed promise are the following.

1. Augmented Training Systems
2. Saritasa
3. Index AR

One highlight of the discussion with the vendors indicated the readiness of offering custom made solution without having an off-the-shelf product. The cost to build an AR system would be driven by the complexity of the training module. Hence, it was only possible to obtain an estimated cost range of a typical AR project which is between USD 10,000 to USD 60,000 per training module. The described cost is only applicable for the software development of the training. Additionally, the time frame for executing project stages is as follows.

1. Content development: 3–6 months.
2. Prototype: 3–4 months.
3. Full scale project: 6–24 months.

Adding to our effort of researching the cost of building an AR system, we have referenced a cost structure (Vakhnenko, n.d.) in Tables 6.2, 6.3, and 6.4 that may give an idea of overall cost to build such a system.

6.3 Computer Simulation

Computer simulation is a technology which can be used to improve the quality of learning in safety training by playing games (Means et al., 2020). The main advantages of this technology are the retention of the training material, sense of presence, and greater cognitive skill-based gains over the traditional instructional methods (Cole et al., 2001; Kincaid & Westerlund, 2009; Rieve, 2015; Wilson et al., 2008). It represents the real-world scenarios in a risk-free environment which helps workers to identify and mitigate hazards more effectively (Wojcik, 2003). However, it comes with high initial costs, and it is less interactive than other advanced tools like VR and AR.

According to the research, the use of computer simulation in learning shows that workers who experienced simulation training perform 20% better in the test after training compared to traditional learning (Ahn et al., 2020).

Next, the vendors providing computer simulation-based training were contacted. The estimation of cost for content creation and the deployment of the content is presented in Table 6.5 (Chapman, 2010).

6.4 Learning Management System–Gamification

Based on our research, it was evident that LMS is a very effective tool to keep track of training progress,

TABLE 6.2
Pricing of Training Content Deployment in AR

Content Deployment	Qty	Cost/Unit	Total Cost
Platform Creation[1]			
Strategic analysis	115 hours	USD 150	USD 17,250
Processing of gyroscope data	300 hours	USD 150	USD 45,000
Implement gyroscope data	500 hours	USD 150	USD 75,000
Design solution	500 hours	USD 150	USD 75,000
Extra features implementation (3 features)	90 hours	USD 150	USD 13,500
All kinds of ratings implementation	30 hours	USD 150	USD 4,500
Different sound effects implementation	80 hours	USD 150	USD 12,000
Awards and achievements implementation	60 hours	USD 150	USD 9,000
Testing	100 hours	USD 150	USD 15,000
Total Platform Creation	*1,775 hours*		*USD 266,250*

[1] Golosovskaya, 2020.

TABLE 6.3
Pricing of Equipment for Training in AR

Hardware	Qty	Cost/Unit	Total Cost
User Interface Hardware			
1. MS HoloLens 2	10 unit	USD 3,500	USD 35,000
2. Glass Enterprise Edition 2	10 unit	USD 1,195	USD 11,950
3. iPad	10 unit	USD 329	USD 3,290
4. Google Cardboard	10 unit	USD 15	USD 150
Server			
1. Dell PowerEdge T640 Tower Server (on-premise)	1 unit	USD 3,549	USD 3,549
2. AWS Server Subscription (cloud based)	12 months	USD 1,202	USD 14,424

TABLE 6.4
Pricing of Training Content Deployment and Equipment Combinations

Combination	Cost
Total Cost: Software with Hardware 1 & Server 1	USD 304,799
Total Cost: Software with Hardware 2 & Server 1	USD 281,749
Total Cost: Software with Hardware 3 & Server 1	USD 273,089
Total Cost: Software with Hardware 4 & Server 1	USD 269,949
Total Cost: Software with Hardware 1 & Server 2	USD 315,674
Total Cost: Software with Hardware 2 & Server 2	USD 292,624
Total Cost: Software with Hardware 3 & Server 2	USD 283,964
Total Cost: Software with Hardware 4 & Server 2	USD 280,824

performance, and even for gamifying safety trivia and concepts. Our vendor outreach has provided insights about the innumerable benefits of the LMS, such as the following.

1. Little to no installation.
2. 24 × 7 access to training content from any device.
3. Customized to fit requirement.
4. Easy to monitor progress in real time.
5. Interactive features.
6. OSHA compliance.
7. Availability of offline access.
8. Increased project engineer/worker engagement.

Additionally, the time frame for executing project stages is as follows.

1. Content customization: 1 month.
2. Integration with off-the-shelf gamified LMS: 1 month.

We researched customizing the current LMS system with gamification tools from vendors, as presented in Table 6.6.

