New simulated gas detector offers realistic training for mine rescue teams

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ABSTRACT: The United States is trending away from traditional mine rescue contest training toward hands-on skills training that focuses on being better prepared for an actual mine emergency response. New technologies and engaging training exercises are providing more realistic experiences to mine rescue teams. The National Institute for Occupational Safety and Health (NIOSH), in partnership with LightsOn Safety Solutions (LightsOn SS), has just completed the first phase of a research investigation of a multi-gas simulated gas monitor system (GMS). This endeavor is designed to add a higher level of realism during mine rescue contests and training exercises. The GMS is a wireless simulation tool utilizing a personal computer, wireless local area network, and simulated gas detectors. It is designed to assist mine rescue team members to learn about gas detection, understand the significance of gas concentrations, and encourage subsequent decision-making actions by team members. Moreover, it 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 using a simulated hand-held gas detector. In 2009, NIOSH tested the LightsOn SS GMS technology with twenty-three mine rescue teams during two separate field trials. The first was during mine rescue training in the presence of dense theatrical fog that simulated smoke. The second integrated the GMS into a mine rescue contest held in a simulated mine. The research objective was to determine if the GMS technology could be used by mine rescue teams instead of placards, whether the teams would accept the new device, and if its functionality was suitable, reliable, and practical. This paper provides a brief history of the development and testing of the GMS, a description of the GMS functions for this initial phase, and the plans for the next phase of research.

1 Introduction

The mining industry goal has always been to reduce the number of emergency crisis situations to zero. Until this goal is accomplished, mine rescue teams will continue to be relied upon to save the lives of fellow miners. Situations requiring rescue teams are low-probability, high-consequence events in which mine rescue team members accept some personal risk. Therefore, it is most appropriate that mine rescue teams are fully equipped with state-of-the-art technology and receive the best training possible.

Appeals for mine rescue training improvements have been expressed over the past few years. Several sources identified that training would be more effective and engaging if it was more realistic and would better prepare all teams if this training was available to all teams (Alexander *et al.*, 2010; Bealko *et al.*, 2009; MST&TC, 2006). The most recent National Institute for Occupational Safety and Health (NIOSH) Information Circular "Research Report on Strategies for Escape and Rescue from Underground Coal Mines" (Alexander *et al.*, 2010) recommends that mine rescue contests and national rules be revised to emphasize realistic conditions expected during an emergency event and that mine rescue contests be held in simulated or underground coal mines instead of grassy fields and gymnasiums. The report also calls for the creation of U.S. regional mine rescue training facilities, utilizing simulated or real underground mines, so that hands-on emergency response training can be offered to all teams. Finally, NIOSH researchers recommend that in addition to using engaging and realistic training methods, the trainers' and miners' proficiency be assessed and mentoring be offered to meet minimum standards.

International mine rescue organizations fully support realistic training for emergency response preparedness. South Africa, Australia, China, India, United Kingdom, Germany and Eastern Europe (Russia, Poland, and the Ukraine) utilize numerous centralized and highly-specialized training centers that provide all mine rescue teams with physical, and sometimes rigorous, hands-on training in mines or simulated real-life environments (Bealko *et al.*, 2009). More evidence supporting increased realism is found in the 2008 Mine Rescue Teams Final Rule (CFR 49.11) where annual smoke training has been made mandatory (MSHA, 2008).

