Me and My Report: A Segmented After-Action Review Embedded Report Application for Supporting Maintenance Training in VR

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ABSTRACT

After-action reviews (AARs) have been extensively employed for debriefing in post-operation or post-training sessions, particularly in military contexts. The reliance on AARs is paramount for the effective review of operations. Ensuring proper training in maintenance procedures holds great importance, given their complex nature and multitude of elements. The successful execution of operations by the Air Force, Navy, and Army hinges on the competence of their maintenance teams. However, existing literature on AARs in maintenance functions mainly examines the evaluation of maintenance procedures rather than assessing operators' effectiveness in performing maintenance tasks.

To address this gap, the authors developed an immersive virtual reality (VR) simulation framework specifically designed for training Motor Vehicle Enforcement officers in inspecting vehicles that transport radioactive waste shipments. Conducting a thorough inspection can take anywhere between 45 to 90 minutes and involves examining numerous inspection points, which is similar to the complex nature of maintenance tasks. The complexity of these inspection procedures poses challenges in capturing and reviewing inspection violations. The training framework incorporates a VR simulation with advanced functionalities for recording inspections and identifying violations and includes an After-Action Review algorithm that processes the simulation documentation into a segmented report and interactive simulation playback within a single application.

This paper presents evidence that strategically designed AAR applications that incorporate advanced functionalities for documenting inspections and violations during simulations and segmenting the results yield notable improvements in operator performance. The implementation of structured reports surpasses the effectiveness of traditional AAR playbacks. These findings bear significant implications for optimizing maintenance procedure training for two reasons. First, the arduous task of capturing and reporting results from complex procedures with multiple components is considerably simplified, reducing the likelihood of oversights. Second, the demanding nature of supervised AAR for lengthy procedures can be effectively addressed, benefiting both trainers and trainees.

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BACKGROUND

Implementing After-Action Review (AAR) protocols originated over six decades ago within the US Army, serving as a primary method for analyzing and offering feedback following training exercises and operations (Morison & Meliza, 1999). Since then, AARs have received considerable academic attention (e.g., DeGorsky, 2005; Gerard & Steven, 2009; Villado, 2008). In a study by Allen et al. (2010), the impact of AARs on safety climate perceptions among firefighters was investigated, revealing a strong positive correlation between AAR frequency and safety climate. However, the relationship was moderated by fire station busyness, becoming non-existent in extremely busy stations.

The advancements in simulation technologies led to the I/ITSEC community taking a keen interest in AAR. These developments have led to the creation of sophisticated methods for applying AAR in enhancing military capabilities. For example, Teo et al. (2020) combined audio files from a battle drill with hit data to generate a quantifiable summary of squad performance. The Office of Naval Research's Streamlined Marine After-Action Review Tool for Visualization (SMART-Viz) is an intelligent AAR system focusing on objective data rather than subjective perceptions (Young et al., 2022). They describe SMART-Viz as a tool that "rapidly synchronizes data from instrumented sources and observers to deliver information about tactical events, along with cognitive and behavioral performance assessments of decision-making" (p. 1). In another study, Doge et al. (2021) devised an AAR for an Artificial Intelligence (AAR/AI) agent to "organize ways people assess reinforcement learning agents in a sequential decision-making environment." The results demonstrated that the AAR/AI supported users in organizing their thoughts, broadening their understanding of the agent, and using the agent to clarify false agent predictions. In a meta-analysis by Keiser et al. (2021), AAR led to significant improvements in various training evaluation criteria with a large effect size. The study also highlighted that highly structured AARs were more effective in military-related implementations, whereas high and low-structured AARs demonstrated comparable effectiveness in healthcare operations.

PROJECT GOALS

A search for research on the effectiveness of maintenance procedures training yielded few results. Pokharel & Jiao (2008) focused on the clarity of maintenance procedures and their cost-effectiveness. Qiu et al. (2014) developed an automatic evaluation of human factors aspects of maintenance processes in VR. Similarly, most of the papers reviewed evolved around the evaluation of maintenance procedure and the maintenance space rather than the effectiveness of the user while performing the maintenance.

