Evaluation and Design of Atmospheric Monitoring Interfaces and Approaches for Improved Health and Safety in Underground Coal Mines

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Dissertation submitted to the faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

Doctor of Philosophy
In
Mining Engineering

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May 7th, 2018
Blacksburg, Virginia

Keywords: underground mining, ventilation, interface, atmospheric monitoring, AMS

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ABSTRACT

A majority of underground coal mine disasters in the United States are due to explosions. Current atmospheric monitoring system (AMS) practices in the US could be enhanced to facilitate data sharing and learning of the entire work force. With the inclusion of additional atmospheric monitoring and data collecting, meaningful analysis can be realized and shared with the workforce. AMS data can be utilized to advance the understanding of underground atmospheres for the entire workforce along with adding to the knowledge base for preventative planning. An AMS interface ADAMAS is suggested to facilitate this conglomeration and sharing of the data visually, so that it can be quickly processed and applied in their daily decisions.

An emerging sensor technology for underground mining, fiber optics is explored and tested in emergency, or fire and explosion situations. The fiber optic methane sensor performed well in smoke only showing a slow in response time due to soot on the filter.

The ADAMAS interface was tested in a large population of underground coal miners. The population varied in age, job, classification, and experience. They all primarily found it to be easy to use and helpful to them. Concerns arose when asked how this will facilitate an improved relationship with regulatory agencies. There is trepidation when it comes to additional atmospheric information sharing, that it may not be used advance understanding of mine atmospheres, but to unfairly enforce. The AMS data collected is individual to each mine site but can assist in the understanding of underground atmosphere as a whole. Moving forward, regulatory bodies should use this as a stepping point to consider how this information can be used to advance the field of mine ventilation and also the health and safety of the miner.

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GENERAL AUDIENCE ABSTRACT

Many accidents in underground coal mines in the United States are due to explosions. Explosions occur when there is a spark created in an atmosphere that contains an explosive mixture of methane and oxygen. Current monitoring in the United States standardly follows what regulators stipulate. It is suggested and tested that we use additional atmospheric monitors, including fiber optic technology, to monitor the atmosphere, trend the data and share it with the mining workforce.

Shown is current trends for atmospheric monitoring systems (AMS) and out suggestion for increased monitoring and using an interface called ADAMAS for trending and sharing data visually in graphs and locations on maps. A novel sensing technology a fiber optic methane sensor was also tested in smoke conditions for its applicability in underground mines during an emergency. Both the interface and the fiber optic sensor were successful in testing. Miners found the interface easy to use and informative. The fiber optic sensor was successful sensing methane even in smoke environments although the response time of the sensor decreased.

ACKNOWLEDGEMENTS

I would like to dedicate my research, and the research I continue to do to all the miners who have lost their lives throughout the world. But also to the millions of miners who are currently working in coal mines, I work and continue to work to make your workplace a safer and healthier place. I will continue to strive to do what I can to achieve ZERO fatalities – Everyone should be able to go to work, make a living and go home unharmed to their families.

I would like to thank my family, which has grown during this process and slowed it down a bit. The support and understanding that both Will and Eleanor have had with me has been wonderful. Through this process I have changed and grown, I am very much looking forward to the time where this journey is complete and a new one focusing more on my family can begin. Thank you also to my friends, both new and old, who have been my cheering squad and support throughout. I am so fortunate to have too many friends to name, I am truly a very rich person.

I would like to thank the NIOSH Long Term Training program, and the support of Dr. Jeffrey Kohler, which made this experience possible. I never imagined the personal growth, friendships, struggles, triumphs, successes, and happiness that I would find during this time. I know that my experiences in this program have made me a better researcher. Thank you Lisa Stiner, for your advice and support throughout this expierence, I hope I get to work with more people like you in my career.

I sincerely thank my committee, Dr. Zach Agioutantis, Dr. Michael Karmis, Dr. Kray Luxbacher, Dr. Nino Ripepi, and Dr. Steven Schafrik. Each member has contributed to my research and my experience. A special thanks goes to Dr. Zach Agioutantis, for providing extra assistance and expertise using his advanced abilities to contribute to my research. And an extra special thank you goes to Dr. Kray Luxbacher, thank you for your guidance, constructive feedback, support, friendship, understanding, coffee breaks, lunches, dinners, get togethers, always having an open door, and mostly your integrity. I have learned so much from you and your example, I am very proud to have the opportunity to work with you. I look forward to working with you as my career progresses. I would also like to thank the rest of the facility and staff in the Virginia Tech Mining and Minerals Engineering Department for sharing their knowledge and experience, help, friendship, and advice along the way.

I would like to thank my collaborators on this work, including Dr. Zach Agioutantis (Mining Engineering Foundation Professor, Mining Engineering, University of Kentucky); Mr. Thomas Dubaniewicz (Lead General Engineer, NIOSH Mining); Dr. Michael Karmis (Stonie Barker Professor, Director Virginia Center for Coal & Energy Research, Mining and Minerals Engineering, Virginia Tech); Dr. MingMing Li; Dr. Kary Luxbacher (Professor, Mining and Minerals Engineering, Virginia Tech); Dr. Nino Ripepi (Assistant Professor, Mining and Minerals Engineering, Virginia Tech); and Dr. Steven Schafrik (Associate Professor, Mining Engineering, University of Kentucky). Their specific contributions are acknowledged at the end of each chapter.

I thank Morgan Massey for having the foresight and providing funding and support to help increase safety and health of all coal miners by preventing future accidents. Mr. Massey's steadfast belief in coal miners' safety and health makes him a true pioneer in the industry. I would also like to thank all the coal miners, engineers, and safety personnel that helped me during my field work, particularly the entire workforce of Cumberland Mine and Jackie Saccamano. Jackie allowed me to come in, teach a part of her training, and test the interface with the entire workforce.

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1. CHAPTER 1: INTRODUCTION TO THE STUDY

A recent major fatal mining incident in the United States have fuelled a push for increase change in safety practices and legislation, and have underscored the need for innovative approaches to atmospheric monitoring, data analysis, and data communication. One of the most recent mining tragedies was at the Upper Big Branch Mine (UBB) in Raleigh County West Virginia, where a methane and coal dust explosion occurred on April 5, 2010, which killed 29 miners. When surveying the data of mine disasters in the United States reported by MSHA, the majority of underground coal mine deaths (of >5 people) is by explosion (MSHA 2014). The UBB tragedy continues to have an impact on improved mine safety, health, and training.

Current practices of monitoring in coal mines in the United States concentrate on auditory and visual alarms and written documentation of any out of range or alarm occurrences. Currently, many mines are equipped with atmospheric monitoring systems (AMS), but they are commonly limited to carbon monoxide (CO) in beltline entries. Monitoring of other typical underground gasses like methane and oxygen are done by sensors installed on mining equipment or hand held sensors carried by individual miners. Recent progression in the sophistication of monitoring and computer technologies has influenced improved automated atmospheric monitoring equipment. Additional monitoring creates large databases of information that need to be processed and conveyed to the miner to be the most effective. Finding a way to display and interact with this data in a meaningful way is important to successfully create a safer and more educated workforce.

Many enhanced safety practices can be implemented using automated atmospheric monitoring. For example, currently in inactive areas of the mine, which are inspected weekly, examiners enter these areas with their hand held sensors, and previous week's readings, leaving people relatively unprepared for what changes may have occurred in the atmosphere or surrounds. Additional automated atmospheric monitoring would allow these inspections to be done knowing the atmosphere they are entering and having a better awareness of the surroundings.

