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Web-based Simulator Training and Skill Transfer: Literature Review

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The Federal Railroad Administration (FRA) sponsored research on the impact of training styles on knowledge and skill acquisition, retainment, and transfer for engineer and maintenance workers in the rail industry. Low-fidelity simulators and simulations are simplified training or testing tools that focus on basic functions and concepts, usually lacking realistic visuals, motion, or interactivity. High-fidelity simulators and simulations closely replicate real-world environments with advanced graphics, controls that mirror the real-world task, physical motion, and sensory feedback. Currently, waivers must be provided to rail companies to relieve the in-person provisions of FRA safety regulations outlined in 49 CFR Part 232 in favor of a virtual, low-fidelity simulator training and test for refresher trainings only. The research presented in this document identifies best practices and evaluation criteria for the quality of web-based or low-fidelity simulator training. This is achieved by examining the existing body of research and compiling a literature review. This review serves as a framework for the assessment of criteria of web-based or low-fidelity simulators and the development of refresher training.</td></tr>
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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

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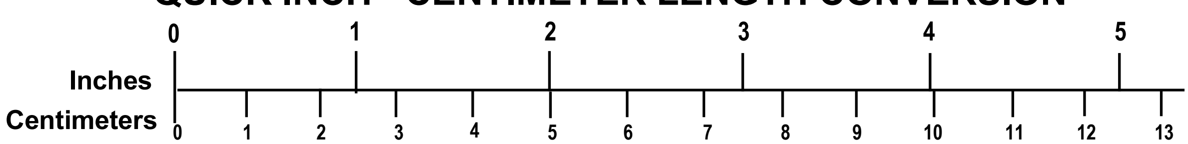
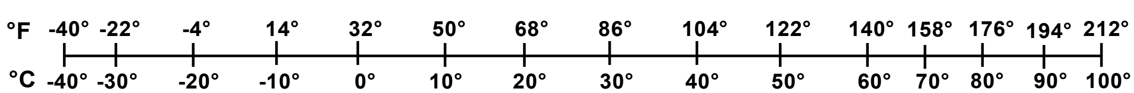


QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSIO



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Executive Summary

The Federal Railroad Administration (FRA) sought to understand the impact of training styles on knowledge and skill acquisition, retainment, and transfer for engineer and maintenance workers in the rail industry. FRA sponsored ENSCO, Inc. and the Center for Urban Transportation Research at the University of South Florida to conduct research to these ends from May to December 2024. Low-fidelity simulators and simulations are simplified training or testing tools that focus on basic functions and concepts, usually lacking realistic visuals, motion, or interactivity. High-fidelity simulators and simulations closely replicate real-world environments with advanced graphics, controls that mirror the real-world task, physical motion, and sensory feedback. Currently, waivers must be provided to rail companies to relieve the in-person provisions of FRA safety regulations outlined in 49 CFR Part 232 (Brake System Safety Standards for Freight and Other Non-Passenger Trains and Equipment; End-of-Train Devices) in favor of a virtual, low-fidelity simulator training and test for refresher trainings only. The research presented here identifies best practices and evaluation criteria for the quality of web-based or low-fidelity simulator training, which will enable effective knowledge retainment, skill transfer, and education quality for refresher trainings. This is achieved by examining the existing body of research and compiling a literature review presenting findings from academia, government, and industry to develop criteria to aid in the assessment of simulator refresher trainings. This review serves as a framework for the assessment of criteria of web-based or low-fidelity simulators and the development of refresher training.

1. Introduction

The Federal Railroad Administration (FRA) sought to understand the impact of training styles on knowledge and skill acquisition, retainment, and transfer for engineer and maintenance workers in the rail industry. FRA sponsored ENSCO, Inc. and the Center for Urban Transportation Research at the University of South Florida to conduct research to these ends from May to December 2024. Low-fidelity simulators and simulations are simplified training or testing tools that focus on basic functions and concepts, usually lacking realistic visuals, motion, or interactivity. High-fidelity simulators and simulations closely replicate real-world environments with advanced graphics, controls that mirror the real-world task, physical motion, and sensory feedback. Currently, waivers must be provided to rail companies to relieve the in-person provisions of FRA safety regulations outlined in 49 CFR Part 232 (Brake System Safety Standards for Freight and Other Non-Passenger Trains and Equipment; End-of-Train Devices) in favor of a virtual, low-fidelity simulator training and test for refresher trainings only. The research presented here aims to assess criteria of web-based or low-fidelity simulators which will enable effective knowledge retainment, skill transfer, and education quality for refresher trainings. This report provides a literature review presenting findings from academia, government, and industry to develop criteria to aid in the assessment of simulator refresher trainings.

1.1 Background

FRA sought to establish criteria for web-based or low-fidelity training on brake system refresher courses. During the Covid-19 pandemic and due to in-person restrictions, waivers were provided to companies to relieve the in-person provisions. With the advent of simulation and less expensive, higher-fidelity training, simulation-based training must be evaluated in comparison to in-person training to assess if it is as effective as a replacement for future refresher course requirements. This literature review is the first step for this process.

