Improving Simulation Training Debriefs: Mine Emergency Escape Training Case Study

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ABSTRACT

While the debriefing literature has made clear the benefits of post-training review and feedback for trainees (e.g., Tannenbaum and Cerasoli, 2013), there appears to be little practical guidance on how to transform the wealth of information inherent in computer-based simulations into easily discernable, actionable feedback relevant to training debriefs. The present study takes an exploratory, research-to-practice approach to address this deficiency by using a mine emergency training simulation as a case study to determine some practical means of improving debriefing. This paper details the following steps of this exploratory process: (1) identify key features of successful debriefs by using relevant findings from debriefing and computer-based training literatures as an evidence-based guideline; (2) determine key trainee actions and behaviors as recorded by the Mine Emergency Escape Training (MEET) simulation, and finally, (3) determine relevant and feasible simulation variables that align with the debrief literature as suggested improvements to the current debrief program design. Future applications for mine emergency simulation training, debriefing research, and quantitative performance assessment in wayfinding tasks are discussed.

ABOUT THE AUTHORS

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INTRODUCTION

In 2006, responding largely to the Sago (12 fatalities) (MSHA, 2007a) and Darby (5 fatalities) (MSHA, 2007b) underground coal mine disasters, Congress passed the Mine Improvement and New Emergency Response (MINER) Act of 2006 (Public Law 109-236). This act, in part, addressed training requirements and best practices for both the escape of all underground miners and for improving emergency response skills of mine rescue teams to successfully face the challenges posed by adverse events. Due to this emergency preparedness focal shift as well as technological advancements in the recent decade, the mining industry has followed the medical and defense industries in considering and incorporating elements of computer-based virtual reality (VR) simulation into training. While VR training has begun to take a foothold in mining as demonstrated by the increased prevalence of simulators and simulation companies (i.e., Immersive Technologies, Thorough Tech, 5DT) as well as training software, little work has been done to critically evaluate these modalities and align the training mechanisms with that of the training literature (Mallet and Orr, 2008; Tichon and Burgess-Limerick, 2011).

The National Institute for Occupational Safety and Health (NIOSH) has made strides in recent years to begin to evaluate such training for mine emergency response knowledge, skills, abilities, and other characteristics (KSAOs), (Hoebbel, Bauerle, Macdonald, and Mallett, 2015), but research to determine the ideal modalities for the practice and retention of non-routine skills is lacking (Ford and Schmidt, 2000). One particular issue is identifying best practices for how to structure debriefs for emergency-based KSAOs training, especially given the complexity and wealth of information collected in computer-based training simulation. Computer simulations can record and display trainee data more accurately and in more detail than low-tech training modalities. While these simulations provide the capability to monitor and display a wide variety of data, the most effective way to quantify and visualize these data is not clearly understood.

Arguably, the greatest amount of learning occurs in the debriefing portion of training, and the debriefing literature has made clear the overall benefits of post-training reviews and providing feedback to trainees (Tannenbaum and Cerasoli, 2013). Historically, when trainers had to rely on low-tech training simulations, trainees were only provided feedback regarding observations made by trainers or other Subject Matter Experts (SMEs) present (Morrison and Meliza, 1999). One benefit of computer-based simulations is that the software engine often records much of the observational data, so that trainers can take a more active role in engaging trainees in the learning process (Johnson and Gonzalez, 2008). Furthermore, while the MINER Act regulates annual training for certain self-escape skills and quarterly escape drills, the quality and content of such exercises can vary considerably from trainer to trainer, mine to mine, and even within the same mine from year to year. Previously collected information or outside SME explanations can be built into computer-based training to give structure and baseline content to the debrief.

However, while there are examples of various debrief modules and solutions for existent virtual reality training (Jaye, Thomas, and Reedy, 2015; Sawyer and Deering, 2013), especially in military contexts (Johnson and Gonzalez, 2008), what is lacking is practical guidance from the literature on how to transform such recorded information into easily discernible, actionable information for trainers and trainees to use in the classroom beyond recorded playbacks of a training session timeline. The present study uses the NIOSH-developed Mine Emergency Escape Training (MEET) simulation as a case study to outline a practical means of improving debriefing for simulation training through an exploratory, research-to-practice approach. Using the relevant debriefing literature as a guide, the present study takes advantage of simulation and SME data to optimize the recommended re-design of debriefing feedback for self-escape.

In order to provide appropriate background in detailing our approach, the following section contains a brief review of the debriefing literature and an overview of the mine self-escape task in general and the MEET software specifically. What then follows is a method section that contains a description of the pilot data collection process, results with suggested debrief support variables, and a discussion which highlights strengths/limitations and future directions based on the current approach.

BACKGROUND

Debriefs and After Action Reviews

Training is a valued intervention and learning tool for a wide variety of contexts. While training effectiveness is certainly contingent on numerous factors, such as context, format, and audience, one noteworthy training component of some training strategies is debriefs, or ‘After Action Reviews’ (AARs). Debriefs occur after the conclusion of a training session, episode, or lesson and allow trainees to “reflect on a recent experience, construct their own meaning from their actions, and uncover lessons learned in a non-punitive environment” (Tannenbaum and Cerasoli, 2013, p. 231). The structure and content of debriefs rely on principles related to feedback, performance, cognition, memory, group dynamics, communication theory, and instructional science (Ellis and Davidi, 2005).

