From the Laboratory to the Field: Developing a Portable Workplace Examination Simulation Tool

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Abstract. To perform a successful workplace examination, mineworkers must be able to find and fix hazards at their workplace. NIOSH recently completed a laboratory study to identify differences in hazard recognition performance for mineworkers, safety professionals, and mining engineering students tasked with performing a simulated workplace examination in a virtual environment. The laboratory methodology and study results were used to develop a training product aimed at improving mineworker safety. The purpose of the current chapter is to describe the efforts that were taken to modify the laboratory workplace examination simulation into a portable software tool called EXAMiner, which can be used for data collection and training purposes in the field. This chapter provides an explanation of the literature and results from the NIOSH laboratory research studies used to inform and motivate development of EXAMiner. In addition, the software specifications are explained.

Keywords: Mine safety · Hazard recognition · Virtual reality

1 Introduction

Over sixteen months, from October 2013 to January 2015, 37 mineworkers were fatally injured at metal/nonmetal (M/NM) mine sites [1], doubling the number of fatalities that occurred in each of the previous two years. To begin to address this concern, the Mine Safety and Health Administration (MSHA) called for an increased focus on "daily and effective workplace exams to find and fix hazards" as one of several areas where improvement was necessary to promote the health and safety of the mineworker [2]. MSHA has also proposed an update to the regulation related to workplace examinations. The proposed rule requires examinations of the working place to be conducted before work begins or as a mineworker begins work in that location. It also requires examination records to include descriptions of adverse conditions that are not corrected immediately and the dates of corrective action for those conditions [3]. Practically, this means that more mineworkers will be conducting workplace examinations, and more mineworkers will be accountable for the results.

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Hazard recognition is the identification and understanding of a condition or behavior that can cause harm [4]. Hazard recognition is a cognitively complex process that mineworkers must be prepared to execute [5], and it represents a special challenge for mineworkers because of their diverse work activities that involve the use of complex machinery and processes that take place in a dynamic, challenging environment [6]. While hazard recognition is critical for mineworkers' health and safety, recent research shows that, when tested in the laboratory, mineworkers are not identifying a significant number of hazards [5, 7]. National Institute for Occupational Safety and Health (NIOSH) researchers further examined hazard identification through a laboratory study where subjects performed a simulated work place exam; this study is referred to as the laboratory study from here on. In this study, researchers asked experienced and inexperienced mineworkers, mine safety professionals, and mining engineering students to perform a simulated workplace examination [7]. Participants performed this hazard recognition task within a virtual environment, and were instructed to search true-to-life size panoramic images of typical locations at surface limestone mines (e.g., the pit, plant, roadway, and shop) for hazards. After completing the hazard recognition task all participants received feedback about their hazard recognition performance and were debriefed about the hazards they accurately identified and missed. Consistent with the findings from other studies, hazard recognition task results show that experienced and inexperienced mineworkers and mining engineering students, on average, identified only 53% of the hazards. In addition and importantly, the participating mine safety and health professionals—those people at the mine site tasked with ensuring that mineworkers are trained and capable of recognizing hazards—were only able to accurately identify 61% of the hazards. These identification rates are well below the previously established 90% standard for mastery [8].

As the industry awaits the final promulgation of the new workplace examination rule, NIOSH has focused their efforts on the development of practical solutions from research findings for industry stakeholders to use to improve hazard recognition ability so that mineworkers can perform more effective workplace examinations and work more safely. Specifically, NIOSH is adapting the laboratory simulated workplace exam methodology to create EXAMiner—a portable workplace examination simulation designed to address critical competencies associated with hazard recognition ability. EXAMiner is designed to give mineworkers the opportunity to perform a simulated workplace examination, much the same way participants in the laboratory study performed a workplace examination in a laboratory environment [7]. NIOSH researchers are using the laboratory study materials and methodology to develop EXAMiner, and incorporating critical competencies and training strategies. The initial development of EXAMiner is described in the following sections

2 Training Strategies to Improve Hazard Recognition Ability

As NIOSH researchers modify the laboratory materials into a training tool, it is important to adopt proven training strategies in EXAMiner. Training strategies are the tools, methods, and contexts that are combined and integrated to create an interesting and engaging delivery approach [9]. An effective training tool forms a cohesive strategy by incorporating information, demonstration, practice, and feedback [10]. Information is the concepts or facts that have to be learned, demonstration provides visual depictions of the information, practice is the application of learned information and competencies in a safe environment, and feedback about performance. Each of these concepts is incorporated into EXAMiner to address hazard recognition competencies and improve hazard recognition ability.

