Development of a gas monitor simulator and mine rescue contest field trials

by D.W. Alexander, S.B. Bealko, J. Holtan, L.J. McWilliams and M. Whoolery

Abstract Researchers from the U.S. Office of Mine Safety and Health Research (OMSHR) of the U.S. National Institute for Occupational Safety and Health (NIOSH) completed field trials during coal mine rescue contests using simulated gas detectors in place of placards. The gas monitor simulator (GMS) devices replaced static, paper placards to deliver gas concentration data. Eleven teams were observed during the field contest, which was approved by the Mine Safety and Health Administration (MSHA). GMS devices were given to three team members (the captain and both gasmen). Observation of teams revealed that team members changed behavior by acknowledging and sharing information more often while using the GMS. As a result of this research, it has been demonstrated that under the existing contest format, the newly developed GMS device may be used with no adverse impact on team contest performance. Furthermore, when GMS technology advantages are used, contest realism is improved. In the future, competency assessment may be incorporated.

Introduction

The gas monitor simulator (GMS) is a new tool used to simulate gas monitoring with a handheld gas detector. Many improvements were made to the hardware and software since field testing the first prototype device in 2009 (Bealko et al., 2010a). The GMS system includes wireless network routers, local communication protocol and single-purpose GMS software running on Apple iPod Touch, iPhone or iPad devices that are used as simulated, hand-held gas detectors. Each GMS detector can function as a trainer or student model. The trainer device is easily programmed with concentration data for three or four different gases, as needed for the training exercise. Hundreds of data points may be used. As a student approaches a placard, the trainer selects a gas reading on the training device, sends it through the Internet connection, and the student device displays the gas concentration. If the gas readings are above the alarm limits set by the trainer, the units give visual alarms (yellow, low alarm or red, high alarm) and audible alarms (different chime sounds). These alarms are similar to the alarms team members hear and see from their actual gas detectors.

These GMS devices are designed to assist mine rescue team members in learning about gas detection, understanding the significance of gas concentrations and encouraging subsequent decision-making actions by team members. Moreover, using this tool eliminates the static practice of using printed gas readings on a cardboard placard (placed on the ground during training or contests) and replaces it with a more realistic method of receiving gas concentration readings — a simulated hand-held gas detector.

Recent mine rescue team training events, contests and publications (Alexander et al., 2010) have highlighted the fact that training realism is important to the adequacy of team preparation for real emergencies. The 2006 Mine Safety Technology and Training Commission Report (Mine Safety Technology and Training Commission, 2006) states the following regarding mine rescue training quality, "We also find that training often is not realistic enough..." and "Many teams we spoke with emphasized the need for more rigorous and comprehensive training with respect to

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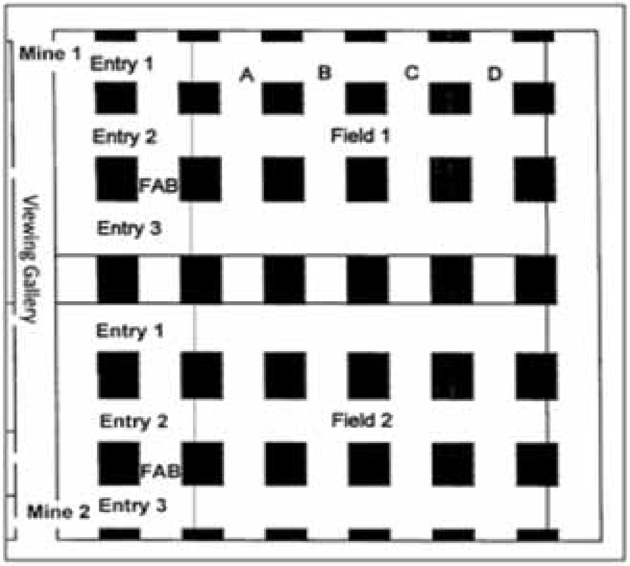
Figure 1

The two indoor mine rescue training and contest fields are located in the new mine simulation building operated by the Mine Technology and Training Center.



mine gases and the instruments used to detect them." It is important to note that mine rescue teams are required to participate in two mine rescue contests per year (in accordance with Title 30 *Code of Federal Regulations* Part 49.20) and would do so whether or not this study was being conducted.