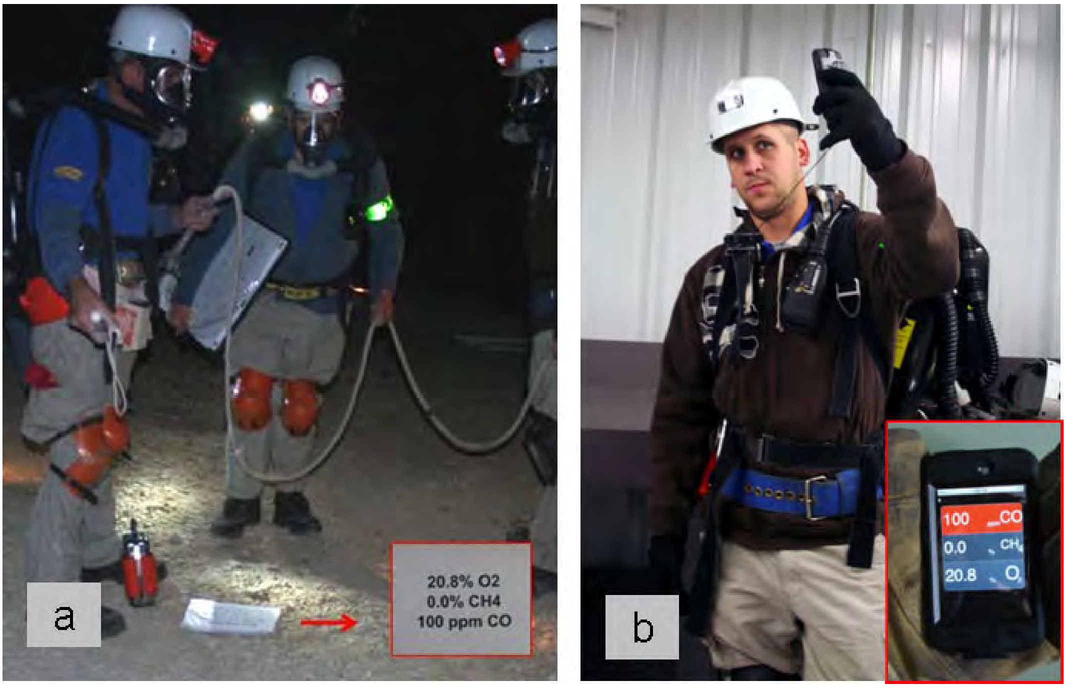

Figure 1 Placard-style gas reading (a) versus GMS-style gas reading (b).

The 2006 Mine Safety Technology and Training Commission (MST&TC, 2006) report states the following regarding mine rescue training quality: "We also find that training often is not realistic enough. Since events are rare, replicating the conditions and stress of a real event in a training environment is essential." This report proceeds to identify the need for federal and state partnerships for teams to have more realistic training experiences. It also recommends improved auditing of how well miners retain their training knowledge, skills and abilities. The most successful training is performance-oriented and competency-based. Gas detection, testing, and interpretation training needs to be strengthened. The MST&TC report states, "Many teams we spoke with emphasized the need for more rigorous and comprehensive training with respect to mine gases and the instruments used to detect them (MST&TC, 2006)." This paper discusses mine rescue contest and training results using a new device that has been demonstrated to simulate the operation of commercial gas detectors without using hazardous or toxic gases. NIOSH, in partnership with LightsOn Safety Solutions[1] (LightsOn SS *http://www.lightsonss.com/*) has just completed the first phase of an investigation of a simulated gas monitoring system (GMS) which has the capability of receiving multiple gas readings. It is a training aid that can serve the entire mining industry and be integrated into educational programs at any of the U.S. mine rescue training facilities that utilize simulated mines or contest fields. The GMS is a substitute for the convenient but archaic practice of writing gas readings on a cardboard placard and placing them on the ground during training and mine rescue contests (Figure 1a). Gas placards are limited to providing two pre-determined readings (one on each side of the placard) and their locations remain static during contests and training exercises. These placards are difficult to recognize in simulated smoke exercises and some mine rescue teams miss them altogether in very dense smoke. Most of all, gas placards don't look, sound, or feel like real-life hand-held gas detectors and encourage developing unsound practices in training that may carry over into real emergencies. The one advantage of using placards is that they eliminate the potential for human error in relaying gas readings as long as the placards can be seen and are properly positioned throughout the exercise.

The GMS offers teams a new device that provides the same information as a placard, but takes on more of the shape, sound, and function of a real portable gas detector (Figure 1b). GMS gas readings can be used in a more dynamic fashion allowing any combination of gas readings to be sent at any time during a training exercise. Current manufacturers of portable gas detectors do not offer simulation functionality on their gas detection devices.