This paper examines the effectiveness of a self-administered hierarchically structured After-Action Review Application designed as an interactive report with multiple functionalities (the **Report AAR**). The Report is designed to capture and analyze the performance of operators conducting inspections of vehicles transporting hazardous waste casks in situ in VR. These inspection procedures consist of more than 300 inspection points, and each inspection typically takes 45-90 minutes. In contrast, a more commonly used alternative to this study's Report After-Action Review method is an unstructured application that is simply based on simulation session playback (the **unstructured AAR**). Teo et al. (2022) wrote, "A 30-minute training event may generate several hours of video footage across all cameras" and that …" video footage does not easily yield quantifiable performance metrics to support evaluation or AAR. To evaluate the Report AAR application developed in this project, we benchmarked operators' performance following a session with an unstructured AAR session. Following is a detailed description of the simulation and the Report.

THE SIMULATOR

The Report AAR application system is threefold: 1) The simulation, 2) The After-Action Review application, and 3) the simulation controls.

The Simulator

The simulation introduces a full-scale truck carrying nuclear waste casks. The vehicle is in a hangar specialized for conducting vehicle inspections. The hangar includes a subgrade pit for undercarriage inspection. Figures 1a and 1b present the truck in the hangar.

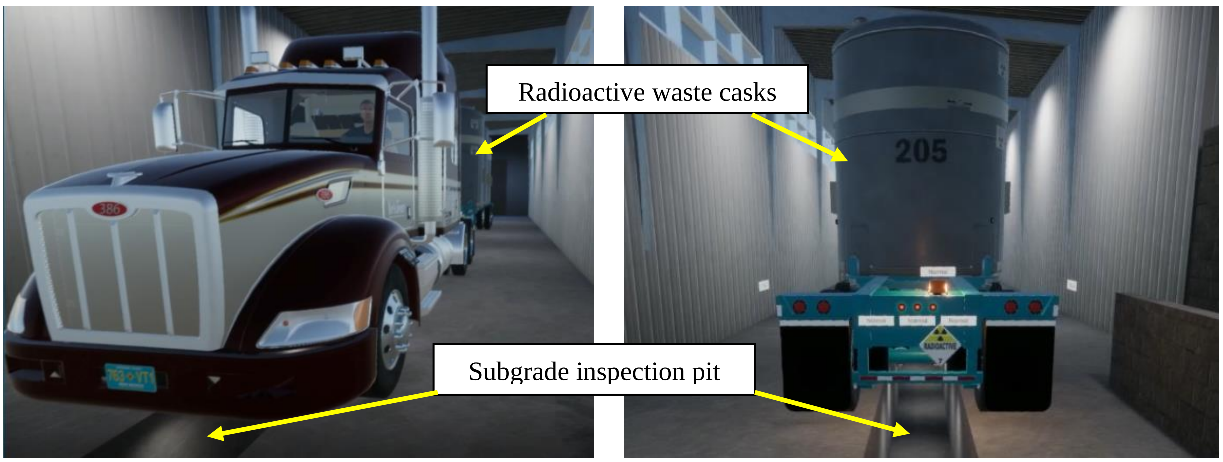

Figure 1a. Front View of the Truck in the Hangar **Figure 1b. Back View of the Truck in the Hangar**

Officers conducting inspections can interact with the various elements in the simulation in multiple ways:

Direct touch: Most inspected items require the officers to touch them; for example, officers examine if lug nuts are tight by physically trying to rotate them. Auto Hands, a Unity package, is used in the simulation to facilitate physical interaction. In the scene, when officers virtually touch items, tooltips appear, indicating the state of the items. Figure 2a shows the officer examining the tire tread depth, and Figure 2b shows the officer examining an air hose for a leak.

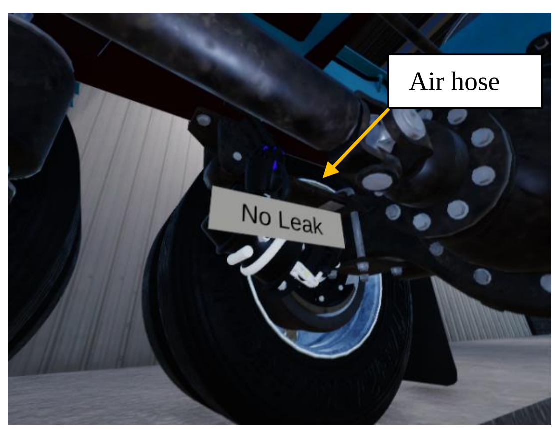

Figure 2a. Tire Thread Depth Inspection **Figure 2b. Air Hose Inspection**

The tooltips in the figures present the information the officers need to determine if the items inspected are up to standard or violate the expected integrity.