Several meta-analyses in recent years have attempted to clarify the scope, nature, and impact of debriefs. In one such meta-analysis, Tannenbaum and Cerasoli (2013) distinguish debriefs from other intervention tools by operationally defining debriefs as using multiple information sources to engage trainees in active learning regarding specific events with a developmental intent (i.e., as opposed to single sources used in passive training for general, administrative events). Further, in analyzing 46 samples, the authors were able to determine that, on average, debriefs improved effectiveness over a control group by 25% (d=0.67), an effect size that was relatively consistent across contexts and designs. Finally, bolstering effects were discovered for alignment between training content and debrief focus (i.e., training at the team level, followed by a debrief that focused on improving performance at the team level), as well as facilitation (i.e., presence of an instructor) and the overall degree of structure imposed on the debrief. Another meta-analysis (Kluger and DeNisi, 1996) suggests that feedback interventions are more effective when focused on task-relevant (vs. self-relevant) characteristics. Feedback supplied by the trainer or program based on task-performance during the training is generally more conducive to improving later performance transfer compared to feedback regarding individual differences of trainees. Finally, in their meta-analysis of the medical education literature, Cheng and colleagues (2014) investigated usages of debriefs in technology-enhanced simulations across 177 identified studies (Cheng et al., 2014). While substantial differences among studies made generalizable conclusions somewhat difficult, results overall demonstrated an advantage of simulation debriefs over no intervention (Cheng et al., 2014).

One noteworthy finding from this meta-analysis in particular is the difficulty of determining the advantages of various features of simulation debriefs or advantages of simulation-based debriefs over other debriefing modalities due to the lack of standardized reporting methods of debrief characteristics across studies (Cheng et al., 2014). Aside from these meta-analyses, much of the information varied considerably on an empirical-anecdotal spectrum. Based on this literature review, along with empirical evidence supported by the meta-analyses above, we summarize our general conclusions regarding research-informed optimal design characteristics of debriefs through five general categories:

1. Debriefs need to be flexible, yet structured enough to allow for targeted feedback.
(DeGrosky and Parry, 2011; Johnson and Gonzalez, 2008; Kluger and DeNisi, 1996; Meliza, Goldberg, and Lampton, 2007)
While each training session can be unique, even when using the same simulation program with the same (or similar) trainees, debriefing sessions should follow a semi-structured format while allowing for deviations that cater to the specific needs or behaviors of the trainees. For example, in discussing the benefits of creating an AAR organizational culture, DeGrosky and Parry (2011) warn about the dangers of using AARs as check-the-box exercises, which may have little value in terms of trainee learning. Additionally, Meliza and colleagues (2007) recommend that any simulation-derived AAR aids should focus on giving trainees feedback on information which may not have been available or obvious during the training itself, requiring flexible debriefs that minimally address specific learning objectives in lieu of a ‘one-size-fits-all’ approach.

2. Debriefs need to be interactive: The more potential for discussion, the better.
(Cheng et al., 2014; DeGrosky and Parry, 2011; Gratch and Mao, 2003; Meliza, 1996)
Effective debriefs not only display what occurred during the extent of the training session, but also create opportunities for discussion and reflection as a key component of the process. DeGrosky and Parry (2011) discuss this concept in terms of favoring “interactive” approaches to “practice[ing] sterile techniques” (which, they argue, contributes largely

to failures of AARs to appropriately influence learning). Gratch and Mao (2003) further this line of reasoning by framing effective AARs as more of an art form: "much of the learning from team training arises from frank after-the-fact discussions of the exercise, combining individual attributions of blame or credit into a more objective view of what transpired." In this sense, simulation-based debriefs may have an advantage over other AAR modalities in the sense that more objective information from multiple viewpoints can be integrated, forming the basis for group discussion in lieu of comparing observations or personal opinions of what actually transpired.

3. Debriefs should be 'forward-focused' and designed to improve future performance.
(DeGrosky and Parry, 2011; Johnson and Gonzalez, 2008; Parry and Darling, 2001)
Debriefs are conceptually distinct from similar exercises, such as post-mortems: while post-mortems are mostly concerned with thorough documentation and explanations of past events, debriefs should be aimed at reviewing relevant moments or actions for the main purpose of preparation for a future event (Parry and Darling, 2001). In this sense, debriefs lie at the core of the intention behind the training, which is preparation for a future event. Especially with regards to emergency events, it is important for debriefs to incorporate some type of tangible feedback by which trainees can improve upon potential future performance. While some advocate for computer-based diagnostics of trainee actions or performance during simulations as 'correct' or 'incorrect' (Johnson and Gonzalez, 2008), this may not be completely necessary and could, if done incorrectly, negatively impact the learning culture in an organization (DeGrosky and Perry, 2011). Indeed, anecdotal evidence with MEET training sessions revealed negative or moderately hostile trainee reactions to "being told by the computer that I did something wrong." Balancing the need to keep the debriefs forward-focused while avoiding unnecessary blame, all while maintaining trainee motivation and attention, perhaps best reflects earlier sentiments of viewing successful debriefing as an art form.

