Colorado School of Mines
mine rescue simulator

by C. Geier, E. Keogh and J. Torma-Krajewski

Abstract ■ Previous mine incidents show weaknesses in mine rescue preparedness from poor training in decision making, leadership and incident command center (ICC) protocols. Computer simulations offer a larger range of training opportunities for mine rescue teams focusing on exploration and communications. The mine rescue simulator developed by the Colorado School of Mines and Rite Solutions Inc. utilizes four computers for the instructor and team, with the instructor monitoring the team's progress. As the team explores, it relays information back to the Fresh Air Base, which then reports to the ICC. This forces a three-step communication procedure, enhancing the team's overall communication skills and developing ICC protocols. The simulator is decision-based, demanding team decisions be made quickly. Upon completion, teams commented positively. Generally, participants said that the simulator is useful for learning how to communicate and make decisions during mine rescue emergencies. This mine rescue simulator improves team training, providing effective communications practice with an easy setup and no production interruption.

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Introduction

Our national interests are best served by having well-trained first responders available for rapid response to emergency situations in underground mines. However, recent mine disasters have indicated that focused training on hazard recognition, decision making, leadership and incident command center protocols needs to be part of a comprehensive training plan for all personnel involved in a mine rescue. A report on the Sago Mine disaster indicated the command center lacked organization, preparedness and control, leading to a poor emergency response (Gates et al., 2007; McAteer et al., 2006; UMWA, 2007). A report on the Upper Big Branch Mine disaster concluded that the command center failed to follow protocols and maintain effective communication (Page et al., 2010; UMWA, 2011; McAteer et al., 2011). A report in 2006 from the Mine Safety Technology and Training Commission listed some improvements for mine safety training and technology and stated that the minimum training time should be increased to eight hours a month, and there should be training for common command centers for the mine managers and mine rescue teams. In particular, the training should focus on decision making and effective communication to strengthen coordination between the command center and teams.

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Currently, there are very few training opportunities for the mining professionals responsible for making the crucial decisions needed during a mine emergency. With recent technical advances, it is now feasible to use a computer-based simulator to train mine rescue personnel for mine emergencies in their mine or any other mine at a convenient location without interrupting normal mining operations. There is currently no information on how the use of computer simulators could be beneficial for mine rescue specifically. This simulated environment teaches underground search and rescue procedures, communications and decision making based on real-time information and hazard recognition. It provides another type of training for mine rescue personnel, while providing a safer environment to work in by avoiding the inherent risks associated with training in a real mine.

Since 2010, the Colorado School of Mines (CSM) has offered computer simulated mine rescue training using an incident command center (ICC) directed toward enhancing decision making and communication skills. To support this training, CSM partnered with Rite Solutions Inc. to modify, enhance and create simulation software for mine rescue applications. Rite Solutions was chosen based on its prior experience in developing emergency response simulation software for the maritime industry. The focus of this partnership was to modify existing simulation technology to address the unique nature of

Figure 1

A team during a training session with the mine rescue simulator.

underground rescue operations, make it applicable to any underground operation, create generic scenarios and develop customized computer simulations, including scenarios, for specific sites.

The purpose of this study was to determine (a) if the quality of the graphics was an important factor in the training experience when learning skills was the primary objective, rather than reproducing an experience, and (b) if the experience level of the teams impacted the value of the simulation training as a learning experience. For novice teams, who have little or no experience in following mine rescue procedures, the simulation training addressed learning these procedures, as well as learning communication skills and decision making skills needed to effect a successful rescue. On the other hand, experienced and expert teams already have knowledge of mine rescue procedures, so the focus of the simulation training as a learning experience for these teams was more on communication and decision-making skills, but also allowed the teams to practice mine rescue procedures, which would enhance their overall level of proficiency regarding these procedures.

Need. The CSM mine rescue computer simulator helps mine rescue teams train for mine disasters where they would be deployed. It provides additional, readily accessible opportunities to train without affecting mining operations. While the simulator lacks the physical demands of a rescue situation, it is very effective for teaching mine rescue procedures, as rescuers seamlessly walk through the process and work out issues before going underground. The mine rescue simulator also introduces students to coordinate through an ICC, which stresses the use of effective communication and hones decision-making skills. Most of the mine rescue teams participating in this study had never trained with an ICC controlling the actions of the mine rescue team, making this an extremely valuable training opportunity. In addition, the mine rescue computer simulator allows instructors to modify mine rescue scenarios and tailor the scenarios to each team's individual needs, resulting in a more versatile training experience. The goal is to ensure that all teams receive the maximum benefit from each training session.