Interactive buttons: Certain inspection points require operating systems on the truck to conduct inspections. For example, testing lights, rotating wheels, and brake operation. Virtual buttons were implemented in the simulation to facilitate operating the systems for the inspections. Figure 3a presents a button panel that is used to check truck lights. Figure 3b presents the button panel for rotating the front wheels.

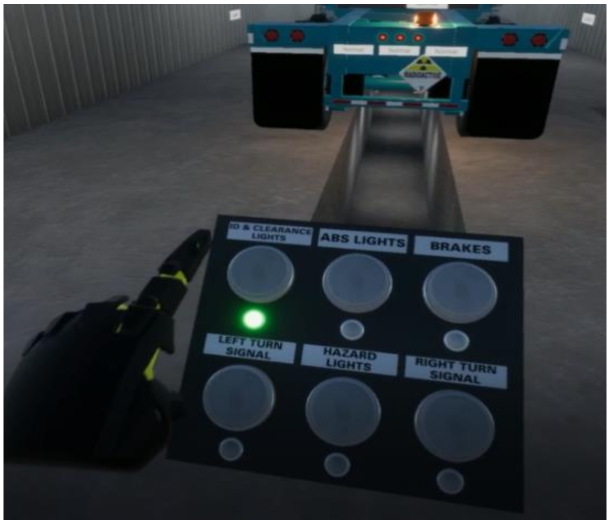

Figure 3a. Light Operating Button

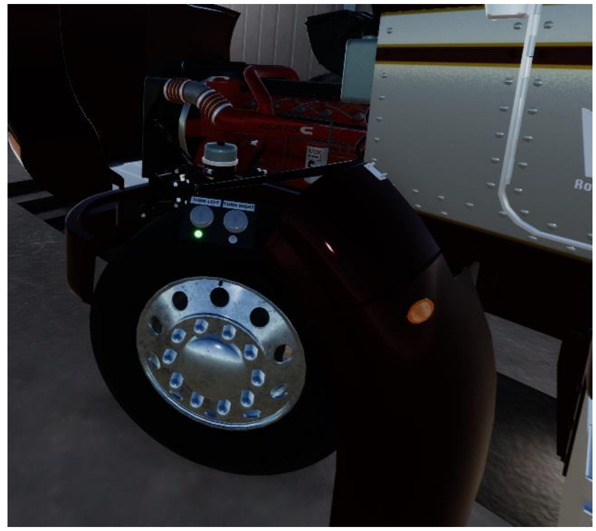

Figure 3b. Front Wheel Rotation Operating Buttons

Observations: The third type of inspection is observation-only. A few examples are examining the undercarriage frame for cracks, the brakes' chambers for completeness and corrosion, and the suspension system for completeness. Figures 4a show a broken brake chamber and 4b a crack in the under-carriage frame.

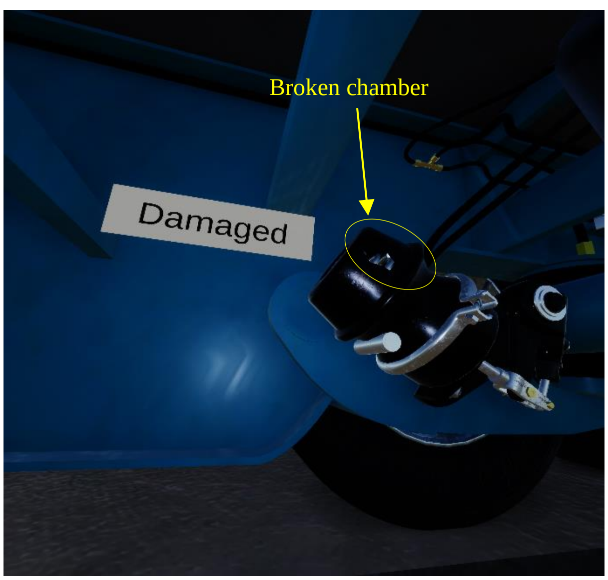

Figure 4a. A Broken Brake Chamber

Figure 4b. A Crack in the Frame

Documenting Inspections and Violations

A virtual camera system is available for officers to document inspection points and violations they identified. To document, the officers press and hold a controller button to release a laser beam directly in front of the controller. The officer can then aim at the items they wish to document and push another button. A virtual camera then takes an image of the scene (see Figures 5a and 5b). The camera menu includes buttons for either recording an audio clip of their reasoning or just saving the image, which then closes the window.