[1] Mention of any company or product does not constitute endorsement by the National Institute for Occupational Safety and Health (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.

Thus, the GMS would provide mine rescue team members the chance to experience detector-initiated alarms as hazardous concentrations of gases are displayed while training in a safe atmosphere. Teams can also realistically experience a continuously-changing gaseous environment and better learn how to make sound split-second decisions in response to the gas readings. This system can also be used during smoke training where there is a near zero-visibility environment.

In addition to providing a dynamic electronic placard, the GMS can relay instant messages to teams as an in-the-field teaching supplement. This unique GMS function can be used to question understanding, require feedback, or reinforce a teams' knowledge about mine gas concentrations, mine rescue regulations and standards, and/or gas detection techniques as part of a field exercise.

The LightsOn SS GMS patent-pending technology was developed with NIOSH assistance and collaboration. This paper describes how the GMS concept for emergency responder training evolved and how the technology was integrated into mine rescue training. It describes the outcomes of two field trials using the GMS technology and offers insight into the opportunities to improve the delivery of quality gas detector training and contest content.

2 Gas Monitoring System (GMS)

The GMS is based on a computer simulation for gas detection. The instructor kit includes the following components:

- a heavy-duty instructor laptop including a control panel and gas concentration database,
- the GMS software,
- a wireless network and router(s),
- multiple gas detector devices, and
- a hard-bodied case that holds all the components of the GMS.

The original GMS prototype was run on a Microsoft Windows operating system and the simulated gas detector was based on a consumer Personal Data Assistant (PDA) device in a protective case. The current GMS, used in the second field trial, uses a combination of Microsoft and Apple operating systems and hardware. Each gas detector operates on a fully-functional iPod Touch® while the control panel uses the Microsoft platform.

The GMS gas detectors can display up to six different gases. However, only three gases methane (CH_4), carbon monoxide (CO), and oxygen (O_2) were selected for the mine rescue training exercises. The graphic displays on the detector can be designed to look similar to the display on any industrial or mining gas meter with the manufacturer's permission. The hand-held detector has audio and visual alarms which emulates a real portable gas monitor device and gives the trainee a sense of how a portable gas monitor operates in the field under emergency situations. A vibration alarm feature could be an option if desired.

The instructor controls the training session via a PC laptop control panel that wirelessly communicates to the gas detector device. As seen in Figure 2, the instructor enters gas concentrations for a specific location into the laptop (Step 1), sends the readings to the GMS device by means of a wireless local area network (LAN) (Step 2), and then the trainee (student) receives and reads the gas reading from the detector (Step 3). This process mimics actual gas detectors with continuous monitoring functionality; no buttons are pushed on the GMS to generate a gas reading. The simulated gas readings appear on the screen after being initiated by the GMS operator.

The current instructor's kit (one total system) can support up to eight simulated gas detectors communicating with one laptop. However, the wireless network can handle many systems. Thus, the exercise can be expanded to handle eight, sixteen, twenty-four or more trainees as needed by adding more laptops and gas detector devices. The instructor can change the air quality levels on each trainee's device individually or all at the same time.

The instructor also has the ability to send instant text messages for display on the trainee's gas detector as a teaching instrument. These messages are expected to be shared among team members to learn and make informed decisions. For example, if a reading of 55 ppm CO is sent to the gas detector, followed by an instant message that reads "Mine rescue national rules require that an atmosphere containing more than 50 ppm of CO be treated as irrespirable," the trainee would then be expected to know that above 50 ppm CO, he must don his breathing apparatus or justify alternative action.

3 Field Trial One – April 2009

3.1 Description of Exercise for Field Trial One

The original GMS prototype developed for Field Trial One included an instructor's PC control panel, a wireless router system, and several handheld devices. The instructor's control panel was run on a durable laptop with a long battery life. The router acted as a base station for the GMS and additional wireless repeaters could be used to increase signal strength, if needed. The gas detector was a PDA running customized software and inserted inside a customized case to protect the PDAs from damage.