1.2 Objectives

This project aimed to identify best practices and evaluation criteria of the quality of web-based or low-fidelity simulator training. This was achieved by examining the existing body of research and compiling a literature review. This review will serve as a framework for the assessment of criteria of web-based or low-fidelity simulators and the development of refresher training.

1.3 Overall Approach

The research team conducted this search using Scopus, Google Scholar, and Google Search. They first compiled and reviewed a bibliography (Appendix B). Then, they expanded the literature review for each of the following topics: skill acquisition, knowledge retention, skill transfer, and performance outcomes.

1.4 Scope

The literature review included the following search terms:

- Difference between web-based and low-fidelity simulator training
- Impact of web-based or low-fidelity simulator training on skill acquisition

- Knowledge retention, skill transfer, and performance outcomes
- Impact of simulator-based training on workforce development and key metrics

The team conducted the search for the rail industry as well as other transportation (maritime and aviation) modes and other fields (medical and nursing).

1.5 Organization of the Report

Section 2 describes the impact of web-based or low-fidelity simulator training on skill acquisition, knowledge retention, skill transfer and performance outcomes. Section 3 describes the impact of simulator-based training on workforce development and safety mitigation. Section 4 provides a list of key effectiveness metrics; Section 5 provides common criteria indicative of quality training, and Section 6 concludes the report.

2. Impact of Web-based or Low-fidelity Simulator Training

In the modern landscape of professional training, web-based and low-fidelity simulator training have emerged as significant methods for skill development across various industries. This section explores the impact of these training methods on skill acquisition, knowledge retainment, skill transfer, and job performance, drawing insights from rail research, other transportation modes, and fields outside transportation. Key takeaways from the search on the impact of web-based or low-fidelity simulator training are:

Skill Acquisition:

Studies in Rail Research:

- High-quality simulators that replicate real-world scenarios are crucial for improving skill acquisition in railroad operators.
- Robust assessment tools are necessary to evaluate trainee performance accurately and identify areas for improvement.
- Conducting a training needs analysis ensures training programs are tailored to meet organizational needs.

Comparisons with Other Transportation Modes:

- Simulator-based training is effective in aviation and maritime sectors, enhancing decision-making and procedural skills.
- Both high and low-fidelity simulators improve practical skills across different transportation sectors.

Insights from Fields Outside Transportation:

- Simulation-based training in healthcare improves clinical skills and patient outcomes.
- Web-based and low-fidelity simulators are effective for initial skill acquisition in various fields, including healthcare, aviation, and engineering.
- The level of fidelity may not be as crucial as the quality and consistency of the training.

Knowledge Retention:

Long-term vs. Short-term Retainment:

- Low-fidelity and web-based simulations provide substantial benefits for knowledge retention over several months.
- Repeated practice and reinforcement through web-based simulations enhance long-term retention.
- Effective in various fields, including healthcare, engineering, aviation, and business.

Differences Between Web-based and Low-fidelity Simulator Training:

- High-fidelity simulators may offer better short-term retention, but significant knowledge loss can occur in both high and low-fidelity groups over time.

Skill Transfer:

Effectiveness of Skill Transfer:

- Low-fidelity simulations are valuable for developing foundational skills that can be transferred to real-world scenarios.
- Web-based simulations enhance skill transfer in medical, engineering, aviation, and business training.
- Repeated practice and reinforcement through web-based simulations contribute to effective skill transfer.

Factors Influencing Skill Transfer:

- The time to perform a task and the inclusion of subtasks in simulations can influence skill transfer.
- Transitioning from low to high-fidelity simulations does not adversely affect learners.

Performance Outcomes:

Impact on Job Performance:

- Web-based and low-fidelity simulations positively impact job performance, especially when integrated with other training methods.
- Effective in improving clinical decision-making and patient care skills in nursing.
- Provide a cost-effective and accessible alternative to high-fidelity simulations for various fields.

The rest of the Section elaborates on each construct.

2.1 Skill Acquisition

2.1.1 Studies in Rail Research

The effectiveness of simulators in rail training is significantly influenced by their technical features and capabilities. Marcano et al. (2019) emphasized that high-quality simulators, which accurately replicate real-world driving scenarios such as malfunctions, troubleshooting, and abnormal or emergency situations, are crucial for improving the skill acquisition of railroad operators. These simulators provide a realistic environment where trainees can practice and refine their skills, leading to better preparedness for actual operations.

Mera et al. (2008) highlighted the importance of robust assessment tools in simulator-based training. They noted that weak assessment capabilities can hinder the optimal use of simulators, stressing the need for enhanced training and assessment tools to accurately evaluate trainee performance. Effective assessment tools help identify areas where trainees need improvement, ensuring that they acquire the necessary skills to perform their duties safely and efficiently.

Schmitz and Maag emphasized the importance of conducting a training needs analysis to develop comprehensive training programs. They argued that understanding the current state of knowledge among key personnel and comparing it to the desired state is crucial for creating effective training programs (Maag and Schmitz, 2012; Schmitz and Maag, 2012). This approach ensures that training is tailored to meet the specific needs of the organization, leading to better training outcomes in areas such as operator performance, skill acquisition, and retention.