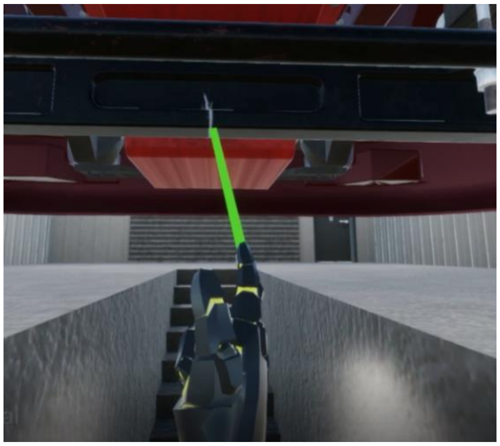

Figure 5a. Officer Points a Laser at a Violation

Figure 5b. Camera Features

THE AFTER-ACTION REVIEW

The Report: A Segmented, Hierarchically Structured, After-Action Review Application

One of the main goals of designing the simulation framework is to provide a tool for unsupervised After-Action Reviews. To accomplish this goal, the team designed the Report as a segmented, hierarchically structured After-Action Review application with various embedded features accessible from an interface shaped like a report (thus, the Report).

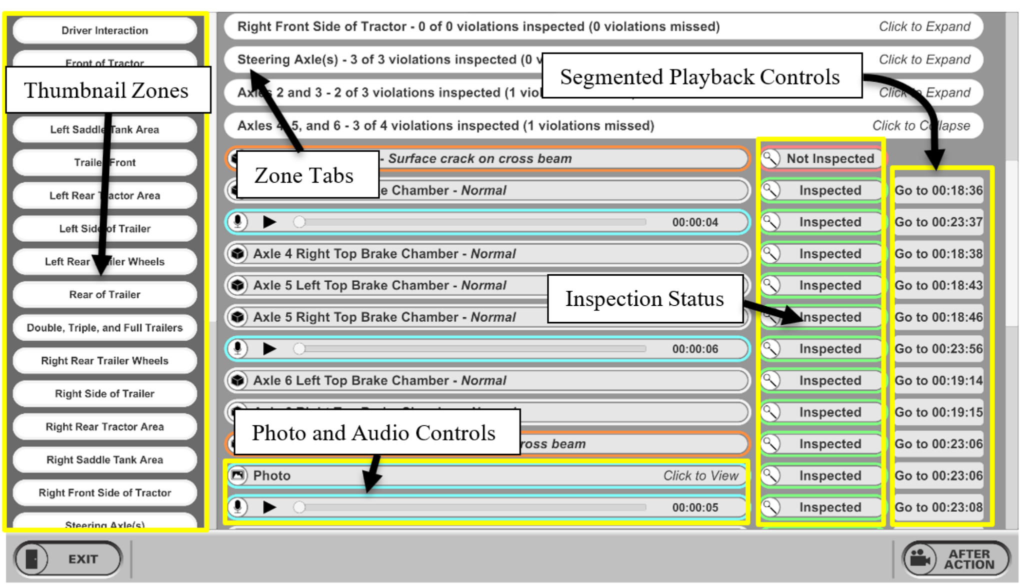

Figure 6. Report Interface

In order to facilitate the structured application, the truck was divided into multiple zones. Each zone includes multiple inspection points. For example, the front tire zone includes all 10 lug nuts, tire pressure, tire quality, tire depth, wheel hub, and rim quality. During inspections, in the back end, the simulation collects all interactions, the status of the items inspected, the images, and the audio files, and organizes them hierarchically into their respective zones for the Report to access. Timestamps are collected for each interaction to review each inspection's interaction in a playback mode. The playbacks in the Report can be in a first or third-person view or in a free-roam mode. For each inspection point, the Report indicates if it was inspected and whether its status is of violation. Further, if the operator used the camera and recorded an audio description of their assessment of the inspection, the Report will present controls to view and listen to those. Figure 6 presents the Report interface. Figure 7 presents the Report in a selected zone playback mode.