TABLE 6.5
Pricing Obtained for Training Content Developed in Computer Simulation

	Qty	Cost (USD)[1]	Total Cost (USD)
Content Deployment[2]			
Client PC–Dell All in One	30 units	699	20,970
Dell PowerEdge T640 Tower Server	1 unit	3,549	3,549
Total Content Deployment			*USD 24,519*
Content Creation (per one unfinished hour)			
Front end analysis	43 hours	USD 150	USD 6,446
Instructional design	62 hours	USD 150	USD 9,296
Storyboarding	53 hours	USD 150	USD 7,983
Graphic production	65 hours	USD 150	USD 9,680
Video production	30 hours	USD 150	USD 4,569
Audio production	27 hours	USD 150	USD 3,992
Authoring/programming	86 hours	USD 150	USD 12,959
QA testing	32 hours	USD 150	USD 4,727
Project management	32 hours	USD 150	USD 4,829
SME/stakeholder reviews	31 hours	USD 150	USD 4,592
Pilot test	21 hours	USD 150	USD 3,144
Other	9 hours	USD 150	USD 1,289
Total Content Creation	*490 hours*		*USD 73,502*
Total All			*USD 98,021*

[1] Jackson, n.d.

[2] An additional note to the above cost—the content deployment cost of USD 24,519, which consists of the cost of procuring user interface and server hardware, is not necessarily needed in the case where the computer simulation content is attached to an existing Learning Management System (LMS) platform. This is assuming the existing LMS is web-based, and easily accessible through any device that an existing server is used and personal mobile devices are used to perform training.

TABLE 6.6
Pricing Obtained for LMS

Vendor	Product Offering	Pricing
Vivid Learning	Offered in any platform with internet connection. Content can be customized.	Subscription (unlimited users): USD 4,000 to USD 10,000 annually.
Alchemy Systems	Mobile device-based gamified learning and progress tracking platform. Content developed in partnership with universities.	Subscription: USD 4–15 per month per user (max 150 users).
Trivie	Mobile device-based gamified learning and progress tracking platform. Collaboration with Skillsoft and Accenture–content and platform. Leaderboard, challenges, metrics–gamification.	Subscription: USD 2–3 per month per user. Can integrate any type of content with platform.

7. OPTIMIZATION MODEL

7.1 Impact of Training Modules

In this section, we present an optimization framework to choose across training modules within each training tool to minimize costs while reducing risk to a desired level. We first describe the risk associated with each attribute for a task and categorize training modules with respect to reduction of such risks. We then optimize the choice of training modules to deliver on the required risk reduction. The net effect is that we match the training tool to the desired type of training required to reduce risk for a task.

The retention rate of training medium previously elaborated play a major role in classifying training modules for each coursework. Depending on the suitability of training module to mitigate risk of certain attributes, an optimization model was developed that aims at putting the risk framework in the context of training module.

With the cost estimates from the vendors, we assessed risk improvements for the training technologies to optimize the training budgets of INDOT. The input for the model comes from market research and research papers—vendor costs mentioned in the section above (cost are for each training technology type), categorization of the training courses in the capabilities, risk reduction achieved for capabilities for potential delivery tech and the risk attributes analysis performed during the project.

Platform creation costs are taken from the vendor research conducted for traditional material, gamification, computer simulation, augmented reality (AR) and virtual reality (VR).

Training courses selected based on the attributes contributing to the incidents recorded are categorized based on the capability of the course in the following groups—categorical data, spatial data, logical data, and factual data.

The optimization model is built in MS Excel and run using solver. In the model, the desired reduction in the risk index is used as an input value for the solver. The model analyzes the risk reduction by the technologies for the training courses to optimize the selection of the training technology per course. This model is designed to minimize the total cost of the trainings to achieve desired percentage reduction in risk.

It bridges the risk attributes analysis, selection of the technologies, and the cost required to develop the technologies. Considering the national level data and the mix of training attribute, the optimum cost obtained for different level of risk reduction is mentioned below. The data are based on national level data for SIC 1611.

The solver model works with multiple categories in terms of risk reduction for each training tool and training attribute. The training attributes involved with each training module are also considered. A brief of the optimization model is provided below.

i – type of training attributes (categorical, spatial, logical, factual).

j – type of training technologies (AR, VR, etc.).

k – type of training modules (confined space, fall protection, etc.).

A_{ki} – type of training attribute i associated with each training module k – [0,1].

R_{ki} – risk distribution for training attribute i associated with training module k.

B_{ij} – Binary value for attribute i associated with training technology j.

$R^{/}_{i,j}$ – Risk reduced in attribute i by technology j.

C_{ij} – Cost of training with technology j for attribute i.

X_{ijk} – Decision variable.

α – Expected percentage reduction in risk.

$$\sum_j \sum_i (X_{ijk} * B_{ij} * R^{/}_{ij}) = R^{//}_k$$

$$\sum_j X_{ijk} \leq 1$$

$$\sum_i X_{ijk} \leq 1 \text{ and } \sum_j X_{ijk} \geq A_{ki}$$

$$R^{//}_k \geq \alpha * \sum_i R_{ki}$$

Thus,

$$Total\ cost = \sum_k \sum_{ij} C_{ij} X_{ijk} = C$$

minimizing C provides the optimum solution. Figures 7.1 and Figure 7.2 show how the optimal cost varies across different levels of risk reduction α (expected percentage reduction in risk). Note that as the desired level of risk reduction increases, it becomes necessary to reduce risk across all attributes for tasks, thus requiring more expensive training tools. Figure 7.1 and Figure 7.2 show the pattern on risk reduction and training technologies as an outcome of the optimization model.