By monitoring in key areas of the mine, data can be interpreted to allow for better understanding of the possibility of unusual incidences occurring. Trending of data and identifying key factors like weather, mining activity, under or over mining, and exposed rib can be helpful to identifying key natural or operational trends and flagging abnormal or irregular conditions which could signal development of dangerous atmospheres.

Within underground coal mining it is stipulated that monitors placed in hazardous areas such as returns, bleeder systems or active mining sections be permissible. To be approved as permissible, the device must be tested and meet all the requirements, restrictions, exceptions, limitations and conditions set by the federal Mine Safety and Health Administration. The approval process may be lengthy and costly, leaving many manufactures to not enhance existing approved devices, or not to pursue approval of appropriate devices. Presently there are technologies like fiber optics that readily fall within the qualifications and requirements for permissibility.

The first objective of this project is to survey existing interfaces within the mining field. This is fulfilled by the background work detailed in Chapter 2 and published in the proceedings of the International Mine Ventilation Congress (IMVC) in August of 2014. The second objective is to research, create, and evaluate a prototype atmospheric monitoring interface. Expanded atmospheric monitoring creates data that can be transformed into an intuitive interactive interface for miners with dynamic information to assist in the understanding of how the atmosphere is changing in the mine prior to entering or during the shift. This work is accomplished in Chapters 3 and 5. The third objective of this project is to asses and verify new fiber optic sensing technology in an accident situation in an underground atmosphere, which will be accomplished in Chapter 4. The final objective will be laid out in Chapter 6, where an analysis of the collected atmospheric data will take place. Showing critical trends in collected data, along with supplementary data collected from other sources, e.g., weather station or mining reports to miners and attaining their feedback. Ultimately, this work aims to provide real time information to miners and technical personnel in a meaningful and intuitive way, such that more educated and informed decisions can be made.

Major contributions of this work will be the advancement in information gathering and sharing, and training of the work force and industry as a whole, and creating a safer and healthier work force. With advancement in the collection and analysis of atmospheric data there will be progress to the understanding of how underground atmospheres change. Great strides can be made in having a greater ability to anticipate, forecast, and mediate possible hazardous conditions prior to their development.

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The following paper was presented at the 10th International Mine Ventilation Congress, August 2-8th 2014 in Sun City South Africa and is included in the meeting preprints. Heather Dougherty conducted the literature review and wrote the paper with technical and editorial input from coauthors: Dr. K Luxbacher, Dr. M Karmis and Dr. Z Agioutantis. Please cite the article as Dougherty H.N., Luxbacher, K, Agioutantis Z, (2014). Approaches to communication of mine atmospheric monitoring data. 2014 IMVC. Sun City, South Africa. p267-273

2 CHAPTER 2: APPROACHES TO COMMUNICATION OF MINE ATMOSPHERIC MONITORING DATA, LITERATURE REVIEW

In the United States, continuous atmospheric monitoring of gassy, underground coal mines has yet to be fully implemented in a meaningful and accessible manner. Many mining operations do not provide a continual or continuous means by which ventilation parameters including gasses like methane, oxygen, and CO can be measured and recorded. Subsequently, these measurements could be used to determine trends and instances of changing atmospheric conditions that indicate the presence of potential ventilation hazards. Additionally, existing mine interfaces are simplistic, out of date and do not have the capabilities to convey important atmospheric information to the miner. Recent and emerging technologies including interactive applications, touch screen, etc., offer the possibility for improved mine interface systems. This research identifies the need for the integration of atmospheric monitoring systems with more accessible, user-friendly interfaces. Mining software and equipment interfaces that are currently in use will be investigated, along with human factors influencing visual data interaction. Potential computer science and industrial engineering contributions will be examined to develop new ways for the mine operator to proficiently view, interpret, and apply collected information towards a safe and productive mine.

2.1 *Introduction*

There have been a series of high profile mine disasters in developed countries over the past decade where the key component was unsafe mine atmospheric conditions. The Upper Big Branch explosion in the US and the Pike River explosion in New Zealand, in particular, demonstrate the need for improved monitoring and control of the mine atmosphere. To accomplish this aim, research into real time monitoring and data analysis of underground coal mines is vital. In order to utilize these real time monitoring systems, rapid data analysis and communication via robust user interfaces is critical.

In the United States, current atmospheric monitoring in coal mines consists primarily of audio and visual alarms on equipment and in belt entries as stipulated by law (CFR 2011)(30 CFR § 75.351), and minimal application of criteria is typical. Generally, it is with these alarms at the stipulated threshold limit values (TLVs) that remediation of dangerous gas concentrations is initiated. Additional monitoring is also required by individual personal sensing devices and regular examinations (30 CFR § 75.361 & 362). Collection and trending of this data is not explicitly required and not typically found in the United States. Furthermore, these data are only available to the miners that are interacting with the referenced equipment, or to a person on the surface observing the data, and not usually communicated to workers in real time or near time, rather they may be passed by word of mouth, or written reports that may not be consistent.

Jim Walter Resources in Alabama (Armstrong and McNider 1985) started experimenting with monitoring in the late 1970's when the need arose to use belt air to ventilate the working faces. Low level carbon monoxide (CO) sensors were installed along the beltlines with communications to a central location, generally outside of the mine. This CO system was installed to monitor belt air ventilating the face areas which then evolved to a larger monitoring system for both CO and belt power systems. Currently, US law requires that belt entries must be monitored by an atmospheric monitoring system (AMS) monitoring CO and smoke, other areas that may, but do not require monitoring are various underground electrical installations. Beyond these areas real time monitoring of methane (CH_4) at cutting equipment is required, but other fixed monitoring of the mine is not explicitly required, although some mines may have more stringent plans.

Australian regulations require mandatory implementation of AMS including the Gas Monitoring Systems (GMS) that are part of the Trigger Action Response Plan (TARP) and Explosion Risk Zones (ERZ). GMS are installed to detect methane, carbon monoxide, carbon dioxide, and oxygen and calculate trends using the Coward diagram. The TARP is established on a per mine basis and has approximately four trigger levels, but can also be configured for more complex conditions. In the place of prescribed values for air quantities at defined areas as is the case in the US, Australia guides mines to determine the safest course of action for their mines within thresholds and each mine designs their own safety mandates that they are held accountable for (Goertz, Brune et al. 2013).

South African coal mining regulations implement a Code of Practice (COP) similar to the plans in Australia, which are predominantly based on risk assessment. Guidelines provide minimal stipulated regulation and do not specify detailed procedures but dictate that safety hazards must be addressed in the site specific COP. In Germany and most EU mines it is required in all face areas that air quality will be recorded including CH_4, O_2, CO, CO_2, and H_2S (Goertz, Brune et al. 2013).

While optimization of atmospheric monitoring sensor placement can allow for gains in safety and efficiency (Griffin 2013) the improved communication of data can substantially enhance the value of real time monitoring systems in mines. Real time monitoring systems are measuring and accumulate large data sets which can be difficult to analyze in a meaningful way, particularly in real time or near real time. Management and analyses of these data, along with the development of improved interfaces for a range of stakeholder groups is critical to utilization of existing and improved monitoring systems.