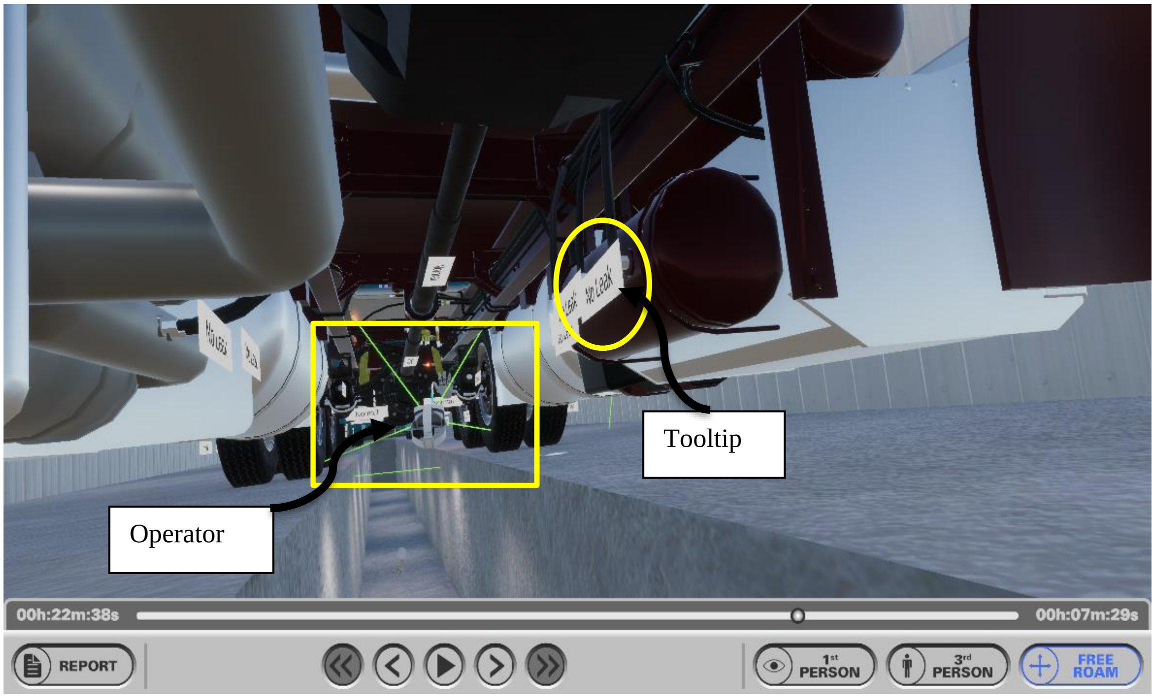

Figure 7. Interactive Simulation Playback View

By leveraging the features mentioned above, trainees can easily track the inspection status of each item, review the associated visual and audio evidence, and precisely pinpoint moments of interest during the interactive simulation playback. Our working hypothesis is that with the combination of the above features, trainees can gain a comprehensive view of their inspection process, enabling them to better understand their inspections, leading to improved performance and continuous improvement in their inspection skills.

The Unstructured, After-Action Review playback

As mentioned earlier, to examine the merit of the Report as a segmented, structured, After-Action Review, a traditional, unstructured playback interface was created, where officers can ‘scrub’ through their inspection journey unrestrictedly the playback controls (see Figure 8 for playback interface).

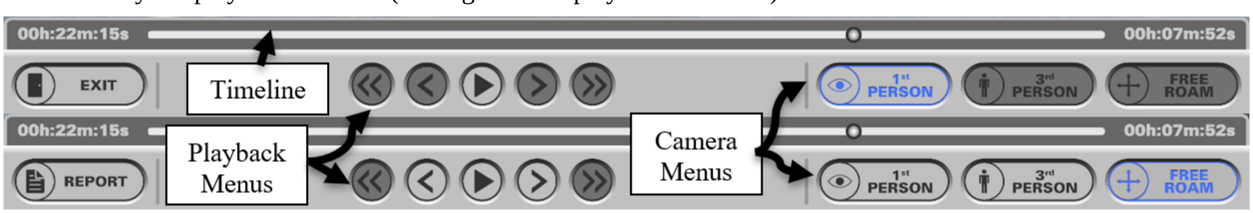

Figure 8. Unstructured After-Action Review Playback

Simulation Controls

The Iowa DOT Motor Vehicle Enforcement Training Officers requested that the simulation design include simulation controls that will allow the officers to facilitate the inclusion of variations in the simulation with desired numbers and types of violations. Figure 8 shows the simulation's authoring screen. Slider controls allow for implementation of violations and how prevalent they will be in the scene. Additionally, some violations are offered in drop down menus that will load different models or alter the scene entirely. The following sections describe the process of documenting the merit of the hierarchically segmented After-Action Review Report application.