Field Trial One was conducted at the Academy for Mine Training and Energy Technologies at Southern West Virginia Community and Technical College (SWVCTC) in Logan, WV. The exercise was held in the basement of a warehouse that was converted into a simulated coal mine. This area is divided by plywood interior walls for coal pillars. The mine layout is 3 entries wide by 4 crosscuts deep and had an average height of 1.52 m (60"). It is equipped with stoppings, mandoors, a hoist/elevator, mine fan, cribs, belt lines, and a working refuge chamber to create a nearly realistic mining environment. The entire building had both wireless and hard-wired communication systems. During the training exercise, the mine was filled with dense, non-toxic theatrical fog to simulate smoke

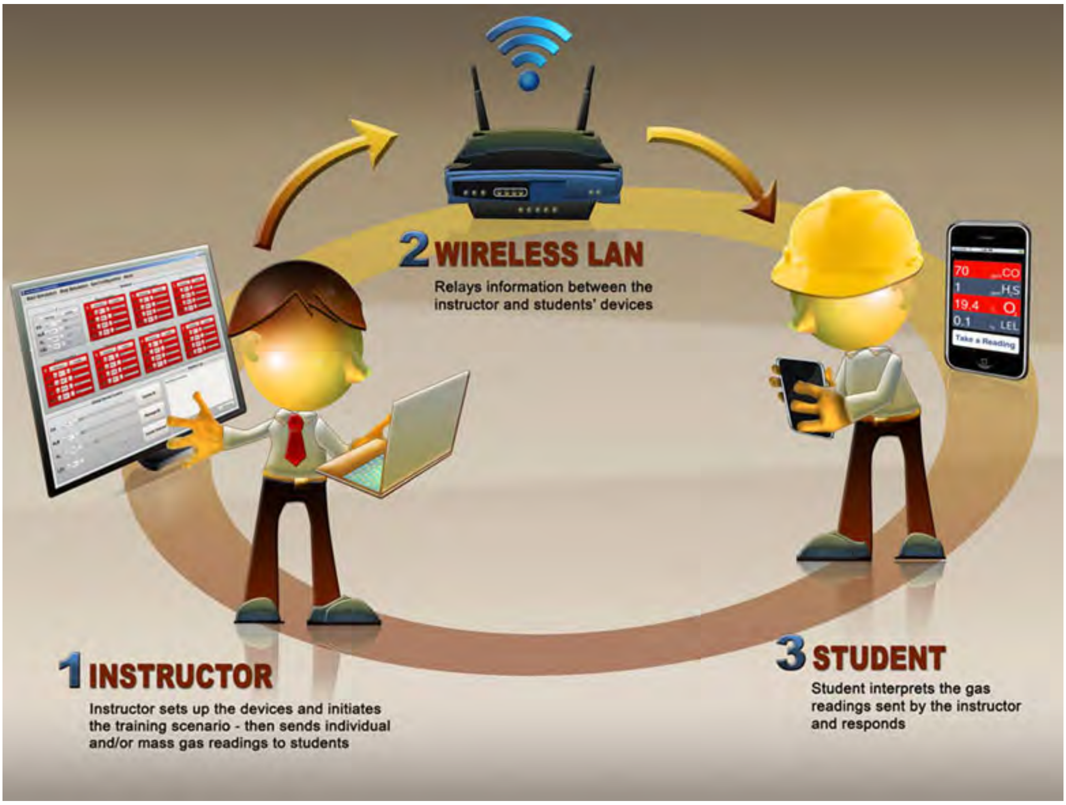

Figure 2 GMS process with instructor, wireless LAN, and student.

making it very difficult to see anything more than 0.3 m (12") away. The mine rescue exercises were not timed events and lasted between three to four hours. In all, nine days were required to train seventeen different teams. The research objective was to determine if the GMS technology could be used by mine rescue teams instead of placards, whether the teams would accept the new device, and if its functionality was suitable, reliable, and practical.