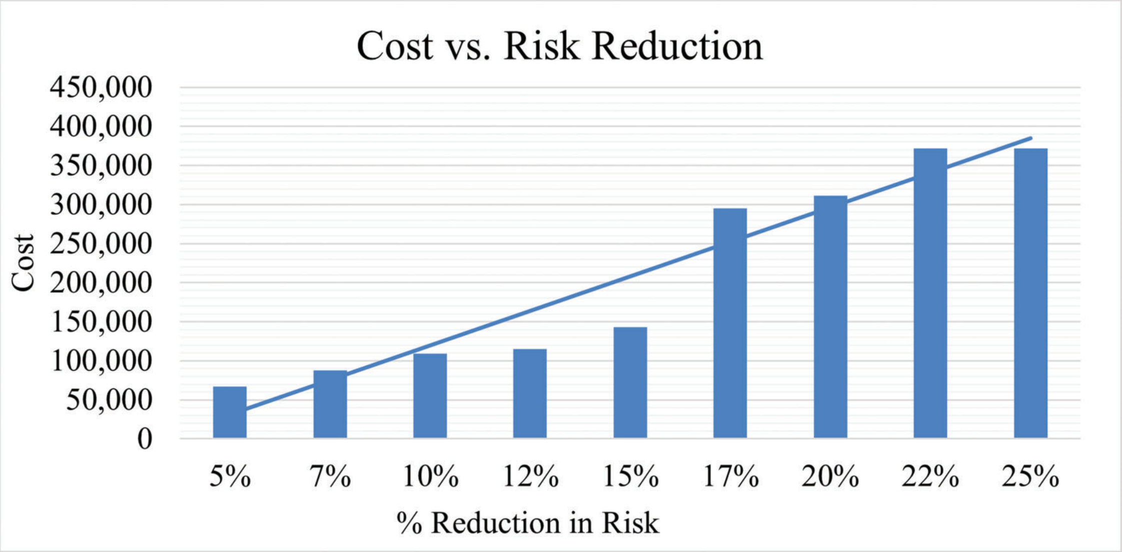


Figure 7.1 Training tool cost vs. risk reduction.

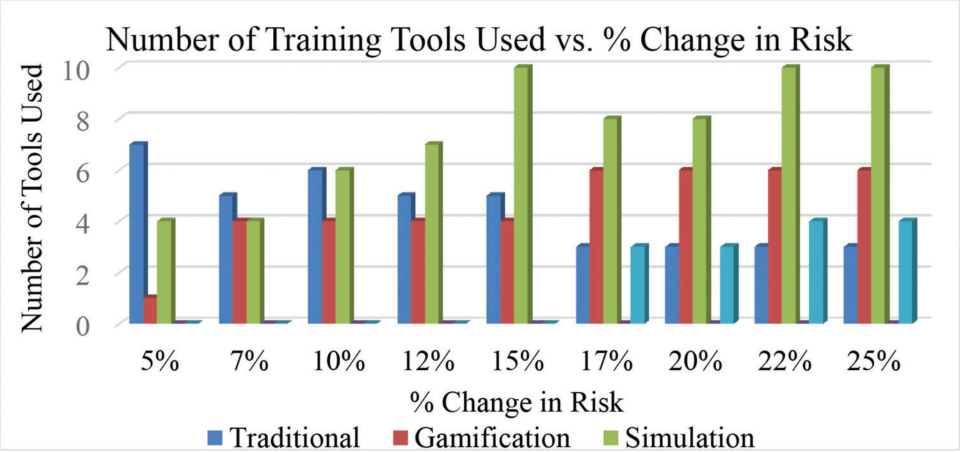


Figure 7.2 Training tools vs. change in risk.

8. SAMPLE VR SCENE

VR gives a real-life experience to the worker to get accustomed with the on-job tasks and steps to follow. As traffic control has high risk index, we have prototyped one of the lessons in VR to implement the arrangement of cones for setting up work zone on rural two-lane highway. The VR training set is modeled in Unity software. The use of flaggers is also included in the training content of the VR scene. Figure 8.1, Figure 8.2, and Figure 8.3 provide a pictographic representation of the work done in different stages. The entire training set is provided as a separate file.

Initial Condition

Initial scenario displayed in the training lesson is two-way highway where traffic is stopped on both sides of the road and flaggers are placed with stop sign held manually.

Workers Tasks

1. Locate both the flaggers.
2. Place the cones at the appropriate locations to set up a work zone.

The worker undergoing the training should be assisted by the trainer of the course.

Final Condition

Work zone set up correctly to release traffic and start the work. Steps in the scene in the prototype are as follows.

1. Worker enters the advance warning area.
2. Worker is asked through prompt "Check flaggers are in place and all traffic is stopped." Worker may move around on the highway to verify.
3. Worker will have to select the type of traffic control device from (cone, barrel, or barrier).

Once you locate both flaggers, pres

Figure 8.1 Sample VR scene—initial condition.

Figure 8.2 Sample VR scene—tasks in progress.

Figure 8.3 Sample VR scene—final condition.

4. He/she will place the cone in the right sequence to define different zones of the work zone.
5. After completion of task, worker will provide the go ahead to flaggers for traffic movement.