2.1.2 Comparisons with Other Transportation Modes

Comparative studies in other transportation modes, such as aviation and maritime, have also demonstrated the effectiveness of simulator-based training. In aviation, high-fidelity simulators are commonly used to train pilots, providing realistic scenarios that enhance their decision-making and procedural skills. Similarly, maritime training programs use simulators to teach navigation and emergency response skills. These studies suggest that simulator-based training, whether high- or low-fidelity, is effective in improving practical skills across different transportation sectors (Lefor et al., 2020).

2.1.3 Insights from Fields Outside Transportation

Fields outside transportation, such as healthcare and military, have also benefited from simulator-based training. In healthcare, simulation-based training has been shown to improve clinical skills and patient outcomes. A systematic review in medical education (Nnaemeka Ajemba, 2024) found that simulation-based training is superior over no intervention and in some cases to traditional methods in terms of skill acquisition and retention among medical professionals.

Web-based and low-fidelity simulators are effective tools for initial skill acquisition. Studies have shown that these methods can significantly improve learners' practical skills. For instance, a study on nursing students found that low-fidelity simulations were effective in teaching basic life support skills, with students demonstrating significant improvements in their performance post-training (Alharbi et al., 2024). Similarly, web-based simulations have been shown to enhance procedural skills in medical training, providing a flexible and accessible platform for learners (Tong et al., 2024).

A randomized, controlled trial comparing high- and low-fidelity simulators for neonatal intubation skills found no significant difference in skill acquisition between the two groups (Al-Wassia et al., 2022). This suggests that the level of fidelity may not be as crucial as the quality and consistency of the training. Another study highlighted that low-fidelity simulations could effectively teach advanced life support skills, with participants showing significant improvements in their performance (Massoth et al., 2019).

Moreover, web-based simulations offer the advantage of accessibility, allowing learners to practice skills at their own pace and convenience. This flexibility can be particularly beneficial for learners who may not have easy access to high-fidelity simulators or in-person training sessions (teachfloor, 2024). For example, a study on medical students using web-based simulations for surgical skills training found that participants showed significant improvements in their technical skills and confidence levels (Tong et al., 2024).

Web-based and low-fidelity simulations have also been effective in other fields such as aviation and engineering. A study on aviation students using low-fidelity flight simulators found that participants demonstrated significant improvements in their piloting skills and decision-making abilities (Park et al., 2022). Similarly, engineering students using web-based simulations for laboratory experiments showed enhanced understanding and application of theoretical concepts (Kassabry, 2023).

Additionally, military training programs use simulators to prepare soldiers for combat scenarios, enhancing their tactical and operational skills. The U.S. Army has used low-fidelity battle simulations to train and evaluate command, control, and communications skills for armor platoon leaders. These simulations, such as the Simulation for Combined Arms Training (SIMCAT), provide a cost-effective way to develop tactical skills without the need for high-fidelity equipment. Low-fidelity simulators are also used for basic tactical training. These simulators can replicate simple battlefield scenarios, allowing soldiers to practice decision-making, teamwork, and situational awareness in a controlled environment. This type of training is essential for developing foundational skills before moving on to more complex and high-fidelity simulations (Schradin, 2023).

While virtual reality (VR) technology can range from low- to high-fidelity, many military training programs use lower-fidelity VR environments to simulate urban terrains and complex battlefields. These environments help soldiers develop critical decision-making skills and situational awareness, which are essential in modern warfare (Total Military Insight, 2024).

2.2 Knowledge Retention

2.2.1 Long-term vs. Short-term Retainment

Knowledge retention is a key metric for measuring the overall effectiveness of simulation training. Research indicates that while high-fidelity simulations might offer more realistic scenarios, low-fidelity and web-based simulations still provide substantial benefits in terms of knowledge retention. A systematic review highlighted that students retained knowledge effectively over several months after participating in low-fidelity simulation training (Lefor et al., 2020). This suggests that the level of fidelity may not be as crucial as the consistency and quality of the training.

A study on nursing students found that low-fidelity simulations were effective in retaining knowledge related to basic life support skills, with participants demonstrating significant retention of knowledge six months post-training (Raines, 2024). Similarly, web-based simulations have been shown to enhance long-term knowledge retention in medical training. For instance, a study on medical students using web-based simulations for anatomy training found that participants retained knowledge effectively over a period of six months (Thompson, 2021).

Moreover, the use of web-based simulations allows for repeated practice and reinforcement of knowledge, which can further enhance retention. A study on nursing students using web-based simulations for laboratory experiments found that participants retained knowledge effectively over a period of one year (Kassabry, 2023). This suggests that the flexibility and accessibility of web-based simulations can contribute to long-term knowledge retention.

In addition to healthcare, web-based and low-fidelity simulations have been effective in other fields such as the automotive industry. A study on driving simulators using low-fidelity flight simulators found that participants retained knowledge related to flight procedures and safety protocols effectively over a period of six months (Kearns, 2009).