Methodology

Training. Training was conducted with four computers, one for the instructor, and three for team members (captain, gas person and co-captain), who can be seen using the simulator in Fig. 1. The individuals in the fresh air base (FAB) and the ICC did not have computers, but instead relied upon verbal communications from the rescue team as would normally occur during an actual emergency. The instructor's computer was used to initialize the simulation, make any necessary changes to the scenario, and to monitor the team's progress through the mine. The other three computers were nearly identical, except that the captain had extra items in his/her inventory, such as a scaling bar and hammer. Screenshots of the simulator can be seen in Fig. 2. The simulation was conducted similar to how the team would proceed through the mine in an actual exercise, with the captain leading, the gas person taking gas measurements and the co-captain reporting back to the FAB, who reports back to the ICC. The map person tracked the team's movement through the mine, as normally would be done, and the first aid person determined what actions should be taken when the team found victims. For this study, the rescue team, FAB and ICC were located in the same building but in three different rooms, and all communications were conducted with radios.

Figure 2

Screenshots from the simulator: The left image is what the team would see (first person mode). The right image is what the instructor can see.

Prior to starting the training, the team members completed an orientation on how to use the simulator, which included some hands-on practice. The team members were also given instructions regarding the use of an ICC. Once the team members were confident in operating the simulator, the rescue problem was read to all participants. At the end of the training, each participant was asked to complete an evaluation questionnaire, which was done on a volunteer basis and anonymously.

Simulation software. The simulation software was developed by Rite Solutions Inc. and is a specialized configuration of Rite-EMTTM, which uses Real World databases (Terrain, Bathymetry, Imagery, 3D Models, Digital Nautical Charts, etc.) to automatically build a virtual training scenario at any location. Scenarios run on Windows-based laptops and desktop computers with 3D capable graphics cards. The scenarios are run in first-person mode, providing a graphical perspective from the viewpoint of the player character, where what is seen on the screen represents what the character would see with their own eyes. All movement and decisions by participants are recorded on an instructor station for immediate after-action review and can be used to develop multimedia training products. The mine model used for the simulations was the Edgar Experimental Mine.

During the past three years, the software has been upgraded based on user input. Three different versions of the

Table 1

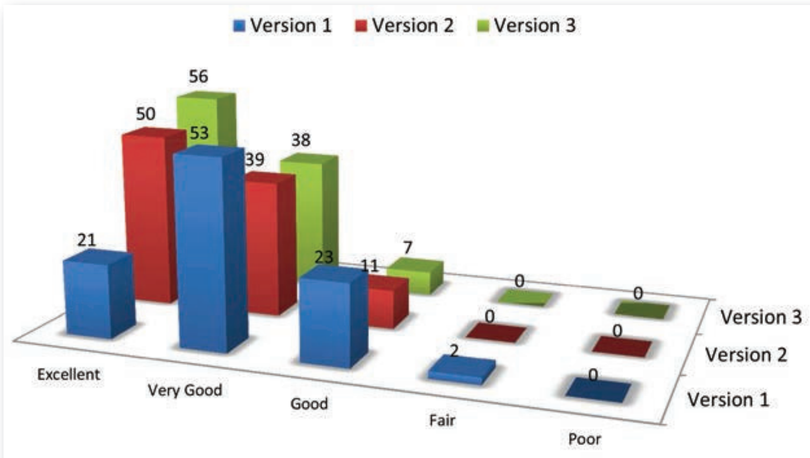
Number and type of rescue teams using the different versions of the simulation software.

	Version 1	Version 2	Version 3
Coal MR teams	2	0	0
M/NM MR teams	3	1	5
Student MR teams	0	2	0
Novice UG S&R teams	0	3	3

simulator were tested and used to train mine rescue teams. As the simulator was modified, more interactions were added to the software and the graphics improved slightly. The first version of the simulator software used placards to display gas readings and hazards, and very little interaction occurred between the characters and the mine. Objects in the mine were static and there was no smoke or change in lighting. Only doors could be opened and closed. The second version of the software incorporated more interactions, though they were still overall fairly limited. The team members could now open and close airlocks and place ventilation curtains at preset locations. Hazards could be seen but, again, no abatement of the hazards could be accomplished. With the third version of the simulation software, more interactions between the team members and the mine were added, including the most notable change – gas and smoke regions. Regions with heavy smoke drastically decreased visibility, along with cap lamp lighting, which gave a more realistic feel to what it would be like being in an underground mine. It was also possible to place ventilation curtains at any location in the mine model, take gas readings, pick up objects and victims, and correct hazards. The team members could now see some of the effects of their decisions. For example, when the team encounters a fire, they have the option to use different types of extinguishers. If they use the right one, the fire will be extinguished or lose intensity, but if they use the wrong one, the fire will become more intense. The other difference between Versions 1 and 2 and Version 3 was the controller. For the first two versions, joysticks were used to run the simulation, while game controllers were used to run the third version.