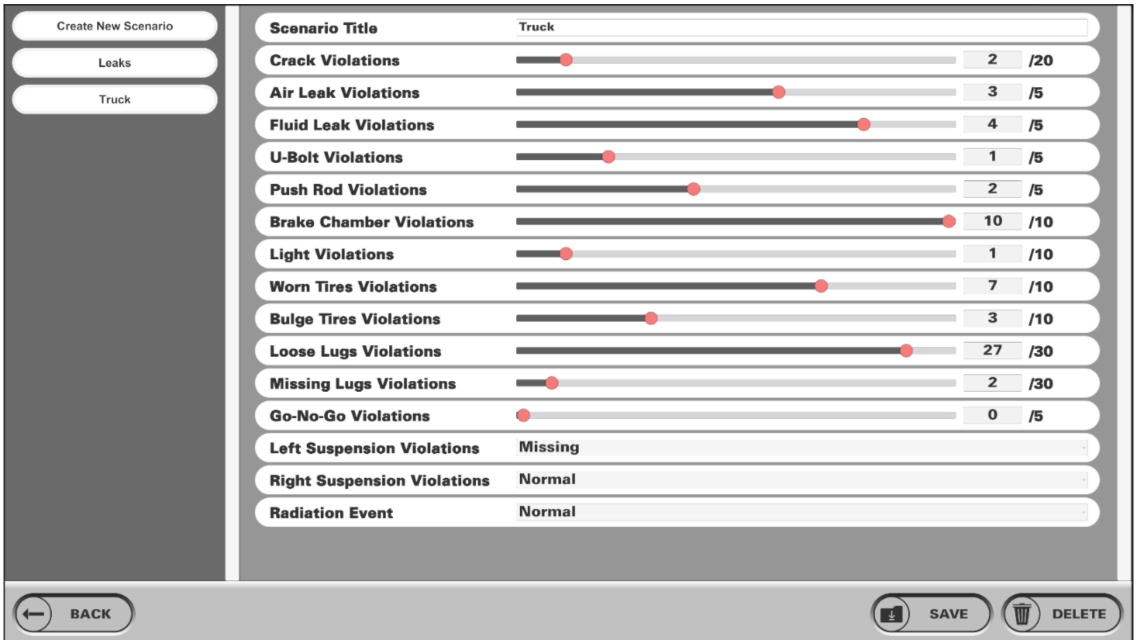

Figure 8. Simulation Authoring Controls

METHOD

Twelve operators participated in the evaluation session. The operators were divided into two groups. Group A was assigned to the unstructured After-Action Review (AAR). Group B was assigned to the Report, i.e., the hierarchically structured and segmented AAR application described in the previous section. The experimental design is presented in Figure 8. Unfortunately, three participants, one from Group A and two from Group B, could not complete the experiment due to experiencing simulation sickness. Following is the experimental description.

The experiments were conducted in inspection sites. Only one operator participated in an experiment at a time. After reviewing and signing informed consent, the operators viewed a ten-minute-long tutorial video describing the simulation, the controls, and the type of interactions. A Virtual Reality (VR) experience session followed, where the operators experienced how to move in the simulation and operate the controls. At this point, when the operators indicated that they understood all functions and were ready to begin, the first inspection simulation commenced.

The simulation collected the following information during the inspection:

- Inspection time.
- The number of items inspected, out of total inspectable items in the simulation.
- The number of violations detected, out of total violations present in the simulation.

After the inspection, the operators conducted their designated After-Action Review (either as Group A or Group B). When satisfied with the After-Action Review session from the first inspection simulation, the operators engaged in the second inspection session. The same information was collected during the second inspection. The simulation was set to select violations randomly. Therefore, the probability of encountering the same violations in two consecutive sessions is extremely low. When the second inspection was completed, the operators were asked to fill in an Operational Assessment Training Scale (Vickers, 2022; Measuring Training Effectiveness, 2023). The Operational Assessment Training instrument is based on a 7-point Likert Scale to measure training relevance, efficacy, and quality.