EXAMiner delivers information about general and site-specific hazards through descriptions, statistics, and mitigation strategies during session debriefs. Hazard recognition is demonstrated within EXAMiner through a computer-based simulation that allows interactive and immersive activity by recreating all or part of a work experience [11] and encourages experiential learning [12]. EXAMiner provides high-fidelity panoramic images that allow the mineworker to visually experience all of the details of the mining environment. Additionally, using EXAMiner, mineworkers can practice searching for and finding hazards through a simulated workplace exam. The realistic and relevant hazard recognition practice in EXAMiner makes the skills and concepts practiced more likely to transfer to the job [13]. Finally, EXAMiner provides feedback about performance on the hazard recognition search task through debrief. Research indicates that technology-based simulation is more likely to be impactful and practice is much more likely to result in learning when it is paired with a debrief session, where trainees are given a post-training review and provided feedback about their performance [14].

3 Hazard Recognition and Critical Competencies

A growing body of research suggests that successful hazard recognition requires an individual to possess a complex set of competencies. These competencies include stable attributes such as intelligence [15], risk perception [16], and general and site-specific hazard knowledge [17]. They also include hazard recognition skills such as visual search [18], situational awareness [19], and lastly, they include temporary states such as alertness and distraction [20]. NIOSH researchers focused on four competencies to improve hazard recognition ability while developing EXAMiner: general hazard recognition knowledge, site-specific hazard recognition knowledge, visual search, and pattern recognition. Researchers selected these competencies because they are important, basic competencies all mineworkers should have and they were easily visualized using panoramic images in the hazard recognition laboratory study. In the following, we present how these competencies transfer from the laboratory to implementation in EXAMiner.

3.1 General Hazard Recognition Knowledge

General knowledge of hazards better prepares mineworkers to recognize hazards when they are present, and therefore, it is presumed, results in fewer incidents and accidents [17, 21]. General hazard recognition knowledge in mining is the knowledge of basic hazards found at most mine sites, regardless of commodity (e.g., gold, limestone, or coal). Examples of general hazards include slip, trip, and fall (STF) hazards such as material on a walkway or stairwell, electrical hazards such as splits and splices in electrical cords and cables or open electrical boxes, and fire hazards such as flammable material in close proximity to an open flame, or missing or inaccessible fire extinguishers. General hazard recognition knowledge is essentially the minimum level of training because mineworkers must first know and understand what hazards are in order to be able to find them at the worksite [5].

Within the laboratory study, general hazard recognition knowledge was represented by the hazards that were included in the panoramic images. Examples of general hazards include STF (e.g., material on walkway) and electrical hazards (e.g., unattended open electrical box). These panoramic images are also included in EXAMiner. General hazard recognition knowledge is also reinforced during the session debrief with information about the specifics of the hazards. Hazard information includes a description of the hazard, statistics to support why the hazard is risky, and information from the Code of Federal Regulation (CFR Part 46.5 and 46.8 of Title 30 Mineral Resources) that can be used to mitigate the hazard.

3.2 Site-Specific Hazard Recognition Knowledge

While there are hazards that are common across and within commodities, there are also site-specific hazards. Surface M/NM mineworkers face unique challenges. For instance, mineworkers operating a dredge work around water and have to be knowledgeable of how to correctly don the appropriate personal protective equipment (PPE), such as a life vest. Mineworkers operating front-end loaders and haul trucks in pits and quarries have to be knowledgeable about the unique geological characteristics of the material being mined at their site. This knowledge is critical for identifying areas of instability during highwall inspections. It is critical that mineworkers know and understand the specific risks that may be present in their work environments so they can recognize hazards.