Overall, the evidence suggests that web-based and low-fidelity simulator training can be highly effective for knowledge retention across various fields. These methods provide a cost-effective and accessible alternative to high-fidelity simulations, making them a valuable tool for educational institutions and training programs.

2.2.2 *Differences Between Web-based and Low-fidelity Simulator Training*

A study on the effect of task fidelity for an electronic maintenance task has shown that using lower-fidelity training situations helps most where there is less time to practice, and that if there is extensive time to practice full-fidelity has nearly the same outcome (but perhaps not the same costs or risks; Ritter et al., 2023).

2.3 Skill Transfer

Skill transfer refers to the application of skills learned in training to real-world scenarios. The effectiveness of skill transfer from low-fidelity and web-based simulations can vary. Some studies suggest that while high-fidelity simulations might better mimic real-life conditions, low-fidelity simulations are still valuable for developing foundational skills that can be transferred to more complex tasks. For example, a study comparing high- and low-fidelity simulations found no significant difference in the skill transfer outcomes between the two groups (Gu et al., 2017).

A study on nursing students found that low-fidelity simulations were effective in transferring skills related to basic life support to clinical practice, with participants demonstrating significant improvements in their performance in real-world scenarios (Aqel and Ahmad, 2014). Similarly, web-based simulations have been shown to enhance skill transfer in medical training. For instance, a study on medical students using web-based simulations for surgical skills training found that participants were able to transfer their skills effectively to real-world surgical procedures (Tong et al., 2024).

Moreover, the use of web-based simulations allows for repeated practice and reinforcement of skills, which can further enhance skill transfer. A study on engineering students using web-based simulations for laboratory experiments found that participants were able to transfer their skills effectively to real-world laboratory settings (Al-nakhle, 2022). This suggests that the flexibility and accessibility of web-based simulations can contribute to effective skill transfer.

In addition to healthcare and engineering, web-based and low-fidelity simulations have been effective in other fields such as aviation and business. A study on aviation students using low-fidelity flight simulators found that participants were able to transfer their skills related to flight procedures and safety protocols effectively to real-world flight scenarios (Risukhin, 2015). Similarly, a study on business students using web-based simulations for management training found that participants were able to transfer their skills related to decision-making and strategic planning effectively to real-world business settings (Lovelace et al., 2016).

Overall, the evidence suggests that web-based and low-fidelity simulator training can be highly effective for skill transfer across various fields. These methods provide a cost-effective and accessible alternative to high-fidelity simulations, making them a valuable tool for educational institutions and training programs.

Studies have shown that the time to perform a task modifies the learning curves for each system, with the low-fidelity simulation initially providing about four times as many practice trials in a given time period compared to high-fidelity simulation. Learners that move from low- to high-fidelity simulation appear to not be adversely affected, and factors such as subtasks included in each simulation could influence this transfer (Aqel & Ahmad, 2014).

2.4 Performance Outcomes

The goal of any training program is to improve job performance. Evidence suggests that web-based and low-fidelity simulations can positively impact job performance, especially when integrated with other training methods. For instance, in the field of nursing, low-fidelity simulations have been shown to improve clinical decision-making and patient care skills. Similarly, web-based training modules have been effective in enhancing job performance in various industries by providing ongoing, accessible training opportunities.

A study on nursing students found that low-fidelity simulations were effective in improving job performance related to basic life support and clinical decision-making, with participants demonstrating significant improvements in their performance in real-world clinical settings (Hochmitz and Yuviler-Gavish, 2011). Additionally, a review of existing studies on simulator fidelity found that procedure skill after training with low-fidelity simulators was not inferior to skill after training with high-fidelity simulators in the majority of the studies reviewed (Norman et al., 2012).

Overall, the evidence suggests that web-based and low-fidelity simulator training can be highly effective for improving job performance across various fields. These methods provide a cost-effective and accessible alternative to high-fidelity simulations, making them a valuable tool for educational institutions and training programs.

3. Impact of Simulator-based Trainings on Workforce Development and Safety Mitigation

Simulator-based training has become a cornerstone of workforce development and safety mitigation in the rail industry. By providing realistic, hands-on learning experiences, simulators enhance skill acquisition, knowledge retention, and overall performance.

3.1 Key Benefits of Simulator-based Training for Workforce Development

3.1.1 Improved Safety

The principles of reducing errors and improving performance are equally applicable to rail as they are to the medical field. Simulation-based training allows rail operators to practice and refine their skills in a controlled, risk-free environment. This type of training has been shown to reduce operational errors and improve both individual and team performance. For instance, a study on the use of train simulators found that simulation training significantly enhanced the ability of operators to manage critical situations, leading to better safety outcomes (Patel et al., 2024).

3.1.2 Enhanced Learning

Simulator-based training provides a unique opportunity for learners to practice skills and experience mistakes without real-world consequences. This hands-on approach to learning enhances competency and fosters collaboration among team members. Novak-Jankovič emphasized that simulation-based learning environments allow trainees to engage in active learning, which is more effective than traditional didactic methods (Novak-Jankovič, 2022). St. Pierre et al. (2017) also noted that simulation training improves critical thinking and decision-making skills, which are essential for effective teamwork and operational efficiency.