4. Debriefs should emphasize displaying multi-faceted data aggregations and visualizations where possible.
(Akin, Green, Arntz, and Meliza, 2005; Johnson and Gonzalez, 2008; Raij and Lok, 2008)
Given the wealth of information inherent to computer-based training simulations, debriefs based on such modalities should utilize such data to visualize critical moments or unique features of the actions taken in the exercise, particularly if such information, data calculations, or visualizations would contribute to discussion and learning and are likely to not be immediately obvious to trainees after-the-fact (Meliza et al., 2007). In their design of an AAR for virtual human interactions for health care workers, Raij and Lok (2008) described using multiple visualization formats, such as spatial, temporal, and event-based data, to increase learning during AARs. Perhaps, however, Akin and colleagues (2005) phrase it best: "The power of the AAR process…is based upon the capability to draw upon information from a variety of sources to provide an improved perspective regarding exercise events, resulting in greater awareness and understanding of the tactical situation after the fact" (Akin et al., 2005). In this way, visualizing simulation data can reinforce the second point above by giving more potential information for discussion that would not have been available to trainees or trainers otherwise.

5. Debriefs should contextualize trainee actions and behaviors.
(Cheng et al., 2014; Gonzalez, 2005; Johnson and Gonzalez, 2008; Parry and Darling, 2001; Raij and Lok, 2008)
While an earlier point discussed the cautionary nature of framing trainee actions as 'correct' or 'incorrect,' trainee actions or performance should be contextualized with regard to the actions or performances of experts, the 'average' trainee, or other trainees within the same classroom, especially if performance in the training task is complex and difficult to operationally quantify. In her study using a dynamic decision making computer-based simulation task, Gonzalez (2005) observed that the only training group with improved outcomes over the course of several trials was a type of feedforward control in which, after each trial, participants were shown replay clips from expert decision-makers regarding their real-time decisions. In this way, participants were able to compare their decisions to expert decisions on each trial and adjust their mental models of how to complete the task accordingly. Additionally, Parry and Darling (2001) advocate for contextualizing trainee actions or performance with a comparison between intended and actual outcomes. Johnson and Gonzales (2008) similarly argue that a common feature of automated AARs should be an available comparison between the actions trainees took in a simulation with what 'good' or 'expert' actions would have looked like in the same scenario.

Underground Coal Mining, Emergencies, and Self-Escape

Underground coal mines are created using several extraction methods (Hustrulid and Bullock, 2001). Most underground coal mines extract coal in a grid pattern made up of parallel tunnels called entries and perpendicular connecting tunnels known as crosscuts, similar to the layout of a city center. The remaining blocks of coal, pillars, act as a method of primary roof support, to keep the surface from caving in. Roof bolts, long metal bars, are drilled into the roof immediately after coal extraction to aid in roof support. This process of supporting the roof is critical to preventing dangerous rock falls, because underground coal mines can lie from several hundred to more than a thousand feet below the earth's surface. Basic support systems are used to maintain the operation of the mine including ventilation, electrical, water, and personnel and material transport, as well as communication systems to coordinate the use of these systems.

Depending on the size of the mine and work assignments, miners may work several miles from the nearest exit to the surface. Because work locations can be several miles from the surface, workers must be largely self-reliant in case of accidents or emergencies. Mandated safety training for these workers includes a curriculum common to most industrial worksites, but a unique requirement is having the ability to respond to a catastrophic event such as a fire, explosion, or gas inundation that can compromise air supply and cut off escape routes (30 CFR Parts 48, 75). These events are particularly concerning in underground coal mines because of the combustibility of the coal and the potential for explosion from coal dust or methane accumulations. As such, underground miners are trained in evacuation or 'self-escape' routines and skills to help them either reach safety through their own efforts or arrive at a safe location where they can await search-and-rescue crews.

Mine Emergency Escape Training (MEET) Software

NIOSH originally developed the MEET software to demonstrate the feasibility of VR-based training as a sandbox type tool for trainers to use as a part of their mine escape training. It is flexible enough to use across the various geographic regions of the United States, as well as in large and small operations. While mine emergency protocols vary from mine to mine relative to specific details, such as location and identification of escapeways (marked paths meeting specific safety criteria such as caches of self-contained self-rescuers that are ideal routes of escape), the MEET mine setup is generic enough to provide a baseline for expected routes and other critical decisions points. Because MEET was developed through several early iterations (Orr and Girard, 2002; Orr, Mallet, and Margolis, 2009), the VR simulation was created using Unreal® Engine 2 (Epic Games, Inc.; Cary, NC). While this engine was somewhat aged at the time of this writing, NIOSH elected not to retool the application for a newer engine due to limited resources and the existence of outside simulation training companies.

To familiarize trainees with the controls and interface of the simulation, MEET contains a pre-shift tutorial. The self-paced practice level allows trainees who might be less familiar with computer game-based simulation time to become acquainted with the keyboard, mouse, and display interface used to operate the simulation. During this time, a trainer can provide one-on-one assistance to ensure that all trainees are ready to proceed with the training.

Figure 1. First-person trainee view of two other avatars in the MEET software at the SCSR cache displaying the messaging system that can be used for in simulation communication between computer stations.