Site-specific hazard recognition knowledge was also represented during the laboratory study by the hazards in the panoramic images, for instance cracks in the highwall. Again, the panoramic images are included in EXAMiner and reinforced during the session debrief with a description of the hazard, statistics to support why the hazard is risky, and information from 30 CFR that can be used to mitigate the hazard.

3.3 Visual Search

In addition to hazard knowledge, miners have to be able to search their surroundings efficiently and effectively to actually identify hazards. There is ample research from a number of industries (e.g., aviation, mining, automobiles) suggesting that visual search skills are trainable [12]. Visual search performance changes both qualitatively and quantitatively with extended training [22], and visual search training that engages workers in exercises that requires them to actively detect hazards is more effective than training that only provides verbal information about the hazards [23].

The laboratory study was designed to identify differences in how mineworker experience affected how they search for and find hazards. To complete the hazard recognition task, participants were instructed to search the panoramic images for hazards. While they performed this visual search task, study participants wore eye-tracking glasses to monitor and record their eye-movements. EXAMiner gives mineworkers approximately the same visual experience as the participants in the laboratory study. Using EXAMiner, mineworkers can practice searching for and finding hazards in the panoramic images visualized through a projector or monitor instead of in theater virtual laboratory environment.

3.4 Pattern Recognition

Pattern recognition or pattern matching is another skill that influences hazard recognition abilities. Experienced decision makers use it to more efficiently identify whether a specific situation reflects either normal operations or an abnormality [24]. Examples of safety-related patterns in mining are acceptable locations of equipment or personnel during operations, how equipment typically operates, or the typical cycle of changes in a mine environment over time. Changes to these patterns can signify when something is out of place, not operating correctly, or "does not look right," which may trigger the mineworker to recognize a hazard. Loveday et al. [25] suggest that while experience may be a necessary precursor to pattern recognition it is not sufficient on its own.

The panoramic images used during the laboratory study were developed to include multiple examples of the same hazard. For instance, there are several hazards related to a fire extinguisher: the fire extinguisher is missing, the signage denoting a fire extinguisher is missing, a garbage blocks the fire extinguisher, etc. Including multiple examples of a hazard within EXAMiner should strengthen the representation of that hazard in the mineworker's memory. Consequently, the mineworker should be more likely to recognize a fire extinguisher hazard in the future, even if it was not specifically in the training [26].

4 Use Case Definition for EXAMiner

NIOSH researchers identified the most critical areas and common training limitations to guide the development and determine how EXAMiner could ultimately be used to deliver training to the mining industry.

To be Used by the M/NM Mining Sector. NIOSH researchers developed EXAMiner as a response to the increase in M/NM fatalities and the call for more effective workplace examinations [1, 2]. The first step toward developing this simulation tool was a laboratory study that was designed to identify differences in hazard recognition ability based on mineworker experience [7]. Materials for the study include thirty-two panoramic images of typical locations at a surface limestone mine, where there are 101 hazards represented. These materials address general and site-specific hazards and strengthen pattern recognition common to the M/NM mining sector.

To be Used During Part 46 Training. EXAMiner was specifically designed to be used during training. The Code of Federal Regulations (CFR Part 46.5 and 46.8 of Title 30 Mineral Resources) requires mine operators to provide safety and health training to all new mineworkers and refresher training to all of their mineworkers each year. MSHA regulates the content of training plans. Trainers must follow an MSHA-approved training plan and meet the following criteria during their training classes:

- **New Miner Training:** Includes an initial 24 h of safety training within the first 60 days of work and 4 h of site-specific training before beginning work. The training must address site-specific hazards and include an introduction to the work environment, electrical hazards, emergency medical procedures, the health and safety aspects of tasks to be assigned, and the rules and procedures for reporting hazards.
- **Annual Refresher Training:** 8 h refresher training typically covers similar topics to new miner training. Refresher training must include instruction on changes at the mine that could adversely affect the mineworker's health or safety. Refresher training should also include a discussion of the hazards associated with the equipment that has accounted for the most fatalities and serious injuries, including mobile equipment conveyor systems, cranes, crushers, excavators, and dredges.