Further trainings can be produced with the help of storyboards provided along with the report.

9. WORK ZONE DESIGN–TRAFFIC CONTROL

The two types of traffic controls reduce the incidents occurring inside the work zone due to the heavy-duty vehicles, material handling, falling of objects, etc., and the external incidents occurring due to the intrusion of traffic vehicles in the work zone. The measures, mentioned in the sections, improve the safety of the area.

9.1 External Traffic Control

After the study on established publications, we observed that external traffic control plays a key role in the crashes occurring in the work zone.

For interstate work zones, some of the findings are as follows (Ullman et al., 2018; Venugopal & Tark, 2000).

1. Placement of patrol troopers reduced motorist speed, but its effects are reduced further downstream.
2. Panel signs mentioning “construction zone traffic fines” had a significant effect on motorist speed in the work zone which reduced accidents in the work zone.
3. Variable message signs did not have a significant effect on mean speed reduction compared to fixed panel signs.

9.1.1 Night-Time Work Zones

Risk factors in the work zone are increased at the night-time leading to accidents. Driver related issues like irresponsible driver behaviour, higher vehicle speeds traversing the work zones, and driver confusion are heightened during the night-time. Work zone related issues like glare from work zone lighting and vehicles passing through work zone, poor visibility, inadequate lighting, worker fatigue, and availability of design consultants are increased in night-time works (National Academies of Sciences, Engineering, and Medicine, 2012).

The safety precautions which can be taken in such scenario are as follows.

4. Lighting which includes high mast and balloon lighting rather than using portable lights.
5. Retroreflective clothing which is visible from a 1,000-ft distance.
6. Traffic control devices with retroreflective strips and regular cleaning.
7. Communication with workers of proactive safety plans.

10. SPECIFIC TRAINING REQUIREMENTS

The section explores training options for each specific work/task/job role. Since the most impromptu way of defining training is by the job role or task, we identified 15 different roles for defining the training module. For each module, we explored the different assumptions we made in the process and the corresponding risk associated with it. In case a specific job assignment requires an overlapping of more than one training module defined in this section, we recommend that the task with highest criticality (or risk) be chosen to define the overall training selection criteria. However, to precisely evaluate the assumptions and risk presented, a field experiment is recommended for INDOT where these training tools are tried to test the performance of retention rate improvement.

We approached this selection by considering four categories of training defined in the previous part of this report—namely categorical, spatial, logical, and factual. Categorical training is identified as the domain in which specific learning of the training depends heavily on the work to be performed, rather than on the general understanding of the training. Factual is identified as to be depending on facts that can be learned by an individual. Spatial is identified as to requiring an understanding of the space in the work field. Logical is inclined more towards using reasoning in each situation.

The 15 different roles identified in this section are obtained from OSHA guideline for training requirements. Specific focus to obtain the roles was based on classification of general industry and construction industry. Since OSHA guidelines do not specifically mention the requirements for transportation industry, the rationale behind choosing the two industries was to provide a holistic approach through the choice of general work common for all industries and to have a specific focus on the construction industry, in which INDOT is more focused. Besides, the following other roles were considered to align the goal of this report with the basics of working for INDOT.

- Drivers
- Route planners
- Hazardous material handler
- Material handler
- Grinder/welder
- Electrical services
- Scaffolders
- Riggers
- Excavators and trenchers
- Confined space operators
- Crane/derrick operators
- Highway service providers
- Equipment (heavy) operator
- Stairway or ladder operators
- Tool users

10.1 Training Classification

10.1.1 Drivers

The understanding of training requirement for this role includes ability of the driver to understand the basics of driving (factual); clear and concise measure of driver's ability to drive backward or forwards in a work zone (spatial); and knowledge of specific work zone (categorical).

Assumptions: We assumed that a driver's role is to safely move vehicle within, to, and from a work area. Also, in context of training requirement for INDOT, the basics of driving are not extensively important as these are learned while obtaining a driver's license. Thus, the two components we focused on while deriving the training requirement for this module are know-how of the driver about spatial arrangement of things/people in the work zone (especially blind spots) and respond to any criticality arising from the nature of work area.

Recommendation: Combining the above assumptions and considering the heavy requirement of drivers for INDOT, we recommend that INDOT pursue VR training for this module. Our rationale for this recommendation is as much based on the technical as on the monetary side. Given the large number of drivers INDOT manages, it will be efficient for INDOT to achieve the scale in implementation for the high initial investments associated with VR training. However, if the assumptions or considerations seem misaligned, it is recommended that choice of training be further investigated.

10.1.2 Route Planners

In this context route planners are defined as responsible for designing and management of routes in and near a work zone.

Assumptions: It is assumed that the requirements for this role are specific to knowledge of traffic volume in the route and the nature of work going around. Thus, the nature of the training required is specific to the category of work and facts about the nature of surroundings, meaning the two components of training important in this regard are categorical and factual.

Recommendation: Our recommendation is thus this type of training be restricted to traditional setting or be conveyed through gamification. While gamification has a cost implication, it is not as much as simulation, or AR/VR. Thus, to provide a more comprehensive view of the routes and enabling the trainee with more comfortability in facts that might be missed, we recommend gamification for this module.