MEET is a 'first-person-shooter' style multi-trainee simulation that allows up to four trainee computer stations to assume the roles of miners evacuating an underground coal mine after a fire breaks out (Figure 1). The simulated environment is a fictitious underground coal mine that contains more than 10 miles of tunnels. It can take trainees anywhere from 10 to 45 minutes or more to successfully navigate from their work area through smoke and other obstacles to safety. Trainees are instructed to follow a baseline evacuation protocol, which is standard in most underground coal mines. The protocol calls for trainees to assemble in a pre-determined location and wait for other trainees before continuing with the egress. Trainees can interact with the environment and each other using simple keyboard and mouse controls. The basic

MEET functions include the ability to attach to a lifeline, sample atmospheric gas levels, pick up and don a Self-Contained Self Rescuer (SCSR) breathing apparatus, and send messages to other trainees. Additional information regarding these tasks are detailed below.

Lifeline – Underground coal mines are required to have lifelines installed in both a primary and secondary escapeway leading to the surface from each work area (30 CFR Parts 48, 75). A lifeline is a rope hung along the wall (or 'rib') of an escapeway with plastic directional cones. The main purpose of the lifeline is to provide tactile feedback that, in the case of smoke or limited visibility, gives escaping miners information regarding their overall direction (i.e., 'inby' or deeper into the mine, vs. 'outby' or closer to the surface). Tactile directional, branch, doorway, and other indicators are placed along the line to assist in evacuation. To simulate this functionality, trainees must intentionally attach themselves to the lifeline by pressing a key on the keyboard before they approach the lifeline. Once attached, their movement is restricted along the axis of the lifeline. Direction of travel is indicated on the on-screen menu. Other tactile indicators are not simulated, but are still visible on screen, even in the simulated smoke.

Gas Monitor – Although not all miners are required to carry a portable gas monitor, the simulation provides each trainee with a monitor to get practice with the device. The unit displays methane, carbon monoxide, and oxygen levels at the current location. As the fire progresses toward the evacuating miners, carbon monoxide levels begin to rise, oxygen levels drop, and visible smoke arrives. At 20 ppm (parts per million), an alarm will sound. At this point, trainees should don their SCSRs (as described below). Typical alarm values of carbon monoxide are 50 ppm. However, the lower value used for the MEET simulation was intended to help instruct trainees on the importance of continuously monitoring air quality levels, even without the presence of smoke. Trainees can check the gas monitor at any time through the use of the keyboard.

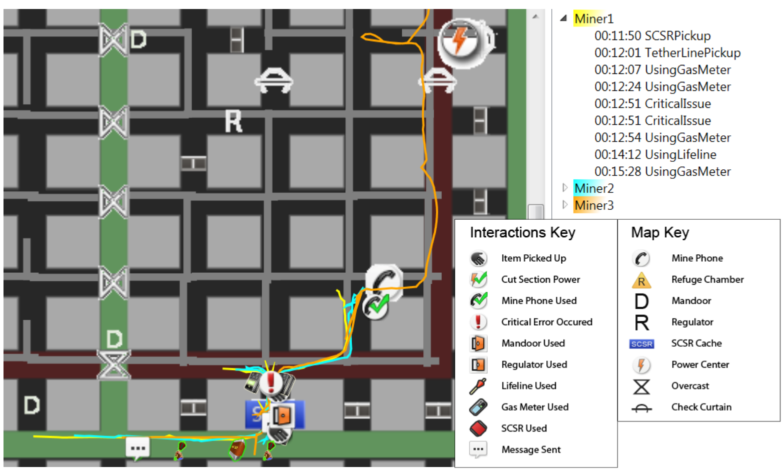

Figure 2. The MEET debriefing software provides a conceptualized map of the mine with position and event log data overlaid for use during after-action review. The avatar positions are represented by the orange, cyan, yellow, and magenta lines, and the smoke advance is represented by the thick gray lines.

SCSR – SCSR units allow escaping miners to isolate their lungs from toxic gases in the environment. The units depicted in MEET are rated to provide one hour of breathable air. Miners are trained to don these at the first sign of smoke or when carbon monoxide gas reaches harmful levels. Activating the SCSR using the keyboard will cause the trainee to pause for 10 seconds while an animation depicts the avatar donning the apparatus. The purpose of the animation is two-fold. It simulates the delay a miner would experience while stopping to put on his or her SCSR, and it also shows other nearby trainees that one of their comrades has chosen to don his or her SCSR. Once the SCSR is donned, the avatar model includes the apparatus attached to the face and chest.

Log Files – Avatar locations and all trainee actions in MEET are written to a log file to be used by the debrief software (as described below). Trainee locations are logged every second. Events are also logged at a one second resolution whenever they are generated. Each log entry contains the location, time, and other relevant data (gas readings, message data, etc.). A typical location log entry looks like:

VREvent: @PLAYER=Miner4 @TYPE=LocUpdate @LOC=16898.32,-3377.79,-73.80 @TIME=0:1:54.

Debrief – MEET also includes an open-ended debrief software that facilitates an instructor-led review of the trainees' emergency evacuation. The MEET debrief software is used to show trainees their paths, actions (i.e., opened a door), critical errors (such as failure to don a SCSR), and other key decision events on a conceptualized map (Figure 2). The trainer can chronologically play through the events from a bird's eye view in which trainee routes and actions are represented by colored lines and icons, respectively, and the smoke progression is depicted as gray lines.