To address content relevant to Part 46 new miner and annual refresher training, EXAMiner provides information about general and site-specific hazards. This information is presented as hazard descriptions, statistics, and mitigation strategies during the session debrief.

To be Used in Group, Classroom Training. Part 46 of the CFR does not include specific requirements for where new miner or annual refresher training should take place. However, it is common for mine operators to choose to hold training either in a classroom at the mine site or a meeting room at a hotel or convention center near the mine site. Therefore, the infrastructure and resources available for training can vary greatly from one mine operator to another. While some mine operators may have technologically advanced classroom spaces equipped with up-to-date computer and projector systems, the vast majority rely on older model laptops and portable projector systems. In addition, given the remote location of some mine sites, a reliable internet connection may not be available. These factors affect what materials trainers select and how trainers choose to conduct training classes.

To minimize the overall cost and impact of training, mine operators typically conduct new miner and annual refresher training in groups led by one or two instructor trainers. Notably, this approach is consistent with training across industries, where 49% of training happens in an instructor-led, classroom setting [27]. To accommodate this training approach, EXAMiner was developed for group training sessions.

To be Used with Customized Materials. Mine safety and health trainers working in the mining industry have a limited supply of mining-specific training materials. NIOSH previously produced hazard recognition training materials that were delivered using the View Master [5]. This training program was an innovative and effective approach to hazard recognition training in that it provided mineworkers with a 3-D experience of their work environment. There are, however, some limitations with this program. First, it was developed for single-person use, so trainers had to buy the View Masters for all the students to be able to use materials. Additionally, the training program only included a small set of materials, limiting their usefulness for subsequent trainings.

Finally, while the authors detail the process for developing 3-D materials, the process is complicated and time and material intensive.

EXAMiner was created to give trainers the opportunity to customize training scenarios either by creating their own training scenarios or by choosing to create random scenarios from thirty-one panoramic images included with the software. They can also use one of the NIOSH scenarios to focus on specific types of hazards (e.g., electrical or slip, trip, fall) during training.

5 EXAMiner Workflow

As a portable, simulation, training tool, EXAMiner addresses the aforementioned hazard recognition competencies and constraints, and as a research-to-practice product, EXAMiner closely mirrors the methodology used in NIOSH's laboratory study [7]. Consequently, the initial version EXAMiner is a stand-alone, downloadable software application designed for optimal use during an instructor-led Part 46 annual refresher or new miner training held in a classroom setting. Once installed, EXAMiner does not require an internet connection and can be run on a standard laptop with a projector system. While EXAMiner includes a general hazard recognition training intervention, it can also be coupled with other training packages, as it provides the framework to demonstrate, practice, and review hazardous scenes. The following sections outline the how the software currently operates, with the basic components including the session setup (red), search task (blue), session debrief (green), and training intervention (orange) as depicted in the software flowchart in Fig. 1.

5.1 Session Setup

In EXAMiner, a session is defined as a single instance that a scenario—a set of panoramic images—is used for the search task, and it encapsulates the entire training (e.g., pre- and post-intervention panoramas). The trainer can create a new scenario, randomly generate a scenario, or load a previously saved one. To create a unique scenario, EXAMiner allows trainers to select the panoramas they wish to include and save the scenario to be either used immediately in a session or loaded later. Currently, the included panoramas of the pit, plant, shop, and roadway can be added to a scenario in any order chosen by the user. A randomly generated scenario includes between two and six randomly selected panoramas from 31 included images. Lastly, EXAMiner also allows the trainer to load a NIOSH-created scenario or one of their previously created scenarios.

The current version of EXAMiner includes nine NIOSH-created scenarios, five of which focus on specific hazard types (e.g., electrical or slips and falls). The specific hazard scenes only include hazards of that type. For instance, the electrical scenario includes only panoramas with electrical hazards. In this case, mineworkers should be given instructions to search for and find the electrical hazards, and only the electrical hazards are identified as feedback in the debrief session.