2.2 *Human Computer Interaction in Mining*

While successful implementation of real time monitoring is dependent on physical installation, data management and analyses, timely and efficient communication of conditions to workers is just as essential. Application of successful human computer interaction techniques, and assessment of applicability and best practice in mining conditions is crucial to accomplishing this communication.

2.2.1 *Basic Principles*

Human computer interaction is a field pioneered in the 1960s, with development of the mouse, text editing, tiled windows, and manipulation of graphical objects (Myers 1998), all of which are pervasive in computing today. While the mining industry has certainly applied these basic techniques in computing to business, control, and communication systems, the rugged and specialized nature of the industry, as well as the relatively small market have resulted in fairly limited applications of higher level human computer interaction.

The field of human computer interaction is well studied, and yields many recent and thorough sources for background and introductory information (Smith-Atakan 2006, Rogers, Sharp et al. 2011, Beidler 2013). The thrust of the work detailed here is the communication of atmospheric data from multiple locations in an underground mine by visual means, as visual communication of data is the most practical for underground mine workers; tactile and auditory communication may also have specific applications, but visual communication is likely to have the widest applicability.

While human computer interaction research has been fairly limited in the mining industry there are several specific applications which have significantly advanced the work, including proximity detection (Jobes, Carr et al. 2012); virtual reality applications, primarily for training purposes (Mallett and Unger 2007); ventilation on demand (Bartsch, Laine et al. 2010), and robotics applications

2.3 *Advanced Interfaces in Mining*

Proximity detection systems were employed in the mining industry to prevent accidents involving people and moving equipment, with the basic premise that by measuring a person's proximity to a machine, warning systems can be implemented to warn the user they are in a high risk area, and ultimately a machine can be deenergized when a person's proximity reaches a certain level. The interfaces developed for these systems are varied, from relatively simple, including an auditory and/or visual alarm just before equipment is deenergized to far more advanced interfaces. In one case, a fairly advanced interface inside an operator's cab monitoring several pieces of moving equipment is evaluated and suggestions for improvement detailed, including the utilization of more graphical interface that utilizes spatial movement of vehicles (Cooke and Horberry 2011). Additionally, intelligent proximity detection developments are detailed in the literature which include situational allowances, depending on the tasks that the operator and machine are currently performing (Jobes, Carr et al. 2012). These situation specific algorithms have applicability to atmospheric monitoring where gas concentrations are highly dependent on production, equipment movement, and natural systems, and abnormal concentrations can be difficult to pinpoint prior to reaching TLVs.

The US implemented the MINER act of 2006 which brought about a requirement for through the earth (TTE) systems for underground tracking of miners as well as two-way wireless communication. This could be very important for search and rescue of miners during emergency situations. TTE systems have presented an opportunity for a more robust network of communication using text, voice or both for two-way communication (Yenchek, Homce et al. 2012).

Virtual reality is perhaps the most advanced computer interface currently utilized by the mining industry, and is primarily used for training applications, removing the novice from a high risk environment to learn, although other applications have been identified, including enhanced communication (Schafrik, Karmis et al. 2003). Many studies have examined the effectiveness of virtual reality as a mining training tool (Mallett and Unger 2007) and the successful experimental methods utilized should be examined for applicability to the evaluation of other user interfaces, including atmospheric monitoring interfaces. For example, prior knowledge is an important factor in a user's experience with an interface. Mallet and Unger acknowledge age is often a factor in comfort with the interface in a review of many mining virtual reality applications, most training based (Mallett and Unger 2007). In another, users of a rock bolting virtual reality training tool which assess knowledge gains as well as perception of the tool, little mention of prior knowledge was made, but the participants appear to be students, so they could be considered fairly knowledgeable users of computer interfaces (Nutakor, Apel et al. 2008). These authors did acknowledge the subjective nature of studying interfaces, making the point that quantitative and qualitative evaluation is necessary.

There are many benefits of VOD in mines, including enhanced safety and economic gains, with one study estimating cost savings of 80% (Kocsis and Hardcastle 2003), and another savings of over $3 million per year (Bartsch, Laine et al. 2010). VOD is primarily used in hard rock mines, atmospheric monitoring is significantly utilized and ventilation parameters are monitored and changed by an automated system as necessary to optimize ventilation. VOD is occasionally closely tied to computer modeling of network simulations which assist in interpretation of system data and allow for real time mine ventilation updates (Gillies, Mayes et al. 2000, Gillies, Wu et al. 2003). Various ventilation network modeling software packages are available and there use is widely accepted and practiced throughout the world for mine ventilation analysis and planning (Zhang 2012). This software can be an important tool for an engineer and uses interfaces such as line diagrams and maps to convey projected ventilation information to the user. US law generally prohibits the use of VOD in underground coal mines because of legal limitations to air changes while the mine is operating, but the progress in sensing, data analysis, and interfacing realized through VOD can be leveraged in development of better real time systems for coal mines. Typically these interfaces are based on the mine geometry and autoconfigure with advance (Bartsch, Laine et al. 2010) which allows for a topology that users are already familiar with.

Data fusion or integration can be challenging when collecting large datasets from different sources and integrating them to create a comprehensive output. The aim of data fusion is to integrate multiple records that represent the same object into a single consistent representation (Bleiholder and Naumann 2009). In mining applications, data fusion is primarily discussed in robotics applications; when examining fusion and non-visual feedback for the operator, Hainsworth (2001) described a user interface used to control a remote emergency response vehicle and highwall mining control system. Data fusion is an important aspect of both data management and analysis and communication of data via interface, because a comprehensive AMS will monitoring several different atmospheric parameters, with different units and temporal scales.

2.4 *Development of an Interface for Monitoring Coal Mine Atmospheres*

2.4.1 *Stakeholders*

US coal miners working in production are familiar with multiple monitoring systems within their mines, but rarely interact with the global system. Interaction with a single sensor or a specific cluster of sensors is more common and data are not typically aggregated in real time for the miner or supervisor’s use in decision making.

Five different levels of hierarchy within the mining business culture have been identified that would be concerned with various levels of the data that would be collected from a monitoring system. These groups are broken down into the following categories:

- Corporate Management
- Mid-Upper Management
- Engineers
- Hourly Workers and Frontline Supervisors
- Regulatory Agencies

For the purposes of this interface development hourly workers and frontline supervisors are the intended users, since they make many safety and production decisions without access to real-time data depicting the global state of the mine.

2.4.2 *Content*

Interfaces communicate the information that is collected by monitoring devices to the user; in this case, gas concentrations, airflow, and related indicators including barometric pressure and production. This type of information can be communicated through visual, audio, and haptic interaction. Currently, communication is typically accomplished through visual and auditory alarms on sensors that are mounted within the mine or are handheld. Working towards gathering ventilation data over time and communicating this to the miner, audio and haptic communication of the information is not the most feasible solution in the underground environment. Displaying these data visually will allow the miner to see the data over time and in the area that is of most concern to their daily work and be able to process it rapidly. An audio alarm is still useful when legal thresholds are encountered.