Similar technology is used for training fire, hazmat and urban search and rescue teams (Bullex http://www.bullex-safety.com/hazmat.aspx and LightsOn Safety Solutions http://www.lightsonss.com). The technology has been proven and used successfully in other industries. Our project goal is to determine if this technology intervention is effective in a mining context. This intervention, if effective and accepted by the mining industry, has the potential to improve the competency of mine rescue teams and individual miners. There are multiple company training events, more than 10 regional training centers (Bealko et al., 2010b) and approximately 30 mine rescue contests conducted annually in the U.S. where these devices could be used (MSHA, 2010). International miner training groups have expressed interest in using the devices.

The Office of Mine Safety and Health Research (OMSHR) of NIOSH contracted with LightsOn Safety Solutions (LightsOn-SS) to further develop the GMS to provide a more realistic miner training environment (Holtan, 2010). The contract scope was to develop a miner-confined space entry and evacuation training program incorporating real-time gas detection simulation, scenarios and e-learning (Internet based) modules for student pretraining. This paper documents one activity conducted under that contract — to evaluate the GMS prototype device and software in a mine rescue contest situation.

The purpose of this activity was to increase realism in mine rescue team training and contests by introducing a wireless hands-on gas detector simulator that can replace conventional paper placards. This evaluation was designed to compare usability, acceptance and suitability across two groups of mine rescue teams; one using the paper placards and one using the GMS. We observed team actions after team members received gas readings during contests and then conducted post-contest verbal debriefings with each team. Evaluation forms were completed by members of eight of the 11 teams because three of the teams had to leave immediately following the exercise. This mine rescue team contest was run under the National Mine Rescue Rules by the Mining Technology and Training Center (MTTC), in Prosperity, PA.

Figure 2

These mine rescue team members are wearing breathing apparatuses and using a GMS device that is displaying three gases with high (red) and low (yellow) alarms.

Field trial methodology

A training research exercise was conducted on April 20 and 21, 2010 to validate the OMSHR contract with LightsOn-SS and to evaluate if mine rescue teams can and will use the GMS devices instead of the traditional method of placing paper placards on the ground or floor. Moreover, this exercise was designed to identify different actions of team members in response to receiving information from the GMS or placards. Observers noted the actions taken by team members following receipt of gas data to determine if behavior was affected by the method of delivery (GMS versus placard).

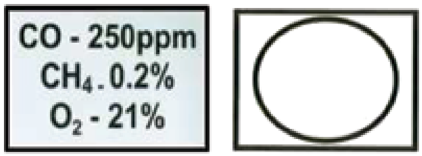
The MTTC mine rescue skills competition includes eight events; of these, the simulated mine or field exercise was used for the evaluation. This field exercise requires the team to follow the National Mine Rescue Contest Rules (approved by MSHA) and the procedures they would follow in an actual mine rescue. The team is given a "problem," which describes the mock emergency that is conducted in the aboveground simulated mine, and proceeds to carry out the "rescue" as required by the problem.

One of the major issues associated with mine rescue competitions is that there must be a clear winner. Because of this, the organizers of the competition did not wish to interrupt the teams with time delays for the purpose of research any more than absolutely necessary. Therefore, novel teaching material available via the GMS hardware was not introduced, even though the GMS system was fully used during the contest for gas readings. This provided a great opportunity to observe the reaction from mine rescue team members with regard to simulated gas readings versus placards.

Over a two-day period, 11 Division 1 (novice) and four Division 2 (experienced) mine rescue teams participated in the skills contest. The simulated underground mine was divided into two equal contest fields, so two exercises could be conducted simultaneously (Fig. 1). Each Division 1 and 2 team had the same mine rescue field competition problem. The 11 Division 1 teams were scheduled on one field with

Figure 3

Mine rescue contest placards showing typical gas readings on the left and the dummy placard to indicate gas reading location on the right.



a minimum of five teams assigned to each day's competition. This schedule allowed consistent data collection by one OMSHR researcher observing all 11 teams. Division 2 teams were not included in the GMS/placard evaluation because of a concern that their more extensive contest experience might alter team behavior in a different way than the novice teams when receiving gas readings.