The remaining four NIOSH scenarios were developed specifically for new miner training. These scenarios include the hazards that were missed most often by

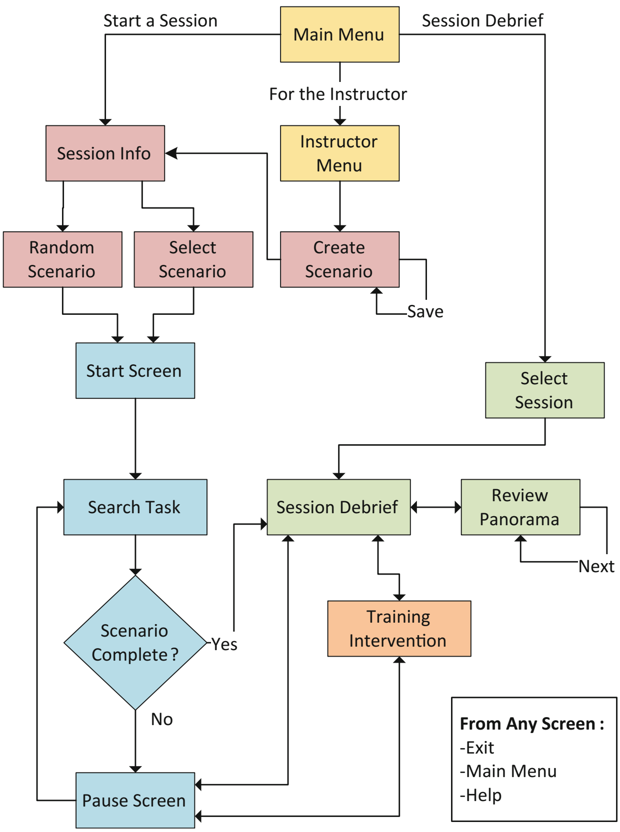

Fig. 1. A schematic depiction of the EXAMiner software workflow, including the navigation components (gold), session setup (red), search task (blue), session debrief (green) and training intervention (orange).

participants in the laboratory study with the least amount of mining experience—who were mining engineering students. These scenarios contain 23 hazards that had at least a 20% difference in hazard recognition accuracy as compared to the safety professionals, and are evenly distributed across the four panoramic locations.

5.2 Search Task

Once a scenario is selected, EXAMiner progresses to the hazard recognition search task. During the search task, mineworkers practice searching for and finding hazards while performing a virtual workplace examination. Once the search task starts, one panorama is displayed at a time, and the trainer progresses through the panoramas in the scenario. Within a panorama, trainers can pan around the image in an unlimited loop, zoom in and out, and pan up and down (see Fig. 2). Hazards are identified by clicking. A two-minute time limit can also be set for each panorama in the session info. For timed sessions, a progress bar is displayed at the bottom of the screen, and after two minutes, the panorama disappears and EXAMiner automatically progresses to a pause screen. Alternatively, the trainer can end the panorama at any time. After the completion on one or more panoramas, the instructor can progress to the next panorama, load the training intervention, or stop the search task early and move on to the session debrief.

Fig. 2. The picture represents a current screenshot of the Search Task within EXAMiner with the navigation toolbar across the bottom of the screen. The green progress bar depicts the time remaining for a timed session. Red click icons represent locations that have been identified as hazards.

5.3 Session Debrief

Following the completion of one or more panoramas or upon loading a previously collected session, EXAMiner allows the trainer to review the results of the hazard recognition search task in a session debrief. The session debrief gives the trainer an opportunity to give mineworkers feedback on their performance and to spend time discussing the hazards that were found and missed. The software displays the results of the training session including: panorama thumbnails and identifiers (e.g., Shop 2), the number of hazards correctly identified (e.g., 3 of 3 for Pit 6), the total search times (MM:SS), and the total number of clicks (e.g., 7 for Pit 6) (see Fig. 3).