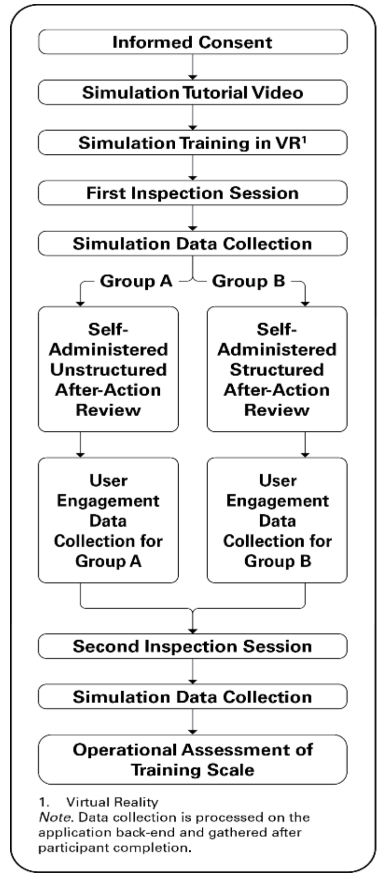

Figure 8. Experimental Design

RESULTS

Due to the limited number of officers participating in the evaluation, Wilcoxon nonparametric tests were used to document statistical differences and effect sizes.

Inspection Time

The means and standard deviations for the lengths of the first inspection are presented in Table 1. Comparison between groups revealed no statistically significant differences, Z(1,8) 1.35, *p*=.1779. This indicates that participants' initial inspections were fairly similar regardless of group. The improvement in inspection times (how much shorter the second inspection was than the first) is presented in Table 2. The comparison between the groups shows a statistically significant improvement in Group B compared to the improvement in Group A, Z(1,8)=1.84, *p*=.05. The effect size is large, *r*=.61.

Table 1. Mean Inspections Times

Session	Group	Mean (minutes)	Standard Deviation (minutes)
First inspection	**A**	55.7	9.1
	B	82.2	26.0

Table 2. Time Differences Between the First and the Second Inspections, by Group

Group	Mean (minutes)	Standard Deviation (minutes)
A	12.4	9.9
B	29.8	9.9

After-Action Review Session Times

The mean time each group used their respective AAR to review their first inspection session is presented in Table 3. Statistical comparison indicated no significant difference between groups, Z(1,8)=0.37, *p*=.7133. This shows that, on average, participants in both groups devoted similar efforts to the review of their inspection sessions.

Table 3. AAR Session Times

Group	AAR Type	Mean (minutes)	Standard Deviation (minutes)
A	**Unstructured**	12.0	6.3
B	**Structured**	14.2	5.5

Number of Items Inspected

As mentioned earlier, the number of inspection points is more than 300. Table 4 presents the number of items inspected in each session by both groups in percentages of the total number of inspection points.

The comparison between groups revealed no statistically significant difference between the percentages of items inspected in the first session, $Z(1,8)=1.59$, $p=.1113$. The comparison for the second inspection demonstrated that group B inspected many more items than group A, $Z(1,8)=2.33$, $p=.0143$. The effect size is also very large, $r=.78$. The results from Table 3 would potentially indicate a similar outcome between groups, but we instead see a greater performance jump in Group B, which used the structured Report AAR.

Table 4. Items Inspected by Session and by Group

Session	Group	Mean (percentage)	Standard Deviation (percentage)
First Inspection	**A**	76	18
	B	90	3
Second Inspection	**A**	79	15
	B	95	1

Number of Violations Detected

Violations are inspection points that should fail the inspection. For example, a broken brake pad is a violation. A crack in the truck frame is also a violation. Table 5 presents the number of violations detected in each session by both groups, in percentages of the total number of actual violations in the scene. The comparison between groups revealed no statistically significant difference between the percentages of violations detected in the first session, $Z(1,8)=0.126$, $p=.8016$). This shows that both groups began on relatively equal performance standing. The same comparison for the second session demonstrated that Group B detected significantly more violations than Group A, $Z(1,8)=1.88$, $p=.0453$). The effect size is also large, $r=0.63$. Again, as Table 3 would foreshadow a potential similarity between groups, we see that Group B was able to use their time more effectively in the Report AAR, resulting in a significant performance increase and tighter group data cluster.