Figure 3

Overall evaluation ratings for all three software versions.



Rescue teams. A total of 19 rescue teams participated in this study. Eleven of the teams were mine rescue teams, who were grouped into one of two experience levels. Teams competing in national mine rescue contests were considered "experts," and teams who had not competed at this level, but had several years of experience were considered "experienced." There were four teams in the first group, with one team winning a national mine rescue contest, and seven teams in the second group. At the novice level were teams with little or no mine rescue experience, two college student teams and six U.S. Army Technical Rescue teams. The total number of team members participating in this training was 120.

Evaluation results

The evaluation data collected from the participants were analyzed according to the version of software used for the simulation training, and by experience level of the rescue teams.

Grouping by software version. Table 1 shows the type of rescue teams who used each version of the simulation software. Version 1 was used by two coal and three metal/nonmetal (M/NM) mine rescue teams, while Version 2 was used by one M/NM mine rescue team, two student teams and three U.S. Army rescue teams. Five M/NM teams and three U.S. Army teams used Version 3.

One of the evaluation questions asked the participants to give an overall rating for the simulation training. The results for this question are shown in Fig. 3. As the software improved from Version 1 to Version 3, there was an increase in the percentage of people who thought it was "excellent" (21% to 56%) and fewer who thought it was "very good" (53% to 38%) or "good" (23% to 7%). None of the versions received any "poor" ratings, and only Version 1 received any "fair" ratings (2%). When combining the percentage of "excellent" and "very good" ratings, the percentage of participants selecting either of these two ratings increased from 74% in Version 1 to 94% in Version 3.

Another question asked the participants to provide an overall rating of the graphics used in the simulation software. The results for this question are shown in Fig. 4. With the latest software version, almost 75% of the participants thought the graphics were either "excellent" or "very good," and the "excellent" category had the highest percentage of ratings. Prior versions had fewer "excellent" ratings compared to "very good" and "good" ratings. For Version 1, the category with the highest percentage was "very good," and for Version 2 the category with the highest percentage was "good." All versions had very few "poor" ratings. Most participants also said the simulator was easy to use for all three versions, even though Version 3 was slightly more complicated than

Figure 4

Ratings for simulation graphics for all three software versions.

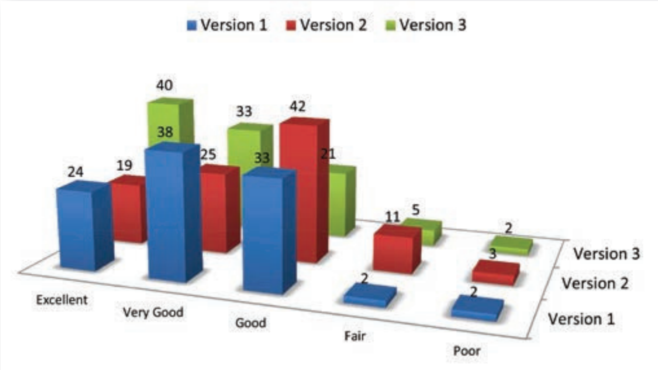


Figure 5

Overall evaluation ratings for all three experience levels.

the prior two versions. Only 10% of the participants using Version 1 thought the simulator was difficult to use, while no one using Versions 2 or 3 thought it was difficult.

Each participant was also asked a series of questions regarding the value of the training for learning certain skill sets and for applying the knowledge gained to their work performance. From these questions, all participants indicated that the simulation training would be useful in their jobs, and 93% (Version 3) to 94% (Versions 1 and 2) indicated it would be helpful for improving performance during a mine rescue exercise. In addition, most people thought that the simulator made them more prepared for specific aspects of a mine emergency – communication, decision making and hazard recognition. When averaging the responses for all three of these questions for each version, the average percentage of positive answers (a "yes" response) for Version 1 was 86%, for Version 2 was 95% and for Version 3 was 93%. Table 2 shows a breakdown of the responses given for each of the questions asked.