10.1.3 Hazardous Material Handler

This specific training module surrounds any personnel involved in transportation or handling of hazardous material. The goal of this module will be to acquaint the personnel with possible risks associated in the material itself as well as the safety precautions necessary in the surroundings for safe transportation of the material.

Assumptions: It is assumed that the requirements for this role are across multiple training components—firstly, it requires spatial knowledge on part of the trainee to understand where and how the material should be moved; secondly, it requires logical reasoning to evaluate the different scenarios and act in a safe manner; and thirdly, it needs an understanding of the different facts associated with the material being transported. We do not categorize hazardous material to have a specific component towards categorical understanding, as the hazards are very common to any job scenario and requires similar attention.

Recommendation: With this specific set of assumptions, we explored the risk attribute chart and recommend that VR module be used for training people in this domain. However, if INDOT finds that it cannot achieve the scale for distributing VR's high costs, we recommend that the training be performed through combination of both gamification and simulation. Our rationale on the technical aspect for recommending this selection is that while simulation will be able to increase the retention rate in spatial and logical categories, gamification will be able to do so in factual category, thus reconciling the two requirements from this module.

10.1.4 Material Handler

This training module is recommended for personnel working with non-hazardous materials. Though OSHA guidelines for material handling in general industry is restricted to handling of rim wheels, the training requirement outlined here takes a holistic view of the general nature of handling material in a construction site. From the risk attribute analysis, it is clear that material handling possess severe risk.

Assumptions: Our assumption is that most of the material handlers require knowledge on the facts of overall process and logical reasoning to oversee certain situations. With these assumptions, the two training components we require to explore in detail are factual and logical. Thus, the recommendation is based on these two training components.

Recommendation: From our mathematical model, we conclude that logical and factual training can be arrested through two approaches—either through two separate training session on gamification and simulation or through VR. Though we recommend VR so that the training time can be reduced, the costs might get overshot if INDOT does not have sufficient people to achieve the scale.

10.1.5 Grinder/Welder

The training for grinder/welder is combined into one to state the common nature of the two works from a training selection perspective. However, it is imperative to keep in mind that separate training content is necessary to adequately prepare an individual towards these works.

Assumptions: Our assumption is that most of the works in this category involve power tools and electrical safety. Combining these two allows us to draw from our risk attribute model that a strong focus is required towards factual, spatial, and logical understanding on the part of the trainee.

Recommendation: We recommend that for this specific requirement AR or VR be used to train workers. Given that the cost of AR is comparable to VR (for the vendors listed in our report), we recommend focusing on VR, which becomes more economical than AR when implemented on a large scale.

10.1.6 Electrical Services

This training module is recommended for personnel working in electrical safety. There are two different aspects to consider in this module. Firstly, whether the person's work is associated with normal electrical safety; secondly, whether the person is associated with power tools.

Assumptions: The assumption in this section is twofold. If a person requires to work on regular electrical connections and does not involve power tools, most of the training requirement will be logical in nature. However, if the person requires use of power tools, the training requirement will be on spatial and factual fronts.

Recommendation: If INDOT chooses to consolidate both the groups mentioned above and have a single training, it is recommended that VR training be employed. This is because VR covers all aspects of training requirement combining the two groups and INDOT can achieve scale to offset the initial investment. However, if such consolidation does not provide scale to work on, we recommend that INDOT use simulation for workers not using power tools and AR/VR for workers using power tools. For the latter task, choice between AR and VR shall be based on the total VR installation to achieve scale.

10.1.7 Scaffolders

The section of scaffolders training may expand from general training to use scaffold to training on working at height, fall protection, or hard hat. For this specific report, general scaffolding training is not considered.

Assumptions: First assumption is that general training on scaffolding rejection and familiarity with scaffold materials are already achieved by personnel working in this area. Second assumption is that the major risk to scaffold workers is fall from height, which requires focus on categorical, logical, and factual training to increase retention rate.

Recommendation: The requirements may vary depending on extent of scaffolding erected in confined space. In case scaffoldings are built in confined space, please include training recommendations for confined space described in this report. Considering risks from fall protection, we conclude, from distribution of risks, that VR be applied for this training. However, if INDOT finds several AR installations and believes that AR can provide scale, from a cost perspective, INDOT can choose to use AR.

10.1.8 Riggers

This section deals with training recommendation for people working with lifting heavy materials. The basis for this considered in OSHA guideline under marine requirements. Though it is not the industry INDOT is in, it might be the case that INDOT requires this training for its workers.

Assumptions: The assumptions made in this section are firstly, all the riggers involved are certified and have basic knowledge of OSHA guidelines. Secondly, it is assumed that riggers require significant spatial and categorical training requirement to function effectively.

Recommendation: With the above-mentioned assumptions, we believe that AR or VR will be best suited for workers involved in rigging work within INDOT. Once again, we recommend that INDOT takes a scrutiny of the scale, before finalizing the training model. If a significant number of roles are trained on a VR platform, it is recommended that this role be trained through VR.

10.1.9 Excavators and Trenchers

This section deals with training recommendation for workers working in excavation and trenching. The training requirement is based on risk factors outlined in SIC codes. Excavation and training have been proven to have significant risk factors associated with them.