METHOD

Data Collection

In order to test the feasibility of potential debrief variables, two sets of uncontrolled MEET log files were obtained from training sessions provided by an underground coal mine operator in the eastern United States in 2014 and 2015. Researchers had arranged for the company to use MEET as a part of their fire school training – a class designed to specifically address underground emergencies such as fires and explosions. This provided NIOSH the opportunity to field test MEET and assess its utility as a supplemental training aid, and it afforded the mining company an alternative to traditional classroom based mine escape training. Over 1,500 employees were trained as they controlled 982 avatars across 273 training sessions. A subset of the sessions were observed and/or included survey feedback from the participants. The observational and survey data will not be discussed here.

For each training class, mine company employees served as the trainers. Prior to the training, NIOSH researchers briefed the trainers on the MEET software, assisted the trainers as they practiced with the software, and discussed how to conduct a debriefing session. Trainers were also coached in how to interact and help trainees with technical issues, but not with escape decision making. Mine employee trainees were situated in a classroom environment and stationed at one of four desktop computers set up as trainee stations. Each trainee station corresponded to an escaping miner avatar in the MEET software. Trainees were provided a detailed account of what to expect during classroom time and asked to give verbal consent of their willingness to participate in the training and research activities. Depending on class size, approximately one to three trainees were stationed at each computer.

Trainers began by walking trainees through the 'pre-shift tutorial.' Once all the trainees felt comfortable with the software, the main MEET exercise was loaded, avatars were dropped into the mine, trainees were given information about the emergency situation they faced (in this case, a mine fire), and the trainees were instructed to escape the mine using whatever strategy they deemed most efficient and/or appropriate. All trainees were exposed to the same training scenario. Each computer station either controlled a miner who was working in the face area of the mine (inby miners) or a maintenance crew member who was working about 500 feet away from the face and closer to the mine entrance (outby miners). After all the trainees had completed their escape, the trainer then conducted a debriefing session during which trainees' actions and performances were discussed.

Between 2014 and 2015, minor improvements were made to the instructor training, the stability of the software, and the trainee instruction materials. These differences, along with the unobserved nature of over 50% of the sessions makes definitive conclusions using inferential statistics on the combined dataset somewhat problematic. However, the general use of the software and the large number of data points gives a better understanding of how the software may be used by independent instructors, providing a good basis for the visualization of the data to be discussed here.

Avatar data was excluded if (1) the total movement was less than 640 'Unreal Units' (approximately equivalent to 40 feet), (2) the avatar did not finish the scenario (i.e., did not reach an outby location relative to the mine fire), or (3) a technical error was detected by movement over 200 'Unreal Units' (12.5 feet) from one frame to the next. Due to a substantial degree of unobserved training sessions and the repeat location, it is possible that avatar data may include repeat subjects or trainer-controlled avatars. After removal of erroneous data and technical errors based on the aforementioned criteria, 922 avatars were retained for the subsequent data manipulation.

Data Extraction and Computation

To facilitate the understanding and extracting of meaningful metrics from the large volume of data produced by the MEET software, the researchers built a modular log parser and analyzer. Both components were written in JavaScript to allow for easier modification. Once the data is parsed, the main program executes any existing analysis modules. New analysis modules can be added at any time, making this solution flexible for the easy development of supplemental variables. Some modules may perform simple averages or other statistics, while others can build tables or run multi-pass analyses on cached data. The output format can also be varied, as file creation can specified in the modules as well. The typical case would be for the module to create a CSV file, which can then be used directly in tables, to create graphs, or for further processing in a statistics program; however, there is no restriction on this. Any module can directly generate images or other data files as appropriate.

Separating the analysis code into small modules offers two major advantages: reusability and simplicity. Because the main program performs all the repetitive tasks, it can be used for any type of analysis with any number of modules. The main program selects which log files to process, parses the log files, displays the progress of the analysis, and controls all other user interface needs, so the analysis modules need only deal with analyzing the data. Therefore the analysis modules are simplified to mostly contain the math used to analyze the data. Because the analysis modules are limited to the analysis algorithms, it is more feasible for researchers without a background in computer programming to make changes to what data is extracted, or write a new analysis module. This, combined with JavaScript not needing to be compiled, makes it simple to quickly change what data is extracted.

RESULTS

Normative Data

One of the advantages of simulation based training is the immediate availability of quantified statistics and data. This allows the presentation of general values to describe what was accomplished. In an effort to provide some context and structure, average time and distance variables derived from a representative sample of users can be supplied as normative data. Though these values must be interpreted with caution, they can be useful for a trainer to offer a baseline for comparison and highlight any common patterns. Table 1 presents a general estimate of what these numbers would look like for the overall dataset and broken out based on starting position. As with most of the variables presented here, separating the inby and outby miner starting position is important, because not only do the inby miners have further to travel, but are faced with slightly different decisions due to their positioning. Normative data is not available for this case study because our samples cover only a subset of miners. In the absence of normative data, central tendency indicators (as displayed here) for time and distance can also be used to help give context to individual results. Trainers would be able to use their internal data to present such values.