The primary goal of monitoring ventilation and atmosphere and interfacing the information is to analyze atmospheric changes to determine if they indicate heightened risk, and to provide real time information in an efficient way to people making health and safety decisions, allowing for improved safety and the resolution of high risk situations prior to escalation. Sheridan (2002) indicates that there are three things should be considered:

1. *Mechanization and integration of sensing of environmental variables*
2. *Computer data process and decision making*
3. *Information action by communication of processed information to people*

2.4.3 *Development*

Interface design is often intuitive; the developer being an expert user. However, Hegarty cautions that although initial design is often accomplished by intuition and expert opinion, scientific testing of human information processing via the interface is critical, and can identify problems and biases. She gives several examples, and also details and reviews the principles of effective graphics (Hegarty 2011). Finally, she outlines several recommendations for visual spatial displays, indicating that they should, “capitalize on emergent features,” do some of the cognitive processing for the user, and must account for the intended users knowledge of the system being referenced (Hegarty 2011)

2.5 *Experimental Design*

When developing the test interface, the main purpose is to rapidly convey pertinent information to miners in an intuitive way. Initial interface configurations will consider miners experience and current visual understanding. Anticipated user knowledge of a familiar visual in mining and training will be a mine map or schematic, as the initial background and base to convey location and proximity. This will include overlays of interactive mining maps showing familiar displays of information including entries, stoppings, pillars, and active mining sections. Using these visual applications for information transfer and users' knowledge for design, interface structures will be designed and evaluated.

Determining how to adequately communicate new information and technologies within mining and monitoring to reveal patterns in complex data is imperative. Identifying the visual cues that are optimal for allowing a user to evaluate risk in a situation is crucial to design. Relational displays, which represent entities that are not spatial, like a plot, and hybrid displays, which display relational information with an overlay of a visual or special entity, like a mine map or schematic, will be evaluated prior to and during testing. Hegarty noted in her work, that vision is used to think, or interpret; when data is mapped into visual variables, patterns are recognized which can more easily be picked up by the visual system (Hegarty 2011). Evaluation of interface design, user experience and knowledge, and interactive learning will be assessed during the design phase.

Computer algorithms and TLV values will determine immediate importance of the data to the safety and health of the miner. Filtering of data such as methane, weather, and mining data will be the default values on the screen with other options such as CO, O_2, and ventilation data available for miners to choose additional displays of data. Additional varied functions will be available for interactions like length of time, the default will most likely be the previous 8 hours, with options to view the previous 24 hours, weekly and monthly data charts interactively for the miner to choose what best fits their needs. Within these graphics, different values can be chosen to show the user standard values, TLV, and historical trending.

Multiple data tags will be collected for various gasses and ventilation information in several locations within the mine. All of the data cannot be displayed coherently and meaningfully in one interface, although all the data is important in several contexts. Kosslyn reminds us of the relevance principle in which the graphics displayed should show no more or no less information than is needed by the user (Kosslyn 2006). Determining what is important to display prominently is a necessity. Mine atmospheric data is typically collected in small increments of time from milliseconds to 1-10 seconds per sensor which can give a data output of approximately 86,400 data points per sensor, per day. Sensor banks can include 4-5 sensors collecting over half a million data points per 24 hour day. These data may have different ranges, TLV, and scales, and their management, analysis, and presentation is challenging. The research plan is to analyze current data and determine the salient data to display and include additional options if miners want to display that information interactively.

The miner, or user's experience and knowledge is important to his or her interaction with the interface and his or her ability to understand the displayed data. Information on user familiarity with computer interfaces like smart TV's, tablets, computers and smart phones will be collected and analyzed to determine the complexity of applications that can be incorporated into the interface. User understanding of the monitoring system, mine geometry, and the data collected in relation to what the information means in the mine is important in understanding any data interface. Additionally, collecting information regarding how the users interact with the developed data in the interface and compiling what they learn will help identify the most coherent interface design.

Determining emergent features is imperative to deciphering data through the interface. For example multiple variables can influence methane concentrations including mining rates, weather changes, or overlying mining areas. Methane will rise due to these variables, but if it remains under the TLV, this is considered normal fluctuation in concentrations due to regular mine activity. Relating the variables that naturally change ventilation gasses in the mine can help miners identify when changes are occurring that can lead to an unsafe mine atmosphere. Monitoring and trending of atmospheric data can be most beneficial when applied to return and outby areas that are only monitored by a certified miner on a weekly basis. Information gathered in these areas assists in many ways by allowing the miner to know the atmosphere they are going to encounter when inspecting, but also allows for monitoring of that atmosphere in areas that may be the first to indicate an unsafe situation.

2.6 *Field Development and Design*

Given the principals of human interface design detailed above an initial interface will be developed and tested with groups of miners and supervisors. Both qualitative and quantitative data regarding their technology, technical, and mining experience as well as knowledge gains during the interaction will be collected allowing for iterative design of the interface. Focus groups of miners will be established and a touch screen tablet will be utilized to display and interact with various test interfaces. Details in collected data include time spent with the interface, test knowledge gains, prior experience, what the test miners like and disliked, whether they felt it was intuitive, could they navigate the interface with little prompting, and were there tools that they would like to see on the interface.

When deploying this interface on the mine site it will be important to place it in a location accessible to all employees and also at a place where all employees will walk by and see the information on a regular basis. Current locations where all miners would see and feasibly interact with the interface would be on the surface in a common area similar to a lamp house or waiting room, or at the top of an elevator or cage. Sheridan notes that dedicated displays can help identify variables at their unique locations, although this can be cumbersome depending on the number of locations (Sheridan 2002). The most appropriate use of space for information transfer is important however information overload may have to take place during testing to determine what needs to be shown and how it is placed to get the most significant transfer of information. Underground accessibility to this interface in both common areas and working sections should be available, along with a progression to hand held data interfaces for employees. Other options for underground communication could be through a voice or text system in the currently installed TTE systems (Yenchek, Homce et al. 2012).

2.7 *Application and future development*

The National Occupational Research Agenda (NORA) for the National Mining Agenda NORA (2013) lists atmospheric monitoring as one of the most important issues in many categories. Out of the seven objectives stated in the NORA Objective, 1, 2, 4, and 6 all specifically reference atmospheric monitoring. These four objectives cover the topics of reducing disasters in mines, improving disaster response, improving atmospheric control, and improving mine design and systems operations to enhance mine health and safety. As over fifty percent of the current NORA objectives identify AMS as a priority, it is likely that it will be a large part of the safety and health culture in the US mining.

Gathering atmospheric data such as methane, CO, oxygen, and airflow is just the beginning of the data that can be collected and analyzed to assist in observing what is happening within the mine. Atmospheric data that is being recorded on the mining machine, hand held monitors, tracking devices, and fan data are all examples of other data that can also be added to the monitoring plan. With improved data and information being available to the miners, the logical next step will be to design a way to display real time data to the miners within their section, or on or with each miner using wireless communication. This would allow continuous monitoring and communication with the miner, who would be continually aware of the situation in every area of the mine even if they are not in that current location.

As networks and communication platforms such as TTE communication develop, data from additional sources could also be added to the database of atmospheric monitoring and integrated into the mine wide system. Additional data sources might include handheld atmosphere monitors communicating with wireless networks, mining machine location and progress, and mining machine methane data, to name a few. This information would complement data collected from existing and developing AMS, improving real time monitoring and prediction. Finally, additional data collected from other mine systems including, electrical systems, atmospheric, ground control, communications and tracking, production, and maintenance can assist in other predictive capabilities, and help realize improved efficiency.