3.1.3 Realistic Scenarios

Simulators offer realistic, hands-on learning experiences that mimic real-world scenarios. This cause-and-effect learning approach enables trainees to gauge their performance and gain experience with complex skills through repeated practice. Patterson et al. (2013) discussed how simulation training in emergency medical services allows paramedics to practice life-saving procedures in a realistic yet controlled environment, leading to improved performance in actual emergencies. Similarly, in the rail industry, realistic simulation scenarios help trainees develop a deeper understanding of their roles and responsibilities, enhancing overall preparedness.

Simulator-based training plays a crucial role in workforce development by providing a structured and effective way to develop and maintain essential skills. This type of training is particularly valuable in industries where safety and precision are paramount. For example, in the rail industry, train simulators are used extensively to train operators, ensuring they are well-prepared to handle various operational conditions and emergencies. A study by Marcano et al. (2019) highlighted the importance of technical features and capabilities of simulators in rail training, emphasizing that high-quality simulators significantly improve skill acquisition.

3.2 Contribution to Safety Mitigation in the Workplace

Safety mitigation is another critical area where simulator-based training has a profound impact. By allowing trainees to practice and perfect their skills in a safe environment, simulators help reduce the risk of accidents and errors in real-world operations. This is particularly important in high-risk industries such as rail transportation. For instance, a study by Mera et al. (2008) on the assessment capabilities of simulators found that enhanced training and assessment tools significantly improved the performance of rail operators, thereby enhancing overall safety.

3.2.1 Reduced Errors

Simulation-based training has been utilized in high-reliability industries such as aviation and healthcare to reduce the potential for human errors and improve safety. Walker et al. (2013) found that simulation training in aviation significantly reduced pilot errors during critical flight operations. Similarly, Moslehi et. al. (2022) highlighted that simulation-based training in healthcare reduced medical errors and improved patient safety. These findings are applicable to the rail industry, where simulation training can help operators practice emergency procedures and reduce the likelihood of operational errors.

3.2.2 Improved Safety Culture

Simulator-based team training has been proposed for medical areas to improve safety culture, technical team performance, and patient-centered outcomes. Walker et al. (2013) emphasized that simulation training fosters a culture of safety by encouraging open communication, teamwork, and continuous improvement. This approach can be adapted to the rail industry to enhance the safety culture among rail operators and maintenance crews, leading to better safety outcomes and a more resilient workforce.

3.3 Limitations of Simulator-based Training in Workforce Development and Safety Mitigation

Simulator-based training has become an essential tool in workforce development and safety mitigation across various industries. However, despite its numerous benefits, there are notable limitations that need to be considered. This section explores the key limitations of simulator-based training, focusing on cost and resource intensity and the risk of over-routinizing procedures.

3.3.1 Cost and Resource Intensive

One of the primary limitations of simulator-based training is its high cost and resource intensity. Developing and maintaining high-quality simulators can be expensive; costs can include the initial cost of purchasing or developing the simulators, as well as ongoing maintenance, updates, and technical support. Additionally, simulator-based training often requires dedicated facilities and specialized personnel to operate and manage the equipment.

Walker et al. (2013) highlighted that simulator-based training can be consuming in terms of cost, time, and human resources, raising questions about the cost-benefit ratio. For many organizations, especially those with limited budgets, the high costs associated with simulator-based training can be a significant barrier to implementation. This can lead to disparities in training quality and access, particularly in smaller organizations or those in developing regions.

Moreover, the time required to develop and implement simulator-based training programs can be substantial. Designing realistic and effective simulation scenarios often involves extensive planning and collaboration among subject matter experts, instructional designers, and technical staff. This process can be time-consuming and may delay the deployment of training programs.

3.3.2 Over-routinizing Procedures

Another limitation of simulator-based training is the risk of over-routinizing procedures. While simulators provide a controlled environment for practicing skills, there is a danger that trainees may become too accustomed to the simulated scenarios, leading to a false sense of security. This can result in trainees becoming overly reliant on the routines and procedures practiced in the simulator, potentially reducing their ability to adapt to unexpected situations in the real world.

Novak-Jankovič (2022) stated that there is a risk of over-routinizing procedures and creating a false feeling of safety through simulation-based learning. This can be particularly problematic in high-stakes environments where flexibility and adaptability are crucial. For example, in the healthcare industry, while simulation training can improve technical skills, it may not fully prepare healthcare professionals for the variability and unpredictability of real-life patient care scenarios.

To mitigate this risk, it is essential to incorporate a variety of scenarios and unexpected events into simulation training programs. This helps ensure that trainees develop the critical thinking and problem-solving skills needed to handle real-world challenges. Additionally, combining simulation-based training with other training methods, such as on-the-job training and mentorship, can provide a more comprehensive and balanced approach to skill development.