Teams used the simulated gas detectors on both days. Three team members (captain and two gasmen) were trained to use the GMS gas detectors. Figure 2 shows an example of a mine rescue team member receiving a gas reading on the GMS device. The mine rescue problem required five gas readings at specified locations. Contest organizers were concerned that using the GMS for some teams would interfere with a fair contest, and that if the devices malfunctioned, the team would experience an unacceptable delay receiving the data. Therefore, dummy placards were used to note the location of where a gas reading would be provided, with the actual gas data on the underside in case of equipment failure. Use of dummy placards detracted from the potential improvement in realism when using a simulated device. In a real emergency, teams will not be warned where gas is located. Although not optimum, this methodology still allowed comparison of delivery mechanisms. Figure 3 shows examples of each of the placards used.

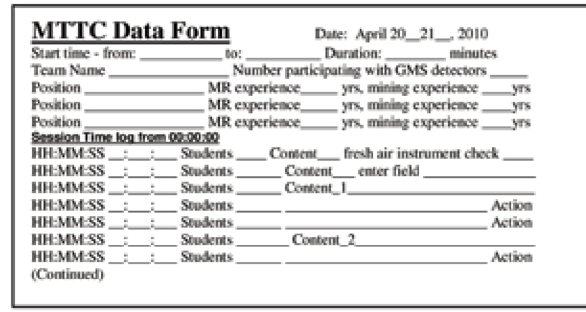
Immediately after the gas readings were received by the team members and recorded by the mapman, the OMSHR researcher recorded team actions (e.g., behaviors, sharing of information, next action, etc.). If the gas readings were above the alarm limits programmed into the GMS devices, the units gave visual and audible alarms. These alarms are similar to the alarms team members would receive from their actual gas detectors. No such warnings were provided to the teams using placards because placards are not interactive.

Teams using placards were provided the same gas readings at the same specified locations as teams using GMS devices. OMSHR researchers observed these team members' reactions to the gas placards and noted actions taken. Participants were encouraged to share their opinions regarding the gas data delivery method with researchers verbally or on the evaluation forms, but were not required to do so.

These observations served to determine if the GMS aided or impeded the teams as they progressed through the simulated mine. The evaluations recorded team members' perceptions of the exercise and whether they believed exercise realism to be improved or not. Each team was allowed 40 minutes to complete the problem. A key objective was to determine if team members changed their behavior because of the gas data delivery method used.

Figure 4

Mine rescue team data collection form.



MTTC Data Form Date: April 20__21__, 2010
Start time - from: __________ to: __________ Duration: __________ minutes
Team Name ______________ Number participating with GMS detectors _____
Position ______________ MR experience_____ yrs, mining experience ____yrs
Position ______________ MR experience_____ yrs, mining experience ____yrs
Position ______________ MR experience_____ yrs, mining experience ____yrs
Session Time log from 00:00:00
HH:MM:SS __:__:__ Students ____ Content___ fresh air instrument check ____
HH:MM:SS __:__:__ Students ______ Content___ enter field ______________
HH:MM:SS __:__:__ Students ______ Content_1____________________
HH:MM:SS __:__:__ Students ______ ______________________ Action
HH:MM:SS __:__:__ Students ______ ______________________ Action
HH:MM:SS __:__:__ Students ______ Content_2____________________
HH:MM:SS __:__:__ Students ______ ______________________ Action
(Continued)

Data analysis

Data were obtained during the MTTC PA Mine Rescue Skills Contest in three ways. First, the OMSHR researchers recorded on a paper form observations of team performance and times when gas readings were sent to compare to the GMS trainer device electronic Session Log available from the GMS software (Holtan, 2010). Second, the team members completed an evaluation form at the end of the day. Lastly, MTTC provided the contest results for analysis in the form of team scores for each skill demonstrated.