The purpose of the GMS was to provide gas concentration readings by utilizing the simulated gas detectors and not the typical printed cardboard gas placards. The gas man from each team was asked to attach the simulated gas meter to his/her person at chest level by means of a clip and retractor device. The retractor system allowed the gas man to take simulated gas readings near the roof, at chest level, and near the floor without losing the device in the fog if it was dropped. The emergency drill was designed so that as many as eight different, pre-determined gas readings would be supplied to the gas man in lieu of the placards as he reached specific locations. The gas man was expected to share these readings with the team, at which time the captain, team, and/or command center would make decisions based on that information. Instant messages were to be utilized in conjunction with the gas readings during the exercises.

Preparation started by installing the GMS in the basement and testing the device operating characteristics. The most practical way to operate the GMS was to utilize two persons. One person with the laptop (representative from LightsOn SS) was located in a central room in the basement and the second person (a NIOSH researcher) followed the teams to identify their location and relay that information back to the laptop operator. Because visibility was limited, a thermal imaging camera was utilized by the second person. When a team arrived at pre-determined locations, the person with the team contacted the operator of the laptop via radio to initiate transmission of a new gas reading. This routine continued until the completion of the exercise.

3.2 Discussion and Findings from Field Trial One

Over the nine-day training period, a number of members from each mine rescue team were able to use the GMS to receive gas readings during the exercise and did not have to use gas placards. However, the system was not fully utilized as originally intended because of system and operational problems causing some delays and disruption to the mine rescue exercises. Challenges included the existence of competing wireless signals and frequent communication drop-outs with the laptop, the inability to automatically reconnect, highly-variable time periods between sending a reading from the laptop to receipt at the gas detector, the inability to send multiple gas readings simultaneously (only one gas concentration could be sent at a time), and unintentional GMS gas detector alarms. Therefore, the GMS gas detectors were not able to be attached to the gas man, but rather were handed to him by a NIOSH researcher when it was time to take a gas reading at a designated location. The detector was then returned to the researcher until it was time for the next gas reading and so forth throughout all of the exercises. In spite of the functional problems encountered, mine rescue team members endorsed the concept and accepted the GMS as a substitute for placards.

NIOSH researchers identified thirteen enhancements, mostly software or system changes, that were necessary for the gas detector system to operate satisfactorily and minimize wireless communication problems. A research and development plan to incorporate these recommendations was created and funding was provided by NIOSH for an improved GMS.

4 Field Trial Two – October 2009

4.1 Description of Exercise for Field Trial Two

The operating system for Field Trial Two remained the same as the first except for a change in the electronic device for the GMS gas detector and the communication protocol. An iPod Touch device was used instead of a PDA. In addition, software enhancements were added to incorporate the thirteen NIOSH-recommended changes into the GMS.

The second field trial was conducted in a simulated mine at the Mine Technology and Training Center (MTTC) located at Ruff Creek, PA. The mine area is constructed inside a 3,700 m^2 (40,000 ft^2) metal building, with plywood interior walls supported on steel studs for coal pillars. The mine layout is slightly larger than used during field trial one; it utilizes 5 entries with 6 crosscuts with an average height of 2.13 m (84") and is designed to replicate an underground coal mining environment. The building has only hard-wired communication systems. Theatrical fog was not used. However, the mine rescue exercises were timed events as part of a mine rescue contest and had a maximum duration of three hours.

As in Field Trial One, the gas man attached the simulated gas meter to his/her person at chest level by means of a clip and retractor device. The contest was designed so that thirteen, pre-determined gas readings were sent to the gas man at specific locations. The gas man was expected to share these readings with the team and then the captain, team, and/or command center would make decisions based on that information. The research objective again was to evaluate viability of the technology and determine if the GMS could be integrated into mine rescue contests without a long learning curve, disruptions, or distractions. Six teams competed over three days.

On the eve of the MTTC training, the GMS system was installed and tested as in Field Trial One. At first, two people were needed to operate the GMS. More numerous and rapid gas readings had to be sent compared to the Field Trial One which required one researcher to identify the team location on the mine the map and provide the appropriate gas readings to the second person who then operated the laptop. The two operators kept in close proximity to the team. After operators became more proficient, only one person was needed to operate the GMS throughout the exercise.