The trainer can choose to debrief any number of completed panoramas during the session debrief. A review of each of the panoramas includes correctly identified hazards (outlined in green), missed hazards (outlined in red), and click locations as well as more information about the hazards in the image (see Fig. 4). The hazard information details the "what," "when," and "how to fix" of each hazard; this addresses general and site-specific hazard knowledge. The hazard information is directly relevant to topics and material that have to be covered during Part 46 new miner and annual refresher training.

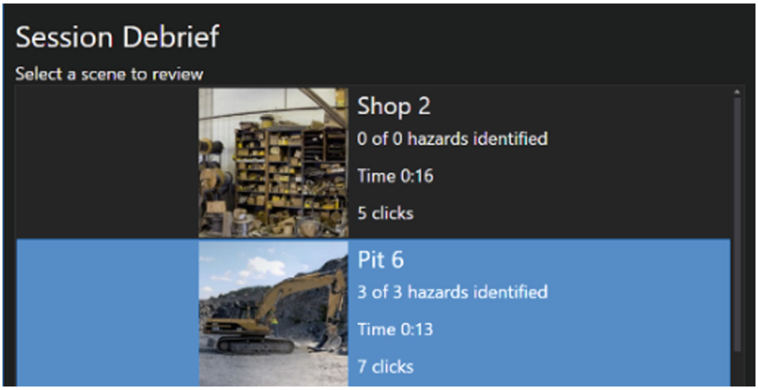

Fig. 3. The picture displays the current version of the EXAMiner's Session Debrief Screen, which provides the results of the loaded hazard recognition search task.

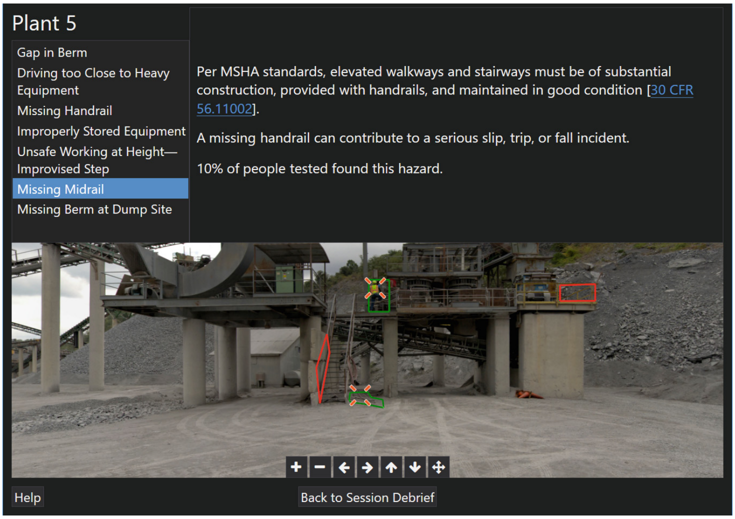

Fig. 4. The picture displays the current version of the EXAMiner's Panoramic Review Screen. Green boxed items indicate correctly identified hazards, and red boxes are unidentified hazards. The red click marks indicate where a trainer clicked during the search task. The upper left corner lists the hazards in the current panorama and the selected "Missing Midrail" hazard information is displayed in the upper right corner.

5.4 Training Intervention

Following the completion of at least one panorama in the search task, EXAMiner gives the trainer an opportunity to use the training intervention. Currently, the training intervention includes three modules: "Workplace EXAMinations and hazard recognition," "Are you searching like an EXAMiner," and "Taking it to the field." These training materials are designed to address general and site-specific hazard knowledge. More modules will become available through software updates as they are developed.

The intervention point also gives the trainer the opportunity to evaluate hazard recognition ability while using the training intervention. As depicted in Fig. 1, the current version of EXAMiner allows the trainer to move between the session debrief, search task, and training intervention to perform the search task on any number of panoramas and review them as they fit with the training modules in the training intervention. For example, in a pre/post format, the trainer can compare accuracy scores to determine whether there was a change in hazard recognition ability before and after the training intervention.

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