In conclusion, while simulator-based training offers significant benefits for workforce development and safety mitigation, it is important to recognize and address its limitations. The high cost and resource intensity of simulator-based training can be a barrier to implementation, particularly for organizations with limited budgets. Additionally, the risk of over-routinizing procedures highlights the need for diverse and dynamic training scenarios to ensure trainees are well-prepared for real-world challenges. By understanding and addressing these limitations, organizations can maximize the effectiveness of simulator-based training and enhance overall workforce development and safety.

3.4 Best Practices for Implementing Simulator-Based Training Programs

Simulator-based training has proven to be an effective method for enhancing workforce development and safety across various industries. However, to maximize its benefits, it is essential to implement best practices that ensure the training is both effective and sustainable. This section explores key best practices for implementing simulator-based training programs, focusing on structured debriefing, continuous improvement, and a collaborative framework.

3.4.1 Structured Debriefing

One of the most critical components of effective simulator-based training is structured debriefing. Providing feedback during a structured debrief allows trainees to reflect on their performance, understand their mistakes, and learn from them. This process is essential for reinforcing learning and ensuring that trainees can apply their skills in real-world scenarios.

Moslehi et. al. (2022) emphasized the importance of structured debriefing in simulation-based education. They found that debriefing sessions that follow a structured format, such as the Gather, Analyze, and Summarize (GAS) model, significantly improve learning outcomes and knowledge retention. By systematically reviewing the simulation exercise, trainees can identify areas for improvement and develop strategies to enhance their performance.

3.4.2 Continuous Improvement

Continuous improvement is another key best practice for simulator-based training programs. Regular training sessions and repeat participation can lead to incremental improvements in safety-relevant attitudes and behaviors over time. This approach ensures that employees remain proficient in their skills and are continuously updated on best practices and new procedures.

Sawyer et al. (2013) highlighted the benefits of annual training sessions and repeat participation in simulation-based training. Their study found that repeated exposure to simulation training led to significant improvements in safety attitudes and behaviors among healthcare professionals. This principle can be applied to other industries, such as rail and aviation, where ongoing training is crucial for maintaining high safety standards.

3.4.3 Collaborative Framework

Implementing a collaborative framework is essential for designing engaging and cost-effective simulator-based training programs. A collaborative approach involves multiple stakeholders, including trainers, trainees, and organizational leaders, working together to develop and refine training programs. This ensures that the training is relevant, effective, and aligned with organizational goals.

Rovaglio and Scheele (2011) proposed a collaborative framework for simulator-based training that emphasizes the importance of engaging all stakeholders in the training design process. By involving trainers, trainees, and organizational leaders, the framework ensures that the training program is tailored to meet the specific needs of the organization and its employees. This collaborative approach also helps identify and address potential challenges or barriers to effective training.

In conclusion, implementing best practices is crucial for the success of simulator-based training programs. Structured debriefing, continuous improvement, and a collaborative framework are key elements that can enhance the effectiveness of these programs. By providing structured feedback, ensuring ongoing training, and involving all stakeholders in the training design process, organizations can maximize the benefits of simulator-based training and improve workforce development and safety.

4. Key Effectiveness Metrics

To measure the effectiveness of simulator-based training in workforce development and safety mitigation, experts commonly use several key metrics. These include qualitative and quantitative measures to capture different aspects of training effectiveness. The research team culled the metrics during their literature review.

4.1 Trainee Performance

This metric assesses the ability of trainees to make quick decisions under pressure and the accuracy of their actions during simulated scenarios. Effective training should enhance decision-making skills and improve the precision of responses in real-world situations (Barashkin et al., 2023; Kahrizi and Ferworn, 2023).

4.2 Scenario Realism

Realism, the degree to which the simulation mimics real-world conditions, is crucial for ensuring the transfer of skills to actual situations. High-fidelity simulations are more likely to produce realistic training outcomes (Allen et al., 2010; Kahrizi and Ferworn, 2023).

4.3 Training Duration and Frequency

The length and regularity of training sessions can significantly impact skill retention and proficiency. Regular and appropriately timed training sessions help maintain and enhance the skills acquired (Abid et al., 2024).

4.4 Resource Utilization

This metric evaluates the efficient use of resources such as time, equipment, and personnel during training sessions. Effective training programs optimize resource use without compromising training quality (Kahrizi & Ferworn, 2023).

4.5 Skill Acquisition and Retention

Assessing the extent to which trainees acquire and retain the necessary skills and knowledge is vital. This metric helps determine the long-term effectiveness of the training (Barashkin et al., 2023; Kahrizi and Ferworn, 2023; Tappura and Jääskeläinen, 2021).

4.6 Safety Knowledge and Attitudes

Improvements in safety-related knowledge, attitudes, beliefs, and motivation among trainees are critical indicators of training effectiveness. These changes can lead to safer workplace practices (Tappura and Jääskeläinen, 2021).

4.7 Behavioral Changes

Observable changes in safety behavior and practices post-training are essential for evaluating the real-world impact of the training. Effective training should lead to measurable improvements in safety behavior (Tappura and Jääskeläinen, 2021).