Assumptions: The major assumption is that excavation and trenching are mostly dependent on location of different machine and people in the work area. Thus, our assumption leads us to consider spatial aspect to increase the retention rate for training.

Recommendation: With the above-mentioned assumptions, we believe that AR or VR will be best suited for workers involved in excavation or trenching work within INDOT. Once again, we recommend that INDOT takes a scrutiny of the scale, before finalizing the training model. If a significant number of roles are trained on a VR platform, it is recommended that this role be trained through VR.

10.1.10 Confined Space Operators

The section deals with confined space entry and has been adopted to serve OSHA guidelines across several industries. In case confined space training is required in conjunction with another training, the model shall be chosen for the one with higher risk index.

Assumptions: Confined space work is assumed to vary from area to area and is strictly contingent on the specifics of the work zone. This assumption leads to considering two major areas in training for reducing associated risks—categorical and logical. While categorical is required to serve the purpose of varied and diverse work zones, logical is required for the ability of the worker to handle any situations that may arise.

Recommendation: With the above-mentioned assumptions, we believe that AR or VR training will be best suited for workers involved in confined space operations within INDOT. Once again, we recommend that INDOT takes a scrutiny of the scale, before finalizing the training model. If a significant number of roles are trained on a VR platform, it is recommended that this role be trained through VR.

10.1.11 Crane/Derrick Operators

Crane/derrick operators are considered in this report from the basis of OSHA guidelines.

Assumptions: It is assumed that most of the work of crane or derrick operators depend on the spatial movement of object or people around the work zone. This calls for more significant approach towards spatial and categorical focus on the retention rate. Also, from the attribute model, we see our consideration for internal traffic control is totally spatial, so we expand that consideration to provide our assumption on crane/derrick operators.

Recommendation: We recommend that INDOT use simulation training in conjunction with traditional training. From the risk attribute model, we see that the goal can be achieved in two ways—either a combination of simulation and traditional or a combination of simulation and gamification. To be cost efficient, we recommend that the first option be chosen, but INDOT may feel free to implement a combination of simulation and gamification.

10.1.12 Highway Service Providers

Highway service providers include external traffic controller, who are responsible for traffic near a work zone. An increasing number of research papers suggest that external traffic control is exposed to severe risks.

Thus, we highly recommend AR/VR training for this module.

Assumptions: The assumptions here are that workers controlling external traffic are actively involved, and that the work is not extended for internal traffic control. This means the workers are exposed to highways with running cars and are associated with entry and exit of heavy vehicle to and from the work zone. This position is not related to work in progress in the work zone, and thus any person required to be shifted to a different role must follow the necessary training requirement for that task.

Recommendation: With the above-mentioned assumptions, we believe that VR will be best suited for workers involved in external traffic control or highway service providing within INDOT. Once again, we recommend that INDOT takes a scrutiny of the scale, before finalizing the training model.

10.1.13 Equipment (Heavy) Operator

For this section, we considered training for workers who are working with heavy equipment. This part was considered based on OSHA guidelines (though for a different industry) and some of our assumptions are stated below.

Assumptions: It is assumed that heavy equipment operator would work within the work zone and thus must extensively follow the internal traffic control, as well as the requirements of material handling. These two assumptions and a look at our optimization model show that two aspects of training that require higher retention rates are spatial and factual.

Recommendation: From our mathematical model, we conclude that spatial and factual training can be arrested through two approaches—either through two separate training session on gamification and simulation or through simulation and traditional. Though INDOT is free to choose either of the two, we recommend simulation and traditional considering the associated costs.

10.1.14 Stairway or Ladder Operators

The section of stairway and ladder operators include work components from scaffolding, working at height, fall protection, or hard hat. This section considers different components or attributes from all the work type associated and forms an overall recommendation for training.

Assumptions: First assumption is that training requirement for stairway and ladder operators include working on scaffolding, using hard hat, and taking fall protection. Another assumption is that major focus on categorical and logical attributes as well as priority on factual attributes will increase retention rate for workers in this area.

Recommendation: The requirements may vary depending on extent of work or whether the work requirement is preceded by requirement by other work requirement. For example, in case work involves confined space, training recommendations for confined space should be used. In considering risks associated, we conclude from our distribution of risks that VR be applied for this training. However, if INDOT finds several AR installations and believes that AR can provide scale, from a cost perspective, INDOT can choose to use AR for this training.

10.1.15 Tool Users

This section is for users of power tools. While OSHA details training requirements for tool users, a majority of SIC codes describe power tools as a major risk factor. With this basis, we decided to include tools and power tools training in our report.

Assumptions: It is assumed that most of the power tools' operators work with spatial components of training that are required for increasing retention rate. Also, in the mathematical model we considered power tools risk factors can be mitigated through increasing retention rate in spatial domain of training.

Recommendation: We recommend that INDOT use simulation training in conjunction with traditional training. From the risk attribute model, we see that the goal can be achieved in two ways—either a combination of simulation and traditional or a combination of simulation and gamification. To be cost efficient, we recommend that the first option be chosen, but INDOT may feel free to implement a combination of simulation and gamification.