Grouping by experience level. Table 3 shows the number and type of team for each level of experience. The "novice" teams included two student mine rescue teams and six U.S. Army rescue teams. The "experienced" teams included two coal mine and five M/NM mine rescue teams, while the "expert" teams included four M/NM mine rescue teams.

When asked to provide an overall evaluation of the simulation training (Fig. 5), a higher percentage of novice participants rated the training as "excellent" when compared to the other two experience levels. When combining the results for the "excellent" and "very good" ratings, the percentage of participants for the novice, experienced and expert groups selecting these two ratings were 93%, 82% and 80%, respectively. Only 2% of the experienced group rated the overall evaluation as "fair." None of the participants for any experience level rated the training as "poor."

When asked about the quality of graphics, more than 50% for all three groups thought the graphics were "excellent" or "very good," while 51% of the novice group rated the graphics as either "excellent" or "very good." The novice group was the only experience level to rate the graphics as "poor" (5%) (Fig. 6). Most participants, grouped by experience level, also said the simulator was easy to use. Only 7% of the experienced group reported some difficulty with using the simulator. No participants from the other two groups

Table 2

Responses to questions regarding the value of the simulation training to learning specific skill sets and job performance. Values are given as percentages of total number of responses for each question.

	Version 1 (*n* = 32 to 40)		Version 2 (*n* = 24 to 35)		Version 3 (*n* = 38 to 45)	
Questions	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**
Will the training you received be useful in your job?	100%	0%	100%	0%	100%	0%
Was the simulator training helpful for improving performance during mine rescue exercises?	94%	6%	94%	6%	93%	7%
Was the simulator useful for learning how to communicate during rescue exercises?	97%	3%	100%	0%	98%	2%
Was the simulator useful for learning how to make decisions during a mine emergency?	88%	12%	97%	3%	95%	5%
Was the simulator useful for learning how to recognize hazards?	75%	25%	94%	6%	90%	10%

thought the simulator was difficult to use.

Each participant was also asked a series of questions regarding the value of the training for learning certain skill sets and for applying the knowledge gained to their work performance. From these questions, all participants indicated that the simulation training would be useful in their jobs, and 85% (expert) and 95% (experienced and novice) thought it would be helpful for improving performance during a mine rescue exercise. In addition, most participants thought that the simulator made them more prepared for specific aspects of a mine emergency – communication, decision making and hazard recognition. When averaging the responses for all three of these questions for each level of experience, the average percentage of positive answers for the novice group was 97%, for the experienced group 90% and for the expert group 92%. Table 4 shows a breakdown of the responses given for each of the questions asked.

Discussion and conclusion

When developing simulation software that is meant to improve skills, one must determine the point of diminishing returns in terms of investing in enhancements and the level of additional learning achieved as a result of those enhancements. When modifying the Rite-EMTTM software for underground mine environments, a minimal approach was followed. The first version had just enough modifications to make it a functional training tool. The graphics were good enough to simulate basic hazards and placards were used to provide additional information, such as gas readings. For the next two versions, some improvements to the graphics occurred, but were still far less sophisticated than one would find in commercial gaming software. The major changes for these two versions required more interactive tasks associated with making decisions and introduced the presence of smoke and lighting levels similar to actual underground conditions. Analysis of the evaluation results for all three versions indicated that the graphics for Version 3 were rated higher than either Versions 1 or 2; for the overall evaluation results, Version 3 had a higher percentage of "excellent" ratings compared to the other two versions. Therefore, it appeared that the quality of the graphics did have some effect on the results or benefit of the simulation training. Also, when considering the percent-

Table 3

Number and types of teams for each experience level.

	Novice	Experienced	Expert
Coal MR teams	0	2	0
M/NM MR teams	0	6	3
Student MR teams	2	0	0
Novice UG S&R teams	6	0	0

Figure 6

Ratings for simulation graphics based on experience level.

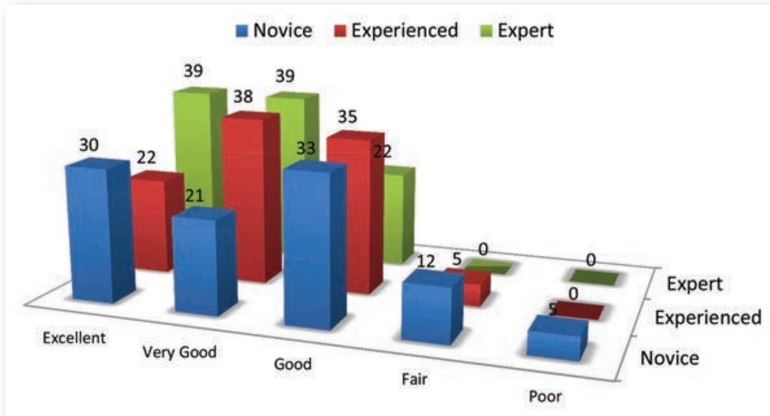


Table 4

Responses to questions regarding the value of the simulation training to learning specific skill sets and job performance based on experience level. Values are given as percentages of total number of responses for each question.