4.8 Operational Performance

This metric examines real-world performance improvements, such as reduced errors and enhanced safety measures. It provides a direct link between training and operational outcomes (Griswold et al., 2012).

4.9 Feedback and Debriefing

The use of feedback mechanisms and debriefing sessions helps reinforce learning and identify areas for improvement. Continuous feedback is essential for the iterative improvement of training programs (Abid et al., 2024; Salas et al., 2005; Schmitz et al., 2016).

Table 1 provides a summary of the metrics, their descriptions, and references. These metrics provide a comprehensive framework for evaluating the effectiveness of simulator-based training programs, ensuring that they contribute to workforce development and safety mitigation effectively.

Table 1. Key metrics summary

Metric	Description	References
Trainee Performance	Decision-making accuracy and speed under pressure	(Barashkin et al., 2023; Kahrizi and Ferworn, 2023)
Scenario Realism	Real-world fidelity of the simulation	(Allen et al., 2010; Kahrizi and Ferworn, 2023)
Training Duration	Length and frequency of training sessions	(Abid et al., 2024)
Resource Utilization	Efficient use of training resources	(Kahrizi and Ferworn, 2023)
Skill Acquisition	Extent of skill and knowledge gained	(Barashkin et al., 2023; Kahrizi and Ferworn, 2023; Tappura and Jääskeläinen, 2021)
Safety Knowledge	Improvements in safety knowledge and attitudes	(Tappura and Jääskeläinen, 2021)
Behavioral Changes	Observable changes in safety behavior	(Tappura and Jääskeläinen, 2021)
Operational Performance	Real-world performance improvements	(Griswold et al., 2012)
Feedback and Debriefing	Use of feedback and debriefing to enhance learning	(Abid et al., 2024; Allen et al., 2010; Salas et al., 2005)

5. Common Criteria Indicative of Quality Training

5.1 Key Quality Criteria for Training in the Railroad Industry

Technical Features and Capabilities of Simulators: The technical features and capabilities of simulators are diverse, and each operator demands different technical requirements (Marcano et al., 2019; Mera et al., 2008).

Assessment Capabilities: Weak assessment capabilities hinder the optimal use of simulators for training; enhanced training and assessment tools are necessary for quality training (Mera et al., 2008).

Training Needs Analysis: Comprehensive training programs should be built on a foundation of organizational understanding, created by conducting training needs analysis to identify the current state of knowledge of key personnel and comparing it to the necessary state to properly support new organizational goals (Schmitz & Maag, 2012).

Human-Centric Perspective: Effective feedback and assessment are necessary to ensure that process operators have the competences required to ensure smooth and safe operation, and training should be based on a human-centric perspective (Lee and Duffy, 2021).

Regulatory Compliance: The Rail Safety Improvement Act of 2008 details rigorous training requirements to ensure that employees are properly prepared to maintain and operate complex systems (Balfe et al., 2017; Schmitz and Maag, 2012).

5.2 Essential Aspects of Simulator-Based Training for Railroad Refresher Courses

Fidelity of Equipment: The fidelity of the equipment determines what levels of training can be achieved, and its ability to enable the suspension of disbelief directly contributes to the students' success (Bonsall and Pitsopoulos, 2012).

Instructor Facilitation: Instructors must facilitate positive training transfer by attaining the best performance possible from the student and provide them with scenarios representative of actual conditions (Bonsall and Pitsopoulos, 2012).

Real-Life Case Studies: Training must be conducted using real-life case studies and in a manner that is engaging and interactive to maximize effectiveness (Schmitz and Maag, 2012).

Simulation Scenarios: The usage of computer-based systems and simulators in training allows for the composition of different technical failures and hazardous operational situations, replicating scenarios at any given time (Schmitz et al., 2008).

Rule-Based Expert System: A rule-based expert system is used to define target behavior for trainees, and the results of the assessment are stored in an assessment database for further analysis (Schmitz et al., 2008).

5.3 Ensuring Effectiveness of Refresher Training Programs

Training Best Practices: Properly applied training best practices can reduce accidents, stem the loss of institutional knowledge, and properly prepare railroad staff to maintain and operate complex systems (Schmitz and Maag, 2012).

Comprehensive Training Programs: Comprehensive training programs should be built on a foundation of organizational understanding, created by conducting training needs analysis to identify the current state of knowledge of key personnel and comparing it to the necessary state to properly support new organizational goals (Schmitz and Maag, 2012).

Human Factors and Training: The importance of crew resource and fatigue management plans is discussed, emphasizing the criticality of comprehensive training programs in reducing accidents and improving operational efficiency (Balfe et al., 2017).

6. Conclusion

This research includes findings from a literature review conducted to provide information on web-based simulator training and skill transfer. FRA sought to understand the impact of training styles on knowledge and skill acquisition, retainment, and transfer for engineer and maintenance workers in the rail industry. The research team found that web-based or low-fidelity simulators and training are used in many fields including rail, automotive, medical, maritime and aviation. Both web-based and low-fidelity simulator training methods are effective for skill acquisition, with web-based training offering greater flexibility and cost-effectiveness, and low-fidelity simulators providing a more tactile learning experience.