2.8 *Conclusions*

Meaningful interfaces that transfer atmospheric information efficiently is critical to contributing to miners understanding of their work environmental conditions and relative health and safety. Visually displaying information is the quickest and easiest way to interface the information to the mine personnel so that they understand the trending of what is happening over time in their work place. A protocol is needed for consistent visual communication of this data so that various systems can adhere to a single structure even if implemented in different mines with diverse systems. These data help the miner determine safety and action within their shift and can assist them in taking actions that allow for remediation of high risk situations. The research outcome will inform us by experimental testing of the interface with professional miners on the design of the interface, and assist on iterative improvements to the interfaces effectiveness.

Acknowledgement

Heather Dougherty is the lead author of this chapter and responsible for most of the original writing. She conceived and wrote the paper with editorial input from Dr. Kray Luxbacher, Dr. Michael Karmis, and Dr. Zach Agiountantis. Much of the work in this chapter was published in: Dougherty, H., Luxbacher, K.D., Karmis, M., Agioutantis, Z. (2015). Approaches to communication of mine atmospheric monitoring data. In the 10th International Mine Ventilation Congress. August 2-8, Sun City, South Africa.

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The following paper was presented at the 37th International Symposium on Application of Computers and Operations Research in the Mineral Industry(APCOM)May 23-27, 2015 at the University of Alaska, Fairbanks, Alaska. Heather Dougherty was the lead author and wrote the paper with editorial input from Dr/ Kray Luxbacher, Dr.Nino Ripepi, Dr.Michel Karmis, and Dr.Zach Agiountantis. Please cite the article as: Dougherty, H., Luxbacher, K.D., Ripepi, N., Karmis, M., Agioutantis, Z. (2015). Design principles for a mining interface, 2015 APCOM, SME. Fairbanks, Alaska p800-809.

3. DESIGN PRINCIPLES FOR A MINING INTERFACE

Computer interfaces for most in-mine applications are tailored to specific uses or mine sites; as well, they generally target expert users, such as control room operators and engineers. This may lead to relatively infrequent updating in software and decreased flexibility in hardware. Additionally, this approach can lead to confusion between mines, miners, companies, regulatory agencies, and vendor support, especially if there is an emergency. Current practice and application of interfaces for atmospheric monitoring in underground coal mining are surveyed, and a detailed human factors assessment of input processes and cognition are taken into account to determine best practices for an effective interface and design practices. Design is determined by specifically targeting atmospheric data and the processing and communicating of these data to the underground miner and front line supervisor.

3.1. Introduction

The current challenge of interfaces in the mining industry is that they are commonly individualized for a single mine or a specific application, sometimes focusing on a specific type of user. The number of user interfaces and users within the mining field is relatively small and specialized from a market standpoint, so as technology progresses there is not always sufficient incentive for companies to create new and innovative interfaces.

On the other hand, monitoring of underground mines has expanded as sensing technology has matured, which has led to greater data acquisition. Processing, using, and sharing this information with miners can help progress the field to create a safer and more knowledgeable workforce.

The aim of this paper is to survey current mine practices for displaying and reporting atmospheric data. Atmospheric data interface indicators considered will be airflow direction and color, and air monitoring (gas) symbols and evaluation points. Current practices in US underground coal mines will be surveyed to determine what visual cues and datum are being displayed and how and where it is shown. This information will be collated, and human factors topics will be reviewed, toward best practices for displaying this information to attain the greatest safety impact for the miner. Recommendations will be made as to a standard practice for use for a public atmospheric monitoring display. In a forward thinking process, this information will be used to assist in the creation of a standardized interface that will be used to collect and display atmospheric data for miners. The notion is that by giving miners access to real time data, they may make more informed safety decisions. This work may also lead to improved and more standardized interfaces for expert users.

3.2 Background and Motivation

There have been a streak of high profile mine disasters in developed countries where the major contributor was unsafe atmospheric conditions. A major incident in the United States has fueled a push for increased safety practices was the methane and coal dust explosion at the Upper Big Branch (UBB) Mine in Raleigh County West Virginia on April 5, 2010. The UBB disaster, which is the worst disaster in the United States since 1970, killed 29 miners, and it was determined by the Mine Safety and Health Administration (MSHA) that flagrant safety violations contributed to the methane and coal dust explosion (MSHA 2010). A non-prosecution agreement written between the US Attorney's office and Alpha Natural Resources (who purchased Massey Energy in 2012) and all legacy Massey companies had many agreed upon expansions in safety practices. Alpha agreed to implement additional safety measures in all of their mines, including installing ventilation airflow quantity and direction and methane sensors in all intake and return airways on every working section. Since 2011, Alpha has worked with a manufacturer to design and install airflow, methane and carbon monoxide sensors in, at a minimum, every intake and return airway on all working sections (DOJ 2010). This is the first of many forward progressions in advancing atmospheric monitoring and understanding of the underground atmosphere.

Many new mine safety reform acts were introduced to the United States senate and congress since 2010, so far they all have failed to be passed (Griffin 2013). All of them included new stipulations on monitoring of atmospheres. Two current bills, are S.805 and H.R. 1373 – The Robert C. Byrd Mine and Workplace Safety and Health Act of 2013 and the Robert C. Byrd Mine Safety Protection Act of 2013 which have been introduced and are currently referred to the subcommittees. In both

H.R. 1373 and S.805, a section on atmospheric monitoring systems requires that all underground coal mines install atmospheric monitoring systems that "provide real-time information regarding methane, oxygen, carbon monoxide levels, and airflow direction, as appropriate, with sensing, annunciating, and recording capabilities" in places where miners normally work and travel. It also requires air monitoring systems, both monitoring and recording, on mining equipment. The bills also include that the coal mine operator install a communication protocol to ensure each miner entering the mine be aware of the current mine conditions (Miller 2013, Rockefeller 2013).

Standard atmospheric data collection in underground coal mines typically includes written paper books and alarm records. Long term data analysis and trending is less common. Although sensor resolution and capability has increased in underground U.S. coal mines, analysis of the data, as well as standard long term data storage has been slow to follow.

There is not much current innovation for interfaces used in mining. Presently the most advanced interactive interfaces used in mining fields are in virtual reality (VR) for training applications, proximity detection, ventilation on demand, and robotics (Dougherty et al. 2014). Less work has been done on integration of global mining data and presenting it in an informative way to the general miner.

Data fusion, as defined by Bleiholder and Naumann (2009), is the development of fusing multiple bits of information that represent the same object into a single, consistent representation of, in this instance a mine. It is important to take the information that is collected by the atmospheric monitoring (ATM) system and present it in a useful and informative way to the miner. Currently multiple atmospheric data that has been collected has not been fused together to assist in the understanding of various aspects, its causes and effects of atmospheric events. Although there are theories and proof as to the principle of these events, current standard data does not prove these events. An example of this is a known relationship between barometric pressure change and methane emissions (Hemp 1994), particularly in sealed areas, and currently there is no long term database of information to validate this concept.

3.3. Human Factors in Design

It is important to consider human factors when planning and designing a system interface. Considering factors such as the thresholds and extents of human vision, hearing and processing of data can increase ease of use, information transfer, and how promptly they adopt the new technology as standard practice.

3.3.1. Standardization

Consideration of standards and criteria of the display when designing interfaces is essential. Creating a guideline detailing the design process can also be valuable. Sanders states that common sense and experience are predominant when designing relevant items (1987). It has been established that there is a high impact from end-user feedback, their early participation can be helpful during the design process. Benefits of defined interface guidelines and standards are: increased productivity, reduced physical and mental workload, reduced training time and expense, and increased user-system interoperability across applications (Reed et al. 1999, Reed et al. 2004).