Data Set 1. The paper data collection instrument is shown in Fig. 4. It is used to record demographic information on the participant and times (in hh:mm:ss format) for team actions in the same manner as the Session Log.

Teams were observed to share more gas information between team members when using the GMS (four out of seven, or 57% of the teams, versus one out of five, or 20% of the teams) than when not using it. Placard team captains were often seen noticing the placard, relaying its existence to the mapman and passing it by without reading it. This action delegated communication of gas readings to the mapman and tail captain without the captain taking time to understand the gas concentrations. However, time was taken later to relay gas data from the mapman to the tail captain, who was anchored and could not see the placard. In the case of the GMS teams, the captain commented on the gas levels and the gasman showed the tail captain the readings on the device while other team members proceeded to explore. In all cases, the tail captain then relayed the gas information back to the briefing officer at the fresh-air base as the rules required, but no team used the gas readings to discuss their own safety during the contest. None of the teams in Division 1 or 2 finished the problem.

Teams noted placards ahead of their position and quickly directed their attention toward them as something of importance or as points of interest. Under contest conditions, teams are trained to minimize time to accomplish the exercise with the minimum deductions for rules violations. Team members apparently see the placard and know that it contains information. It is suspected that team behavior would change in contests without placards to identify locations of important data.

Data Set 2. The second set of data was obtained from the team members by requesting voluntary completion of evaluation forms at the end of the training day. Not all teams or team members chose to complete the forms. To preserve confidentiality, names were not noted on the forms; however, team position and team names were recorded.

Table 1

Mean scores and standard deviations by group.

	Group 1 Mean	Group 1 Std Dev	Group 2 Mean	Group 2 Std Dev	Group 3 Mean	Group 3 Std Dev
Q1	4.00	1.03	4.28	0.67	3.69	0.63
Q2	3.89	1.02	4.39	0.50	3.77	0.60
Q3	4.06	1.00	4.33	0.59	3.77	0.60
Q4	4.11	1.02	4.50	0.51	3.75	0.62
Q5	3.72	1.07	4.22	0.65	3.23	0.60
Q6	4.06	1.00	4.33	0.59	3.75	0.62
Q7	4.11	0.96	4.33	0.59	3.69	0.75

The evaluation form included a place for comments concerning both the gas placards and simulated gas detectors. Team members provided no comments about placards. Handwritten comments were offered by 13 of the 36 GMS participants. The comments of five participants who mentioned the GMS are reproduced below and were generally favorable. One miner reported trouble getting readings reliably. Several indicated that the GMS made them practice as if they were using a real detector.

- *I really like the detectors. They were very helpful to the team to make gas checks. Good job!*
- *Gas detector didn't always work.*
- *It's an ok system, could be improved a bit. Gas readings could come in more places and info could come a bit sooner than right over the box or placard. That would make it more realistic.*
- *Added time to receive readings added to realism.*
- *The iPod worked out very well. Strongly advise the use of them.*

The MTTC evaluation form also recorded comments on the gas detector as follows:

- *[I] like working in the smoke maze, and like the iPod for gas.*
- *The iPod detectors (T-LOC) for gas in mine maze made it a lot easier and saved time.*
- *I like the iPod*
- *Exercises were very well planned out. Stations seemed to move well. Really liked the use of the iPods in the Sim-Mine. They really made the situation more realistic. Very good day.*

A statistical analysis of the MTTC questionnaire data was performed to determine if there was a difference in perception between the use of the placards and the GMS devices. Forty-nine evaluations were usable for the analysis and were divided into three groups.

1. Team members who used the GMS (n = 18)
2. Team members who did not use the GMS but were on teams that used the devices (n = 18)
3. Team members who were not on teams using the GMS, but used placards (n = 13)

The MTTC questionnaire consisted of seven questions

Table 2

Results of Kruskal-Wallis (exact) test to compare responses among groups.