The impact of web-based or low-fidelity simulator training on skill acquisition, knowledge retainment, skill transfer, and performance outcomes are influenced by the level of simulation fidelity. While high-fidelity simulators may offer advantages in certain aspects of skill acquisition and knowledge retainment, low-fidelity simulators have been shown to be non-inferior in teaching non-technical skills and procedure skill training. Factors such as the time to perform a task and the inclusion of subtasks in each simulation can influence skill transfer between high- and low-fidelity simulators. Further research is needed to fully understand the implications of these findings and to determine the most effective approach to simulator training.

Simulator-based training offers numerous benefits for workforce development and safety mitigation, including enhanced learning and realistic scenario practice. However, it is important to consider the potential limitations, such as cost and the risk of over-routinizing procedures. Implementing best practices, such as structured debriefing and a collaborative framework, can maximize the effectiveness of simulator-based training programs.

The key quality criteria for training in the railroad industry include technical features and capabilities of simulators, assessment capabilities, training needs analysis, a human-centric perspective, and regulatory compliance. The essential aspects of simulator-based training for railroad refresher courses encompass fidelity of equipment, instructor facilitation, real-life case studies, simulation scenarios, and rule-based expert systems. Additionally, ensuring the effectiveness of refresher training programs involves implementing training best practices, comprehensive training programs, and addressing human factors and training.

In conclusion, the research highlights the importance of both web-based and low-fidelity simulator training in various industries, including railroads. These training methods are effective for skill acquisition, offering flexibility and cost-effectiveness while also providing a tactile learning experience. The findings underscore the need for a balanced approach that incorporates high-fidelity simulations for certain technical skills and low-fidelity simulations for non-technical skills. By adhering to key quality criteria and implementing best practices, such as structured debriefing and comprehensive training programs, railroads can enhance the effectiveness of their refresher courses. This approach not only improves workforce development and safety mitigation but also ensures compliance with regulatory standards and addresses human factors in training.

Simulator-based training has shown promise in various fields, including healthcare, aviation, military, and engineering for enhancing skill acquisition, knowledge retention, skill transfer, and performance outcomes. However, its application specifically in rail maintenance tasks requires further exploration to fully understand its impact. Further exploration into some key areas for future research include:

1. **Effectiveness of Simulator-based Training in Skill Acquisition and Retention Timelines:** Research should focus on evaluating how effectively simulator-based training helps trainees acquire and retain the necessary skills for rail maintenance tasks over a period of six months to one year.
2. **Transfer of Learning to Real-World Tasks:** Understanding how well skills learned in a simulated environment transfer to real-world rail maintenance tasks is crucial. Research in nursing education has highlighted that simulation-based training can enhance self-confidence and improve clinical skills and judgments in practice. Investigating similar outcomes in rail maintenance tasks could help determine the practical benefits of simulator-based training.
3. **Impact of Simulation Fidelity:** The fidelity of the simulation, or how closely it replicates real-world conditions, can affect training outcomes. High-fidelity simulations are believed to provide more realistic training experiences, potentially leading to better skill transfer however the literature review has shown that low-fidelity simulator training can provide training as effectively as high-fidelity simulators. Research could explore the optimal level of fidelity required for effective rail maintenance training.
4. **Cost-Benefit Analysis:** Implementing high-fidelity simulations can be costly. Future research should include cost-benefit analyses to determine the economic feasibility of simulator-based training for rail maintenance. This includes evaluating the costs of simulation equipment and training versus the potential benefits in terms of improved performance and reduced maintenance errors.
5. **Longitudinal Studies on Performance Outcomes:** Long-term studies are needed to assess the sustained impact of simulator-based training on performance outcomes in rail maintenance. This includes tracking the performance of trainees over time to see if the benefits of simulator-based training are maintained and if there are any long-term improvements in maintenance efficiency and safety. Since some simulation-based training has already been established, evaluating those participants can shed light into their long-term knowledge retention.
6. **Customization and Adaptability of Training Programs:** Research could also focus on how simulator-based training programs can be customized to meet the specific needs of different rail maintenance tasks and individual trainees. This includes developing adaptive training modules that can adjust the difficulty level based on the trainee's progress and performance. This was shown to be an important factor in the literature.
7. **Integration with Traditional Training Methods:** Finally, studies should explore the integration of simulator-based training with traditional training methods. Combining simulation-based and hands-on training could provide a more comprehensive training approach, leveraging the strengths of both methods.

By addressing these research areas, researchers can gain a deeper understanding of the impact of simulator-based training on skill transfer and performance outcomes in rail maintenance, ultimately leading to more effective and efficient training programs.

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Appendix A. Companies Offering Rail Simulators and Training

- Aslrra: https://www.aslrra.org/education/short-line-training-center/
- Corys: https://www.corys.com/en/simulator-training-for-ptc-finding-a-simulator-that-meets-fra-requirements/
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