The crux of standardization is to be consistent and to keep in mind the end user and their experience in their daily practice. The practice of using standards as recommended is essential, but it is always imperative to have a legend or defined help menu available for casual, intermittent, or new users.

3.3.2. Visual display, symbols and codes, and input processing

Sanders explains that research supports that symbolic signs are preferable to verbal (both written out and spoken) because they do not require allot of reading or translation, and therefore can be more quickly interpreted. The symbolic sign must reliably depict what it represents, and sometimes the sign has to be learned. When a symbol is used by similar people the symbol should be informative and always be connected with the same referent (Sanders and McCormick 1987). Also, the user's experience or their 'perceptual set' is important to consider when creating a visual symbol for a display (Easterby 1970).

3.3.3. Color

Color can be important when differentiating between single sensors. Some contaminants and gases commonly recorded in an operating underground atmosphere are methane, carbon dioxide, carbon monoxide, and oxygen. Two gases are standardly found for pharmaceutical and medical uses, so they have a standard USA and International Organization for Standardization (ISO) classification for recognition. Carbon dioxide is grey in both standards and oxygen is either green or white. Many of the gases commonly found in an underground atmosphere are not standard medical or industrial gases, so therefore do not have standard, recognized colors for a pure gas tank. Another standardization is from the Department of Defense for color coding for pipelines and compressed gas cylinders. MIL-STD-101B has a breakdown for warning colors if the gas is flammable (yellow), toxic (brown), oxidizing (green) or physically dangerous (gray). They also have classifications of materials for piping systems, labelling methane yellow, carbon dioxide gray, carbon monoxide yellow, and oxygen green (DOD 1970)

3.3.4. Auditory

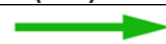
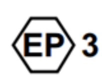
Currently all underground carbon monoxide sensors are mandated by 30 CFR 75.352 to have an auditory and visual warning when exceeding the applicable alarm levels of contaminant in the air. This alert or alarm has a minimum standard that it must be of sufficient magnitude to be seen or heard by the AMS operator ((CFR 2011)§75.351). Auditory alarms are successful for occurrences where the message is short, simple and calls for immediate action and can free up the visual system of someone monitoring multiple systems (Sanders and McCormick 1987). With the addition of various atmospheric sensors, and several alarming levels, distinct alarms at contrasting levels would be hard to differentiate and learn. Auditory alarms for immediate actions can be used for the support, or secondary alert and used with other systems, but should not be used as a main source of alert if multiple sensors and gases are being tracked.

3.4. Current Laws, regulations, and Standards

Carlson software's AutoCAD mining module has the greatest share of the underground coal mapping market in the United States. Included with underground mapping it also has a large array of pre designed mine symbols that are commonly used in mapping (Carlson 2014). This library can assist in creating a standard for most symbols in underground mining.

The US federal mine regulation agency, MSHA, does not currently have an explicit listing of mandated symbols for mapping. MSHA and some states have explicitly stated what is necessary in maps that are submitted for permitting or approvals, but not how they should be shown symbolically. Partly due to similar software, there are many standard symbols that are used in mapping, and example would be arrows used to denote airflow direction. The only definitive standards on symbols were found from the West Virginia Office of Miners' Health, Safety and Training (MHS&T) has a published set of symbols that are mandatory in any mapping done within the state for initial and semi-annual permit maps (WVMSH&T 2014). A breakdown of atmospheric symbols that are used by MHS&T are indicated in Table 3.1. There is currently no defined symbol for the CO sensor.

Table 3.1: MHS&T Symbols used for mapping atmospheric attribute

			Symbol
Intake	**Existing**	Solid blue arrow	 (blue)
	Proposed	Dashed blue arrow	 (blue)
Neutral	**Existing**	Solid green arrow	 (green)
	Proposed	Dashed green arrow	 (green)
Return	**Existing**	Solid red arrow with double head	 (red)
	Proposed	Dashed red arrow with a double head	 (red)
Evaluation point		Hexagon with EP inside and the label on the outside	

3.5. Survey of current mine practices

The use of symbols for mapping in underground mines can vary by company, state or region. Table 3.2 represents a survey of common practice in several large US coal companies for display of atmospheric data. These companies represent underground coal operations in the north east, Illinois, and western basins. Although many had a solid standard for colors of intake, return and neutral airways and a standard symbol for demonstrating airflow showing direction, a comment of “varies” was used to describe some symbols. Refer to Table 3.1 for examples of many of these symbols described in Table 3.2.

Table 3.2: Listing of surveyed companies’ symbols

		Symbols			
		WV MSH&T	Company 1	Company 2	Company 3
Intake	Existing	Solid blue arrow	Solid blue arrow	Green solid arrow	Green solid arrow
	Proposed	Dashed blue arrow			
Neutral	Existing	Solid green arrow	Dotted green arrow	Blue solid arrow	Blue double line arrow
(Belt)	Proposed	Dashed green arrow			
Return	Existing	Solid red arrow with double head	Solid red arrow with double head	Red solid arrow	Dashed line arrow
	Proposed	Dashed red arrow with a double head			
Evaluation point		Hexagon with EP inside and the label on the outside	Hexagon with "EP" inside, all black	"BEP" for Bleeder Evaluation Point, "MP" for Measurement Point, and "IEP" for Inlet evaluation point	Varies
CO monitor		N/A	Red circle with Red "CO" inside	Black Hexagons	Varies

Many of these symbols are displayed in a public area on the map required by 30 CFR, §75.1200 that requires all of the accurate up-to-date information displayed (CFR 2011). Table 3.2 indicates variation in some of the symbols and colors used to indicate atmospheric conditions at different companies. It is also common practice that monitoring systems and their interfaces are not always shown in similar areas to a posted §75.1200 map. Maps are a daily part of miners training and daily work activities. Familiarity with mine maps from training, emergency escapeway training, in mine travel, and their work make them accustomed to mine mapping and able to easy interpret and navigate using these maps for their operations.

The intake and neutral airflow symbol is a solid arrow, pointing in the direction of airflow, but two colors are common and are used for both symbols, blue and green. For the return airflow, all companies use the same color, red, but show the symbol differently by using a solid, double pointed, or a dashed line arrow. The most common color-blindness is red/green, and it is more common in men, so a difference in one of these arrows, by either dashing the line, or a double head allows a work around for this deficiency (Sanders and McCormick 1987). Evaluation points vary, showing a similarity of a hexagon, standardly black or black outline, but some companies use text to indicate the different evaluation points and types of evaluation points. Carbon monoxide (CO) detectors, which are standard monitoring on belts are also shown as varied across the companies, ranging from a red circle labelled “CO” or a black hexagon. Occasionally a colored thumb tack is used to indicate CO sensors on paper maps, this allows easy and seamless updating when sensors advance, without creating a new map. Additionally some companies indicated that a few of the symbols were standard at most operations, but that they can be varied at an individual operation, particularly some of the smaller or contractor run operations of larger companies.

Companies responded with varied responses as to where and how atmospheric monitoring data is displayed. Most operations stated that their CO sensing system, or interface, was in a main computer or operator room where there is an attendant monitoring this information for alarm. This information shows current information, and does not typically record the data, only alarm ranges as required by MSHA regulations. These data can also be viewed within the company intranet system by management. Other than miners going into the operator room to view or review the information, it is not typically displayed in a public area.