Table 1. Gross Performance Variables

	Mean (St. Dev.)		
	Overall (n = 922)	Inby Miners (n = 422)	Outby Miners (n = 500)
Total Time [s]	968 (259)	1,030 (247)	915 (257)
Total Distance [ft]	3,008 (555)	3,261 (480)	2,794 (524)
Distance in Primary Escapeway [ft]	1,625 (747)	1,812 (777)	1,466 (684)
Distance in Secondary Escapeway [ft]	911 (567)	844 (595)	968 (536)
Time in Primary [s]	452 (217)	501 (220)	411 (205)
Time in Secondary [s]	302 (178)	267 (187)	332 (164)

One caveat to the computation of time and distance variables is a meaningful definition of ‘start’ and ‘stop.’ Since we are only interested in the time and distance required for escape, we need to be sure that the ‘start’ corresponds to when the trainees actually enter the mine (as opposed to program launch *prior* to entering the mine) and should ‘stop’ when they pass the ‘exit’ threshold (as depicted by the yellow vertical line in Figure 3). Similarly, position and time can be combined to compute how long trainees spent in the primary and secondary escapeways and how far they travelled in each escapeway. Figure 3 displays the primary escapeway in green and the secondary escapeway in red. Another nuance of basic variable definitions lies in the tolerance of bounding area. The position bounds on these variables could be further fine-tuned based on specific inquiries of the trainees or trainer. For example, the bounding area should be significantly tighter if trainers were more interested in the distinction between trainee presence in the primary escapeway compared to the secondary escapeway, but would be much broader if instead trainers were more interested in total escapeway time and distance. The bounding area used to compute time in escapeways are depicted as semitransparent, color coded regions around both the primary and secondary escapeways (Figure 3). Again, this use-case variability highlights the need for debrief materials need to be flexible, cautionary, and non-prescriptive.

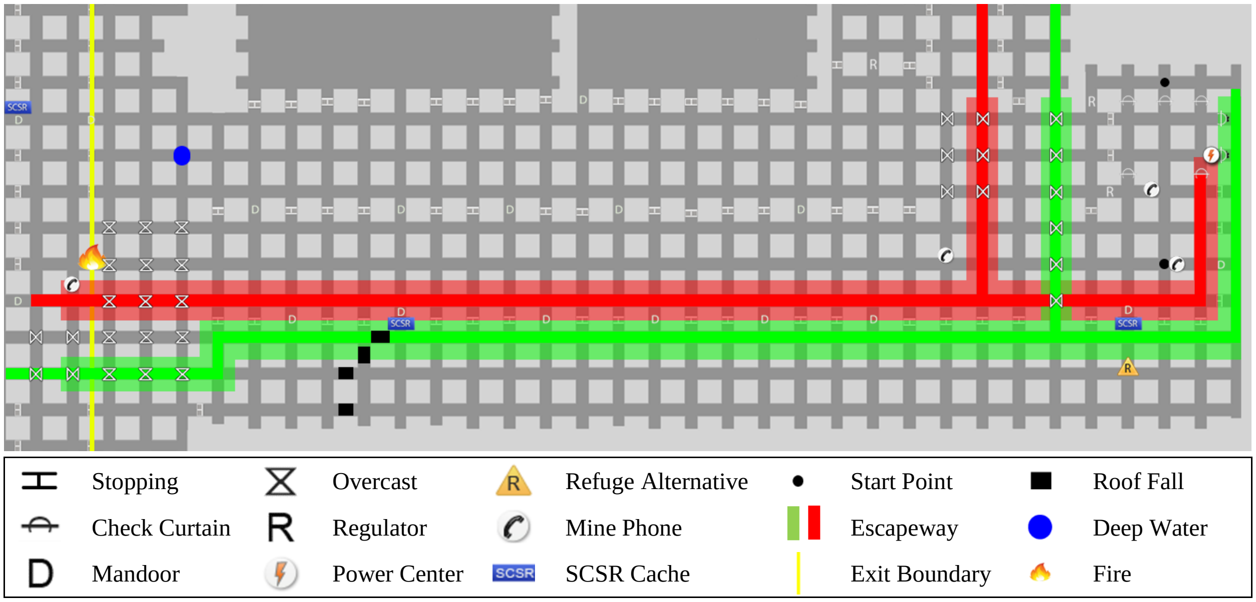

Figure 3. MEET debrief map depicting bounding regions for calculations of start, end, and time in escapeways. The primary escapeway with bounding region (semitransparent) is in green and secondary is in red. The exit threshold is denoted by the yellow vertical line.

The prevalence of context errors – errors specifically related to the mine escape – is another example of normative data that could be valuable to trainers. Common trainee errors in MEET can be found in Table 2 and include SCSR, lifeline, and travelling under unsupported roof (i.e., 'off-limits' areas) errors. An SCSR error was recorded whenever trainees failed to don their SCSRs once a carbon monoxide level of greater than 20 ppm was encountered, causing the multi-gas meter to alarm. Trainees are instructed to don their SCSRs at carbon monoxide alarm levels or at the first sign of smoke. Failure to do so could result in loss of consciousness or even death if the levels suddenly rise. Lifeline errors occur when trainees fail to attach to the lifeline in smoke. Letting go of a lifeline in smoke is hazardous because the thick black smoke caused by a coal fire makes it almost impossible to see more than a few inches. Miners could easily become disoriented and unable to escape the mine. Lastly, unsupported roof errors occur when trainees travel to an area of the mine that does not have roof bolts or other support structures holding up the roof (or ceiling) of the area. This is extremely hazardous because of the risk of a roof fall (i.e., cave-in), especially in emergency conditions. Additional non-critical errors on the individual and group level could include failure to try to communicate with the surface (use the mine phone), failure to cut power to the section, or improper ventilation (leaving a man door open). While these error variables may also suffer from similar definition limitations as noted above for time and distance, such indicators may contribute to discussion opportunities if framed appropriately for trainers.