	Novice (n = 39 to 43)		Experienced (n = 42 to 48)		Expert (n = 17 to 28)	
Questions	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**
Will the training you received be useful in your job?	100%	0%	100%	0%	100%	0%
Was the simulator training helpful for improving performance during mine rescue exercises?	95%	5%	95%	5%	85%	15%
Was the simulator useful for learning how to communicate during rescue exercises?	98%	2%	100%	0%	95%	5%
Was the simulator useful for learning how to make decisions during a mine emergency?	100%	0%	89%	11%	95%	5%
Was the simulator useful for learning how to recognize hazards?	93%	7%	80%	20%	85%	15%

age of participants who thought the training had value for learning how to recognize hazards, a specific skill somewhat dependent on the quality of graphics; Version 1 had much lower percentages than either Version 2 or 3. Improving the graphics certainly appeared to lead to an improved learning experience. Because the percentages of participants reporting positive learning experiences for all three versions were relatively high, these results seem to reinforce the concept that when learning skills, the quality of graphics is less important when the objective is for the participants to experience being in a specific environment, such as an underground mine.

As previously discussed in the introduction, following the Sago and Crandall Canyon disasters, deficiencies were identified during the rescue efforts that were related to a lack of command and control (Gates et al., 2007; McAteer et al., 2006; UMWA, 2007). Despite this finding, almost all of the rescue teams participating in this training had no experience with interacting with an ICC while engaged in a rescue exercise. Their training generally included communication with a FAB, but the team was responsible for all decisions. This operational method is typical for how rescue teams function during mine rescue contests. The evaluation results obtained during this study certainly indicated that the participants thought this training was valuable in improving their performance as a mine rescue team, and in learning how to interface with an ICC. The experience level had some effect on the value of this training. A higher percentage of “novice” team members rated the training overall as excellent when compared to the “experienced” and “expert” groups. However, combining the “excellent” and “very good” ratings resulted in high percentages for both of these positive ratings for all three groups, indicating value to the “experienced” and “expert” groups as well. In addition, although the responses to questions related to the usefulness of the training regarding certain skills provided by the “experienced” and “expert” teams were slightly less than the “novice” team responses for some of these questions, all responses were at least 80% or greater.

When considering the results of this study, it is important to acknowledge the limitations associated with study design. The teams were not randomly assigned to the different versions of the simulation software, nor were they selected based on their experience level. The number of participants was not equally distributed among the groups being evaluated, and the participants were also not screened based on their experience with gaming software. For example, the team using Version 2 of the simulation software was mostly comprised of novice teams, who were much younger than the experienced/expert mine rescue team members and more likely to have used gaming software. The prior use of gaming software could have raised their expectations regarding the quality of the graphics and, subsequently, resulted in the lower ratings.

In summary, all mine rescue teams who have participated in the computer simulation training responded positively regarding the value of training. Participants said they benefitted from it because of the ease of setup, more opportunities to train and familiarization with mine rescue procedures. Trainees also reported that the simulator offered excellent communication, decision making and hazard recognition training. Most participants felt that after completing the training, they were better prepared for a mine emergency, and everyone said the training would be useful in their jobs.

Future development

Currently, the CSM Mine Safety and Health Program is continuing to work with Rite Solutions Inc. to improve the mine rescue computer simulator. Future work will focus on making the interface more user friendly for instructors and rescue team members, allowing for movement on multiple levels to enable use of mine models that have multiple levels, and making the simulation more dynamic by allowing changes in gas concentrations and varying levels of smoke intensity whenever any change in ventilation occurs. Even though we continue to enhance the capability of the simulation software, the main objective of this training is still to provide training to mine rescue teams that will focus on improving decision making and communication skills with an ICC during mine emergencies.

Note: In 2009, 2010 and 2011, the CSM Mine Safety and Health Program was awarded Brookwood Sago Grants to offer computer simulated mine rescue training that targeted decision making and communication skills using an ICC, and to support enhancements to the simulation software. During this same time period, NIOSH funding received as a cooperative agreement was also used to enhance the simulation software and to support additional training sessions. ■

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