4.2 Discussions and Finding from Field Trial Two

The second GMS prototype as used in Field Trial Two was more user-friendly when compared to that used in Field Trial One. On each of the three days, twenty-six gas readings (13 per exercise) were sent using the GMS. The gas man received the gas readings and the system was fully utilized as intended. Multiple gas readings (CO, CH_4, and O_2) were sent simultaneously and the GMS signal transmission time from the laptop to gas detector was less than one second. There were no system errors over the three days. However, four erroneous readings were sent because of human error. Instant messages, used as a coaching method, were sent at opportune times and team members acknowledged the messages and shared the specifics with each other.

Beyond implementing the GMS into the mine rescue exercise, NIOSH researchers evaluated the system to identify some features that could make the GMS more user-friendly. These recommendations will be incorporated into the next phase of research. However, the second GMS prototype functioned as a stand-alone system, the mine rescue team gas men learned to use it quickly and intuitively, the use of the device stimulated team discussions of the gas reading implications within the contest exercise, and the system performed reliably during the second field trial. One trainer group was sufficiently impressed with the realism that the GMS devices brought to the contest, that they initiated discussions to purchase a system for training in their facilities.

5 Future Work In Simulated Gas Detector Research

Research to date has demonstrated that a simulated gas detector system could replace printed gas placards in mine rescue contests and training drills, improve realism for the miners, stimulate discussions of the mine environment, and better evaluate a team's understanding of this knowledge. Anecdotal data from field trial participants revealed a preponderance of positive feedback regarding the GMS and the desire for this technology to replace gas placards altogether. The responses also show a desire for more technologies and training tools that enhance learning and realism.

A second phase is being planned to improve repeatability and automation of the coordinated gas readings that are currently manually controlled. The research objectives for this work would expand upon the

GMS messaging functions to make it more interactive, offer training validation, have tracking ability, and be able to operate automatically during exercises without operator assistance. In-the-field testing will be offered to evaluate trainee's knowledge of various gas detection subjects. The ability to record the trainee's identity, training date, and starting/ending times will also be incorporated. Multiple-choice tests will be developed in which trainees respond by selecting an answer that is recorded into the GMS database. Subsequent field tests can be given to evaluate student comprehension changes. Printed reports of the training activities and test results can be used to assess and track the trainee's level of knowledge and understanding.

Future efforts would examine how tracking and locating devices could be incorporated into the GMS system. For example, RFID tags or pseudo GPS markers could be used to notify the GMS when teams are positioned in a specific location. This tracking feature could trigger the GMS to automatically send a gas reading when teams arrive at specified locations and record their locations on a map (which is pre-programmed into the GMS). In the application for mine rescue contests, this feature would ensure that every exercise is reproducible so that each team has the same experience without the potential for human error when timing and transmitting gas readings. It would also eliminate the issue of determining team locations in the poor visibility encountered during simulated smoke training exercises.

6 Conclusions

NIOSH evaluated two versions of the simulated gas detector during separate field trials with mine rescue teams during training and contest situations that showed a progression in technology and practicality. Results from the second field trial demonstrated improvements with the GMS over the original prototype technology used in the first field trial, especially in regards to wireless and connectivity issues. The GMS was successfully incorporated into the mine rescue exercises as planned with very few problems encountered. Over a three day period, there were seventy-four out of seventy-eight successful gas readings sent to the GMS gas detectors. The GMS instant messaging feature was used to offer additional learning opportunities to the teams.

Right now, the GMS is an available training tool that provides more realism and engagement to mine rescue team members than the practice of using cardboard placards. In response to feedback from GMS users and mine rescue trainers, research that will offer advanced teaching tools and introduce tracking and automation features is being considered.

Acknowledgement

The first and second field trials would not have been possible without the cooperation of the staff and mine rescue team members from Academy for Mine Training and Energy Technologies at the Southern West Virginia Community and Technical College, Mine Technology and Training Center, Mine Safety and Health Administration, CONSOL Energy Inc., Pennsylvania State mine rescue, and mining companies that form the Pennsylvania state mine rescue teams.

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