Table 2. Percent of Miners with Critical Errors

	Overall (N = 922)	Inby Miners (N = 422)	Outby Miners (N = 500)
Failure to Don SCSR	56.7	51.9	60.8
Off Lifeline in Smoke	65.2	66.4	64.2
Entered Unsupported Roof	7.0	14.5	0.8

Subject Matter Expert Data

Subject matter expert (SME) data and choices are invaluable tools in the debriefing process. Every action performed by the SME, especially when compared to actions made by trainees, has the potential to provide a discussion point for the debriefing session. Trainers can discuss with trainees how and why these actions were taken and possible alternatives. The MEET debrief could be augmented with SME paths and action logs as represented by the black line in Figure 4. Again, the metric is broken down by the inby and outby miner starting positions, but only the outby miner is shown here. Providing SME distance and time estimates would similarly support the gross performance variables described above. Rough calculations including distance of the route depicted in Figure 4 and time delays for performed actions (gas check, don SCSR, etc.) resulted in approximately 2,365 feet and 605 seconds for the outby miner route. Similarly, two possible routes were proposed for the inby miners (not shown) with distances of 3,275 and 3,450 feet and times of 810 and 900 seconds respectively.

Alternative Visualizations

Another key feature for good debriefs, as mentioned earlier, is the utilization of multi-faceted data points that can provide a more holistic and objective indicator of trainee actions and performance. For example, while informative, for the current training, distance and time alone provide an incomplete picture of trainee performance. Using a graphical, multi-dimensional visualization technique such as a 'heatmap,' can create a more comprehensive understanding of where trainees spent most of their time, what were the most common routes, and where trainees generally deviated. Figure 4 depicts an across-trainee heatmap for the outby miners that gives trainers a better idea of where the trainees went and where they spent their time. Being able to easily and quickly discern this information during a debrief would allow tailoring of trainer feedback that would not otherwise be achievable in real time.

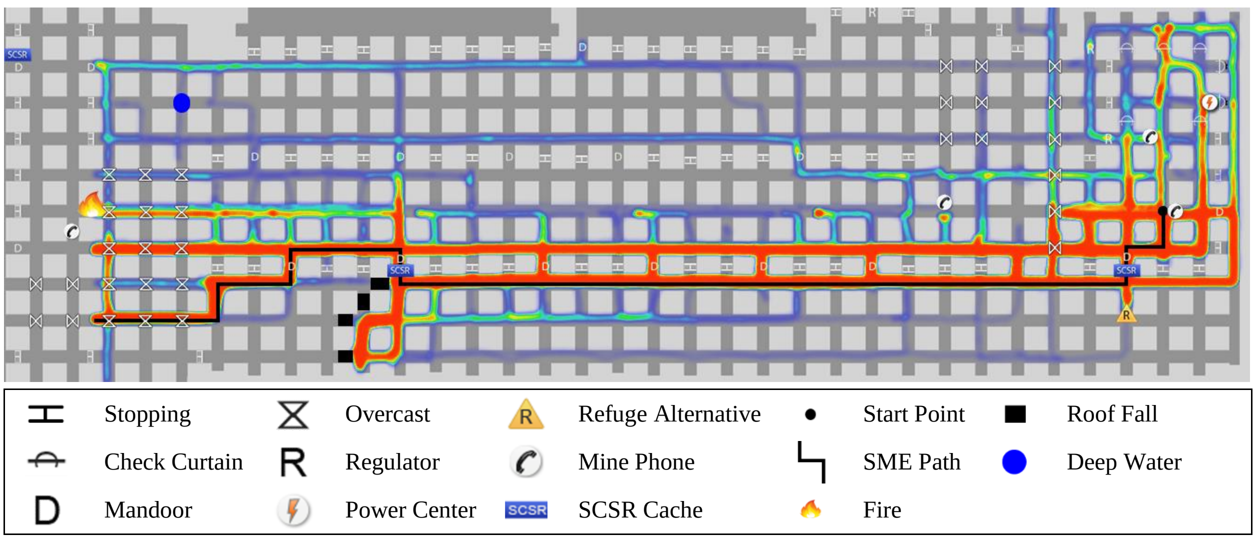

Figure 4. Heatmap of travel locations of outby miners' routes (n = 500) overlaid with SME path in black, where the heatmap is generated from locations weighted by occurrence, where the heatmap colors range from blue (little time spent) to red (most time spent).

More complex visualizations can give further insight into trainee behavior. For example, in the present training, we also calculated where avatars paused during the exercise to more clearly highlight decision points where a trainee was likely deciding what to do or where to move. Figure 5 depicts a heatmap of all trainee pauses weighted by duration and occurrence.