Table 5. Total Violations Detected in Each Session by Group

Session	Group	Mean (percentage)	Standard Deviation (percentage)
First Inspection	A	66	14
	B	68	18
Second Inspection	A	66	9
	B	81	8

Operational Assessment of Training Scale

The Operational Assessment of Training Scale assessed training on relevance, Efficacy, and Quality. Operators rating the three components on a 7-point Likert Scale is provided in Table 6. The Training relevance was highly rated by both groups and comparison between groups revealed no statistically significant difference, $Z(1,8)=1.03$, $p=0.2453$. Similarly, the Efficacy rating was highly rated by both groups, and the comparison between the groups also revealed no statistically significant difference, $Z(1,8)=0.75$, $p=0.3791$. Finally, training Quality was highly rated, and the comparison also showed no statistically significant difference, $Z(1,8)=0.75$, $p=0.3832$.

Table 6. Operational Assessment of Training Scale Ratings

Component	Group	Mean (out of 7)	Standard Deviation
Relevance	**A**	6.0	0.4
	B	6.3	0.3
Efficacy	**A**	5.9	0.9
	B	6.3	0.5
Quality	**A**	6.0	0.6
	B	6.2	0.4

DISCUSSION

The results above demonstrated that officers that used the Report After-Action Review application became more efficient in their second inspection. The comparison between the groups indicates a significant improvement, where the average inspection time was shortened by almost 30 minutes compared to the first inspection, while the second inspection time of officers that used the traditional After-Action Review was shorter by only 12 minutes on average.

The comparison between the average time each group used their respective After-Action Review application was not statistically different, indicating that the improvement reported herein cannot be attributed to the duration of using the After-Action Review application.

Comparing the number of items inspected pre- and post-After-Action Review sessions further supports the merit of the Report After-Action Review application. The number of items inspected by these officers increased in the second inspection, while this number was not different in officers that used the traditional After-Action Review. The comparison also indicated that the effect size was large. Similarly, comparing the number of violations detected pre and post-After-Action Review sessions showed that the number of violations detected following using the Report After-Action Review application increased significantly in the second inspection, while the number of violations detected in the second inspection of officers that used the traditional After-Action Review did not differ in comparison to the first inspection. Here the comparison also indicated that the effect size of the improvement was large.

The results of the Operational Assessment of Training provide that the simulator delivered relevant training that is efficient and of high quality. There was a consensus among all operators on all factors on the levels of the three factors, independent of the group assigned.

In summary, our work hypothesis that a Segmented, Hierarchically Structured, After-Action Review Application such as the Report herein will lead to improved performance and increased efficiency is accepted.

CONCLUSIONS

This paper provides evidence that strategically designed AAR applications that integrate advanced functionalities for documenting inspections and violations during simulations, along with a segmented report and interactive simulation playback review process, yield notable improvement in operator performance. The implementation of a structured review surpasses the effectiveness of traditional AAR playbacks. These findings heightened the significance for optimizing maintenance procedures training for two key reasons:

First, the laborious task of capturing and reporting results from complex procedures with numerous components is significantly alleviated, reducing the likelihood of oversight. By incorporating advanced functionalities, the process of documenting inspections and violations becomes streamlined, enhancing accuracy and efficiency in reporting.

Second, the demanding nature of supervised AARs for lengthy procedures can be effectively addressed, benefiting both trainers and trainees. The structured review approach provides a comprehensive and more organized method for reviewing and analyzing operator performance, enabling trainers to focus on critical aspects and providing trainees with clearer guidance and feedback.

In summary, the strategic design of AAR applications, with advanced functionalities, segmented reports, and interactive simulation playback, yielded notable improvements in operator performance. These findings have significant implications for optimizing maintenance procedures training, simplifying the reporting process, and enhancing the effectiveness of supervised AARs for training and trainees alike.

LIMITATIONS

Substantial efforts have been invested toward reducing the likelihood of sickness during the simulation. Yet, simulation sickness is a significant concern. Further research is needed on the effect of the length of the simulation on the likelihood of experiencing simulation sickness. The team plans to administer pre-experimental VR training to ease subjects into the simulations, hoping to reduce sensitivity to the simulation. Further, the results presented herein are based on experiments with nine subjects divided into two groups. While the effect sizes observed were large, a larger cohort study will allow for analyzing operators' detailed engagement during the After-Action Review sessions.

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