3.6. Current atmospheric monitoring interfaces

Two interfaces were examined from two different companies that service mines for sensor and networking needs. Figure 3.1 shows the outline of the mine, expected air flow directions, and the power and communication status of CO sensors along the belt line. The different sensors can be selected to gain further insight on the sensor read out and alarms. The Conspec system can also be customized to integrate additional information from other monitoring systems within the mine.

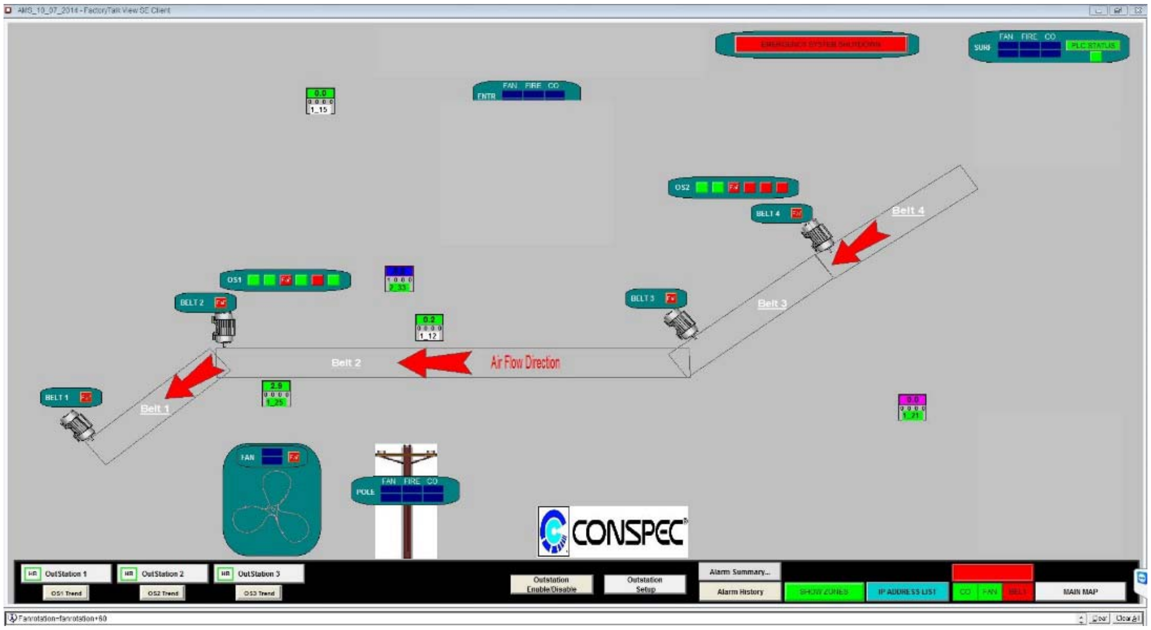


Figure 3.1: Conspec monitoring screen for Atmospheric Monitoring and CO sensors (Conspec Controls, personal communication, December 2014).

Figure 3.2 is an example from Pillar Innovations, LLC (Pillar). It shows a more detailed overlay of the mine with symbols and real time readings from the CO sensors. It indicates the location of the beltlines in the mine schematic, where the CO monitors are located, and arrows showing the expected direction of airflow. By clicking on a particular sensor in the mine, you get the "Sensor Information" pop up box which gives more detailed information on the sensor readout and alarms and allows for modification. Figure 3.3 shows Pillar's standard atmospheric monitoring interface legend. Pillar uses different symbols to indicate different sensors within the mine and different colors to indicate the status of the sensors.

Figure 3.1 and Figure 3.2 are representative of common control or computer room displays. They are not typically in public areas for miners regular viewing and are not interactive. They also show that most mines atmospheric monitoring systems only consist of monitoring CO on belt lines, which is mandated by regulation. Many of these interfaces are not created for or available for the miner.

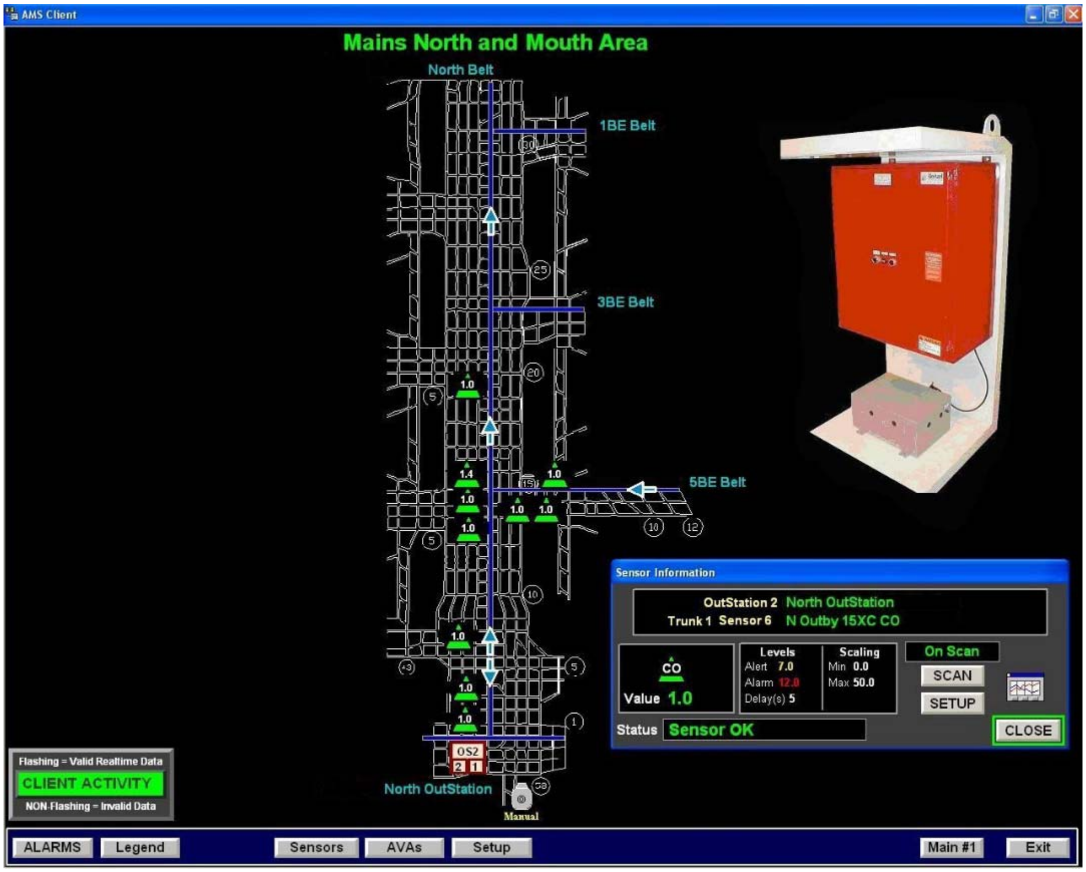


Figure 3.2: Example of the Pillar main mine screen for monitoring, showing CO locations and values (Pillar Innovations, LLC, personal communication, December 2014).