11. RETENTION AMONG TRAINING TECHNOLOGIES

This section explores the difference in the retention rates of the methods of training we have considered in our analysis—augmented reality (AR), virtual reality (VR), gamification, and simulation training. We look at the retention rate of each technology compared to the retention rate of a traditional training method, such as classroom training, presentations, and written trainings. As expected, our research has led us to the conclusion that these training methods do have significant impact of greater learning retention when compared to the traditional training methods. Our research also shows that, when considering the retention rate of learning, each technology is not created equal. The technologies we studied show large variances in the amount of learning retention from each method.

To determine the retention rates of training technologies, we aggregated a multitude of research studies examining the amount of information retained from each form of training technology. Many of the research studies tested two sets of participants, one set which was trained on how to complete a task via traditional learning methods, the control group, and one group trained to complete the same task via one of the new training methods, the experiment group. We then were able to utilize this data to calculate how each different training technology had impacted retention over the baseline of the control group. Once we were able to determine the increase in retention of each training technology, we were able to compare the various technologies. The following are the technologies ranked on the amount of information retained over traditional training methods.

1. Augmented Reality (AR)
2. Virtual Reality (VR)
3. Gamification
4. Computer Simulation

Figure 11.1 depicts, graphically, the difference in retention rates of the studied training technologies. Figure 11.1 shows the percent of information retained over traditional training methods. Augmented Reality (AR) training led study participants to the highest level of retention, with participants retaining 66% more information on average than traditional training methods. Virtual Reality (VR) had the second highest level of retention with study participants, on average, having 33% greater retention of knowledge than the control group. Gamification training had the next highest level of knowledge retention, showing 26% more retention than traditional training methods. Though virtual simulation showed the least amount of retention of the studied technologies, the retention of participants still outperformed that of traditional training methods. Training using simulation showed the least amount of retention of the studied technologies, the retention of participants still outperformed that of traditional training methods.

Figure 11.2 shows the same results as Figure 11.1, but compares the amount of information retained from the different training techniques to a baseline. The black line in the graph represents the baseline of knowledge retained from traditional training methods, at a score of 1. The bars depict the amount of knowledge

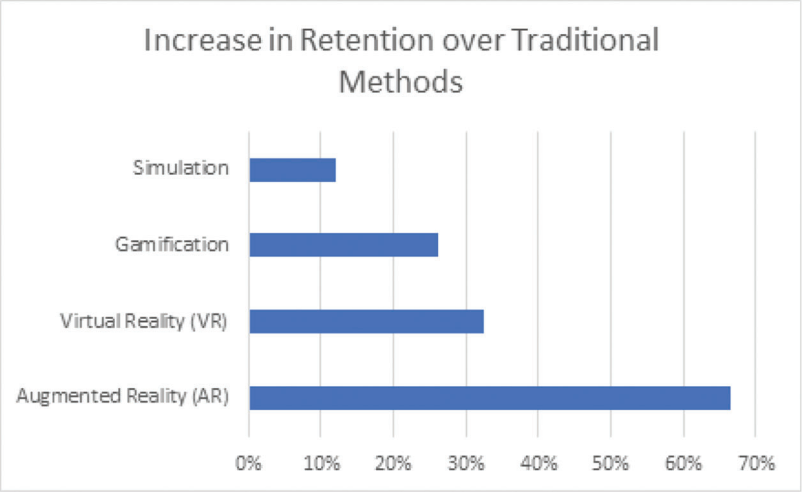


Figure 11.1 Increase in retention rate over training methods (Babu et al., 2018; Gatto, 2020; Luo et al., 2016; Martín-Gutiérrez et al., 2013; Robledo, 2020).

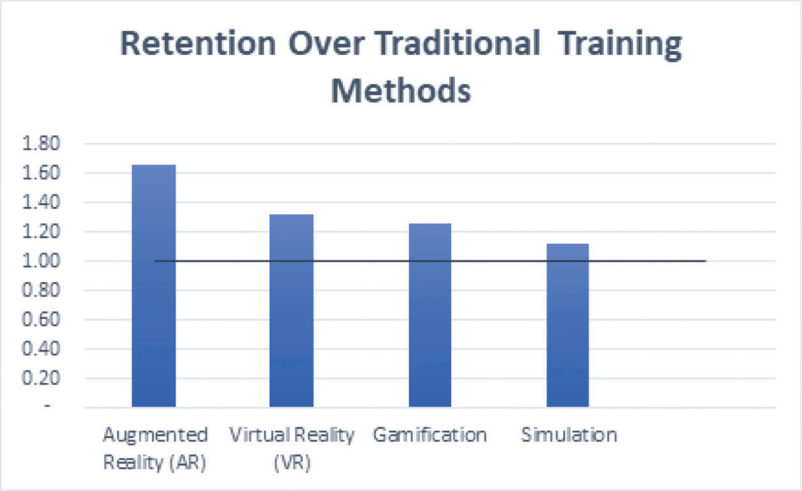


Figure 11.2 Retention over traditional training methods (Babu et al., 2018; Gatto, 2020; Luo et al., 2016; Martín-Gutiérrez et al., 2013; & Robledo, 2020).