The pauses are calculated using a minimum length sliding window algorithm that found the length of time during in which a trainee moved less than a preset distance, and then expanded the window until the trainees' motion exceeded that limit. In this case the minimum window was selected to be 10 seconds in order to capture SCSR donning and the maximum distance was set to 20 feet to allow the subject to wander across an entry or intersection that are 20 feet wide. Trainees may have paused in an area to explore different route options, don an SCSR, pick up an extra SCSR, take a gas reading, or communicate with and/or wait for other trainees. Providing trainees with information on where they and their crewmates paused provides feedback and prompts for reflection on what was happening in the simulation to cause this response.

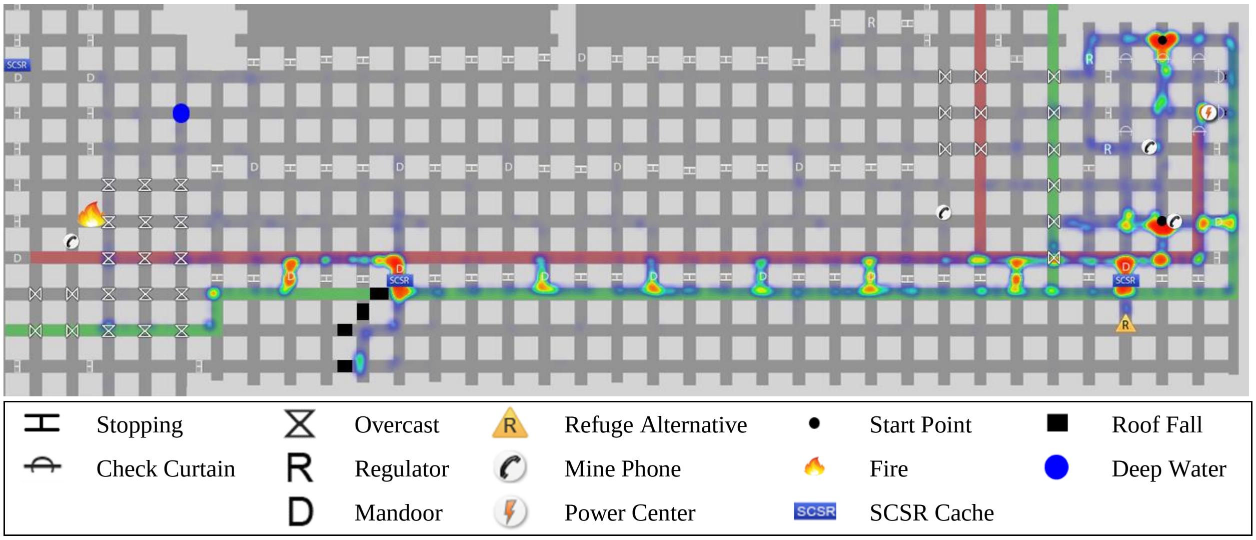

Figure 5. All trainee heatmap (n = 922) depicting pause locations weighted by duration and occurrence, where the heatmap colors range from blue (little time spent) to red (most time spent).

DISCUSSION

The purpose of the research was to take an exploratory, research-to-practice approach to develop improvements for a debriefing program for a mine emergency virtual reality training simulation by comparing findings and themes in the scientific literature on debrief research with simulation log data. These themes confirmed that better debriefs should include flexible yet targeted trainee feedback, greater opportunities for interaction and discussion, and a focus on improving future trainee performance. Debriefs should also incorporate multiple ways of aggregating and visualizing data and contextualization of trainee actions and behaviors with regard to normative and SME performance. The present research demonstrated a practical means of applying such insights to improve a debrief design using simulation data. For the MEET simulation, these recommended improvements included providing trainers with additional tools for increasing potential opportunities for discussion and interaction through increased visualization and contextualization of key simulation variables, such as time, distance, errors, pauses, and escapeway adherence. The information derived as a part of this study is not only important for the industry in considering the design and evaluation of its own training methods, but is also a key stand-alone case study example of how simulation data can be used to improve debrief design for computer-based simulation training.

Certainly debriefs and AARs have a long history with military training, and as such, the implications for the present research seem applicable to the defense industry. The lack of absolute tracking and reliable communication is a common challenge faced by both mine workers escaping from an underground mine and infantry clearing enemies from subterranean structures in urban environments or hardened military complexes. In training for handling unexpected events in Isolated, Contained, or Extreme environments –similarly encountered in mining and the military – it may be crucial to take advantage of all the data available in simulated training sessions to enhance learning. As demonstrated above, aggregating data to conceptualize norms and identify decision points can provide a more directed framework to lead debriefing sessions. However, it is also critical to fully understand the context in which metrics are being used to prevent inflation or deflation of values such as time and distance.

The present research lends itself well to several veins of future research efforts. As mentioned, one foreseeable area of continued research could be evaluating these tools to determine value-added for trainees and trainers. However, one further step may be to evaluate the five themes of successful debriefs derived from the literature, especially in terms of incremental or comparative value-added. While such themes are certainly interrelated, assessing various aspects or qualities of debriefing design and the subsequent effects on training may yield fruitful results for future efforts that seek applied and practical approaches to improve debrief design using simulation data.

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