Question	Group 1 Mean Rank	Group 2 Mean Rank	Group 3 Mean Rank	Pr > Chi-Square	
Q1	25.8	29.0	18.4	0.079	
Q2	23.4	30.8	19.2	0.031	*
Q3	25.8	29.0	18.3	0.066	
Q4	24.8	29.8	16.2	0.015	*
Q5	24.8	32.2	15.3	0.002	*
Q6	25.2	28.4	17.7	0.072	
Q7	26.6	28.9	17.5	0.046	*

* Significant at $p < 0.05$

Table 3

Division 1 mine rescue exercise scores ranked from fastest to slowest with gas data delivery method.

Team	Total minutes	Device
1	138	Placard
2	153	GMS
3	157	GMS
4	157	Placard
5	161	Placard
6	168	GMS
7	175	GMS
8	180	GMS
9	185	Placard
10	220	GMS
11	241	GMS

(below) with a five-point Likert scale response: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree. Table 1 shows the average values and their standard deviations for each question. All responses are greater than neutral and many of those using the GMS are between agree and strongly agree. Because the data values only represented ordered categories, the Kruskal-Wallis test, a nonparametric (distribution-free) test for *k* independent samples, was used to compare the median scores among the three groups. This nonparametric test analyzes the ranks of a variable rather than its original values. When the data are classified into more than two groups, the test is on the one-way ANOVA statistic. When a statistically significant difference was found, then all possible two-group comparisons were conducted to examine the source of the difference (group 1 versus group 2, group 1 versus group 3, group 2 versus group 3).

The seven questions were as follows:

1. I feel more confident about taking gas readings in a real emergency after this mine rescue problem.
2. **Because of the way I received the gas concentrations today, I think I can deal with the changing gas data and take appropriate action.**
3. My ability to use the gas detector in a real emergency improved because of the practice I got today.
4. **The way we received the gas readings increased the realism of the exercise.**
5. **I would like to have more information about what the gas readings mean as I work the problem.**
6. The gas data was delivered clearly to me.
7. **The gas data related well to the problem.**

The statistical analysis was conducted using SAS v.9.2 (SAS Institute Inc., Cary, NC). Due to the limited sample size, exact nonparametric tests were computed. Results were considered statistically significant if the *p*-value of the test was < 0.05 for the three-group comparisons. To account for multiple comparisons, the p-value for the two-group tests was adjusted to < 0.02 using the Bonferroni correction, where the α level is divided by the number of comparisons (0.05/3).

The results of the Kruskal-Wallis test are presented in Table 2. Significant differences among the groups were found for questions 2, 4, 5 and 7 (**bold type** in the list above). The comparisons between group 2 (team members who did not use the GMS, but were on teams with the GMS) and group 3 (team members on teams using the placards) were all significantly different for these four questions, with the mean rank consistently higher for group 2.

Questions 1, 3 and 6 relate to the person actually taking gas readings. Since neither group 2 nor group 3 took actual or simulated gas readings, these questions would tend to show little difference in ranking. The significantly more favorable responses given by group 2 indicates that even though they did not have the GMS device, the increased discussion between members of the team that did have the GMS, as observed by the OMSHR researchers, or the improved realism (questions 4 and 7) affected their understanding of the situation. Question 2 indicates an increase in self-confidence. Question 7 suggests that use of a simulated gas detector in place of placards promoted realism. The interest expressed by the high score of question 5 by group 2 may indicate that these team members are ready to take the next step in skills training to achieve greater understanding of their situation in spite of the time demands of a contest environment, or that they would like to have more analysis and information provided by or through the device. It is interesting that group 1, who carried the GMS device, did not have a statistically and significantly different mean rank from either group 2 or group 3 for any of the questions. However, group 1 scores were higher than group 3 for all questions. This may mean that the process of reading and recording gas data occupied their time or that they may already be confident in their gas reading abilities, whereas the team members in group 2 would be expected to agree more positively that their abilities were improved by this exposure.