TABLE 11.1
Comparison of Knowledge Retention over Traditional Training Methods

Training Method	**Amount of Knowledge Retained Above Traditional Methods**
Augmented Reality (AR)	1.66
Virtual Reality (VR)	1.33
Gamification	1.26
Simulation	1.12

retained over that baseline from each training method. The blue bar over the black line shows the additional retention the given training method provided to study participants.

Based on the above research findings, we can predict how much more information will be retained by each of the technology training methods above traditional training methods. Augmented Reality (AR) will lead to trainees retaining 1.66 times more information than traditional methods. Virtual Reality (VR) will lead to trainees retaining 1.33 times more information than traditional methods (Martín-Gutiérrez et al., 2013; Robledo, 2020). Gamification leads to trainees retaining 1.26 times more information than traditional training methods (Babu et al., 2018; Gatto, 2020). Virtual Simulation training leads trainees to retain 1.12 times more information than traditional training methods. The increase in retention by training method are summarized in Table 11.1 (Babu et al., 2018; Gatto, 2020; Luo et al., 2016; Martín-Gutiérrez et al., 2013; Robledo, 2020).

12. CONCLUSION

The following are five key takeaways.

1. *Quality of Safety Training*

   Benchmarking training practices provided strong evidence that participative programs such as role plays, demonstration of safety devices and risk mapping are some of the best practices. Additionally, training engineers on work zone design, auditing and recording safe work zones can influence project attributes such as length and duration of work zone. Including all these aspects during project planning phase has a greater chance of influencing work zone safety.

2. *Effectiveness of New Technology Tools*

   Our vendor outreach project phase allowed us to understand the different attributes in training course development and customer experience using new technology tools. Established research studies provided significant support to our hypothesis that new technology tools are more effective and interactive compared to traditional learning.

3. *Risk-Based Approach to Training*

   Analyzing the risk index for work zone attributes provides the degree of risk that a worker faces while performing a task characterizing those attributes. We conclude that implementation of new technology tools should be planned based on this risk index and optimization model. This will ensure better student performance and perception of the course content in alignment with the severity of that work attribute.

4. *Optimizing Selection of Training Tools for Tasks*

   We provide an optimization model to choose the optimal mix of training tools to attain the desired level of risk reduction. The tool is spreadsheet based and shows the benefit from using a portfolio of modules across training tools, each targeted at attaining the desired risk reduction by attribute for a task. By using the risk reduction due to training tools from the literature, the cost data from vendors and task characteristics, this tool can enable INDOT managers to manage risk cost efficiently.

5. *Retention Among Training Technologies*

   As to be expected, different types of training methods lead to varying amounts of knowledge retained from training. Based on our research findings we can conclude that training with augmented reality (AR) leads to the highest level of learning retention. Virtual reality (VR) and Gamification respectively, are the next two best methods of training for knowledge retention, with virtual simulations having the least amount of knowledge retained over baseline training methods.

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APPENDICES

Appendix A. Usability-Based Outcome Analysis

Appendix B. Learning Outcome Analysis

APPENDIX A. USABILITY-BASED OUTCOME ANALYSIS

As mentioned in Section 4, this appendix provides comparative summary of the conclusions and comments across these five research studies (Abdel et al., 2018; Martin et al., 2013; Seaborn & Fels, 2015; Tsay, 2018; Wolff, 2017), that was subsequently utilized to compare the usability of these technology tools.

Attribute	Traditional Learning	Gamification	Computer Simulation	Virtual Reality (VR)	Augmented Reality (AR)
Fidelity	1	2	4	4	5
Resolution	1	1	4	5	4
Effort	5	4	2	1	2
Interactivity	1	3	4	5	4
User Experience	1	4	4	5	5
Communication	2	3	4	5	5
Feedback	3	3	1	4	5
Visualization	1	1	4	5	5
Simulation	2	1	4	5	4
Usage	3	3	3	4	3
Cost Considerations	4	3	2	1	1
Total	**24**	**28**	**36**	**44**	**43**

APPENDIX B. LEARNING OUTCOME ANALYSIS

As mentioned in Section 4, Appendix B provides comparative summary of the conclusions and comments across these four research studies (Abdel et al., 2018; Borsci et al., 2016; Martín-Gutiérrez et al., 2013; Wang et al., 2020), that was subsequently utilized to compare the learning outcomes of these technology tools.

Attribute	Traditional Learning	Gamification	Computer Simulation	Virtual Reality (VR)	Augmented Reality (AR)
Learning Modality	3	2	3	3	3
Time Demands	1	3	3	4	4
User Perception	3	3	4	4	4
Ease of Understanding	3	3	3	4	4
Long Term Retention	1	2	2	4	4

About the Joint Transportation Research Program (JTRP)

On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1—evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,600 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at http://docs.lib.purdue.edu/jtrp.

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Iyer, A. V., Dunlop, S. R., Thakkar, D. J., Mishra, S., Banerjee, A., Gokhale, A., Shah, K., Faiz, A., Arora, A., Awasthi, P., & Gebbie, M. (2021). *Evaluation of current technologies for training, web apps, and new technologies* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2021/15). West Lafayette, IN: Purdue University. https://doi.org/10.5703/1288284317317