Data Set 3. A third set of data were obtained by totaling the B card and Map category scores from the judges' summary score sheets for each team (these categories include gas detection criteria in the mine exercise). Time discount scores were not recorded because no team finished the problem. Eleven Division 1 teams earned the scores shown in Table 3. These scores are shown in rank order from the shortest time to the longest.

The distribution of scores is not biased according to the gas reading delivery method. All the teams using GMS are not distributed evenly at either extreme of the scoring, which appears to indicate that the gas reading delivery method did not affect the skills contest results. Thus, the GMS had neither a beneficial or deleterious effect on the winning teams. However, no statistically definitive conclusion on non-randomness could be reached, due to the small sample size.

Local contest plan with GMS

Figure 5 shows a typical indoor mine rescue practice and contest field that is three entries wide and five entries deep, with coal blocks painted on the floor (Alexander et al., 2010). Similar practice fields are used for local contests when held inside or outside on larger grass areas. The GMS system can host multiple independent trainer/student groups simultaneously. Therefore, two, three or 10 teams could compete at

Figure 5

The indoor mine rescue/contest practice field at Consol Energy's Buchanan Mine training facility.

the same time using GMS devices to deliver simulated gas concentration data.

Contests could be conducted using a gas detector simulator similar to the GMS or the Bullex units. No placards for gas data would be required. The trainer would follow the team and send gas readings according to a predetermined plan to correspond to the simulated mine environment. Teams would have to decide what data to record on their maps and communicate to the fresh-air base briefing officer. The scenario could be designed to make team safety an issue. For example, knowledge of gas hazards would allow the team to solve a team safety problem and demonstrate competency. Judging could still be conducted uniformly, as long as gas sampling best practices were defined in the rules.

The GMS "instant messaging feature" allows the trainer to send text messages to mine rescue students during an exercise. The GMS Session Log records all messages. The messages may provide additional information, ask questions of one or all students, or give instructions. This allows the trainer to provide further insight into the significance of the particular gas reading or to verify that the student understands the issue when a response is requested. It was not used during the MTTC skills competition because this would have introduced differences between delivery methods and interfered with the approved contest protocol. However, in future skills training or competency "contests," the use of this feature could document student understanding of the material, provide a traceable record of student performance and allow the trainer to coach individual students or the team during the exercise, when it will have the greatest relevancy.

Summary and recommendations

NIOSH/OMSHR researchers completed field trials of coal mine rescue team contest practices using simulated gas detectors in place of placards for seven of the 11 teams observed during the contest. GMS devices were given to three team members: the captain and both gasmen. They replaced static, paper placards to deliver gas concentration data with no apparent adverse impact on the team contest performance.

As a result of this research, it has been demonstrated that, under the existing contest format, gas monitoring simulation devices may be used whenever desired by the contest organizers and approved by MSHA. According to participants, when this technology is used, contest realism is improved. Teams were observed to change behavior and share information more often while using the GMS system, which is believed to lead to better understanding of the gas hazards encountered in an emergency event and a greater awareness of team safety.

Use of the GMS-type devices to simulate the presence of hazardous gases during mine rescue team contests or training allows participants to experience a more real-life environment, which is not available without exposing them to unacceptable risk. Companies are experimenting with using gas detector simulators in training mine rescue teams, fire brigades, foremen and new miners. International training groups have expressed interest in the technology.

Further research is needed to evaluate the level of team recognition of hazardous situations and decision-making needed to protect team safety. The authors believe that the technology will be used in place of placards for a multifield, local contest in the near future. Another possible venue for the GMS is the expanding field of virtual reality miner training.

Acknowledgments

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Disclosure

The findings and conclusions in this report are those of the author(s) and do not necessarily represent the views of the National Institute for Occupational Safety and Health (NIOSH). Mention of any company or product does not constitute endorsement by NIOSH. In addition, citations to Web sites external to NIOSH do not constitute NIOSH endorsement of the sponsoring organizations or their programs or products. Furthermore, NIOSH is not responsible for the content of these Web sites. All Web addresses referenced in this document were accessible as of the publication date.

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