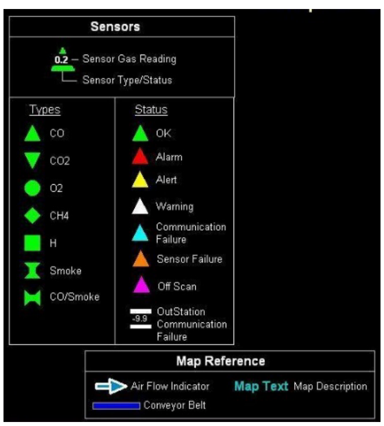


Figure 3.3: Pillar standard atmospheric monitoring legend (Pillar Innovations, LLC, personal communication, December 2014).

3.7. Discussion and Implications

In the United States monitoring of the underground atmosphere continues to expand, increasing the health and safety of the operation. This evolution includes continual and continuous monitoring and banks of multiple gas sensors collecting atmospheric conditions. Communication of this information is important for work force training and understanding. It is imperative that standard, straightforward symbols should be considered and prototypes tested in order to develop an effective protocol. It is suggested that a general rule for symbols for monitors and monitoring banks be accepted. This rule, to adhere with a pattern to identify how many sensors are in the bank. Suggested is the number of sides of the symbol will be used to identify the number of sensors in a bank (Figure 3.4). This leads to easy identification of the number of sensors in the bank by counting the sides of the symbol. When stipulating color, a color should be used that can be seen easily, differentiated from other symbol colors, and easily identified as a sensor. Although not required by law, identifiers can be used to identify the gases that are being monitored. With multiple monitors in one location an alphanumeric identifier may be more suitable than a colored one.

●	1-sensor	Circle
⬬	2-sensor	Ellipse
▲	3-sensor	Triangle
◆ ■	4-sensor	Quadrilateral
⬟	5-sensor	Pentagon
⬢	6-sensor	Hexagon

Figure 3.4: Suggested sensor bank symbols

	Symbol	
Intake	Solid blue arrow	→ (blue)
Neutral	Solid green arrow	→ (green)
Return	Solid red arrow with double head	⇉ (red)

Figure 3.5: Suggested atmospheric air flow symbols and colors

Combining the symbols from various agencies and companies for airflow, a few commonalities stand out. All arrows are solid which are more effective and stand out to convey the message by being more stable (Easterby 1970). Because there are currently laws from MSH&T in WV stipulating the color and symbols of the airflow direction and label, it is recommended that they stay consistent. The intake airway should be blue, neutral or belt airway green, and return airway red. Because of the difference in the return airways to the other airways, it is recommended that the double headed arrow also be used to identify return airways (Figure 3.5). This variance also assists if there is a color disability in the end user or miner viewing the information on a map.

A map background or base is also imperative to adequately interpret this information effectively. A map is a familiar and commonly used item for every miner for their daily involvement in emergency escapeway, ventilation training, quarterly training, planning, and daily mining work. Experienced miners are considered expert mine map readers and interpreters, because they use this skill daily in varying aspects of their regular work. A map gives perspective of relative reference to other mining aspects.

A standard symbolic library and familiar concept and base, e.g., mine maps, allows for a more seamless and quick acceptance for the use of the end user. Currently, many of the suggested symbols are used in some arrangement at a large number of existing operations and are commonly recognized. The use of a legend similar to Figure 3.3 is well established in any mapping or representative computer system. Increasing awareness and recognition of a standard in symbols across software, systems, and companies increases perception and decreases training time and confusion.

Integration of symbols from Figure 3.4 and Figure 3.5 can assist in the creation of an atmospheric monitoring system interface protocol for communication of the ATM data to the miner. The expectation of this protocol, a standardization of symbols within atmospheric monitoring systems, is to increase comprehension of atmospheric interactions in the workforce. Understanding of these symbols will be evaluated during prototype development and testing of an atmospheric monitoring interface for underground coal mines.

3.8. Conclusion

A standardization of atmospheric air flow symbols and colors as well as sensor bank symbols is important for the development of a consistent straight forward interface that will improve communication between miners, companies, contractors and agencies. An accepted symbol library which allows for straightforwardness in training and the ease of recognition of standard symbols, colors, and indicators will be the first step in developing a protocol. This leads to a rapid understanding, acceptance, clear knowledge transfer and capacity building. It also permits adaptation of any existing interfaces to these protocols, not limiting it to a single company, state or software package.

These symbols and associated colors will be implemented in a prototype of an atmospheric monitoring interface system that could include multiple gases, airflow and will be available in a format for miner interaction. It will be an intuitive and interactive design allowing for exploration of historical and current information for single and multiple sensors along with additional pertinent atmospheric data. This standard will be tested and evaluated within a prototype interface to verify its effectiveness for the end user.

Acknowledgments

The authors would like to gratefully acknowledge and thank the contributions from Pillar Innovations Inc and Conspec Controls for providing models of their advanced atmospheric monitoring interfaces.

Heather Dougherty is the lead author of this chapter and responsible for most of the original writing. She conceived and wrote the paper with editorial input from Dr. Kray Luxbacher, Dr. Nino Ripepi, Dr. Michael Karmis, and Dr. Zach Agiountantis. Much of the work in this chapter was published in:

Dougherty, H, Luxbacher, K.D., Ripepi, N., Karmis, M., & Agioutantis, Z. (2015, May 23). Design principles for a mining interface. In S. Bhandopadhyay (Ed.), APCOM Proceedings. May 23-27, Fairbanks, AL: University of Alaska

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4 CHAPTER 4: PERFORMANCE ASSESSMENT OF A FIBER OPTIC METHANE SENSOR EXPOSED TO COAL SMOKE

Fiber optic sensing is a novel technology only recently applied to the underground mining industry. Fiber optic (FO) sensors are valuable in the mining industry due to their electrical isolation and long communication distance for both daily operation and post disaster response. A prototype developed for NIOSH mining of a fiber optic methane sensor for use in mines was selected for testing in laboratory experiments to study the potential effects of post disaster response. An analysis was conducted to determine whether there was continued response after a fire or smoke emergency. Researchers used heat, carbon dioxide (CO_2), and smoke to determine laser power budget changes and the fiber optic sensing practicality both during and after this type of emergency condition. Separate variations of temperature, CO_2, and smoke were administered to a sensor, each showing minimal change in power budget, although smoke tests indicated a change in response time when testing for methane.

4.1 Introduction

Underground mines have the risk of accumulation of gases if not ventilated properly or during and after emergency situations when ventilation controls become damaged or stop working. Common gases that are monitored in underground coal are carbon monoxide (CO), oxygen (O_2), and methane (CH_4). Methane is a gas found in coal and released through mining, its explosive range is between 5% and 15%. Methane is commonly monitored on all mining equipment and with handheld gas sensors carried by most underground coal miners.

Fiber optics (FO) is a popular technology applied in underground mining particularly for its electric isolation. Many miners are familiar with FO cables hung throughout the mine, which are primarily used in communication of voice and data. Advancements in laser and fiber optics have made this technology more suitable for gas sensing the harsh environment of mining applications.

The US Bureau of Mines did work on the use of fiber optic monitoring of gases in mines starting in 1992. Dubaniewicz and Chilton (1992, 1993, 1995) developed a prototype gas sensors including methane, for research purposes. They identified that a drawback in the use of fiber optics is the refractive index in which other gases may interfere with the measurement of the gas of interest. In the spectrum close to CH_4 is CO and CO_2 as carbon oxides that may interfere with the refractive index.

NIOSH developed a broad agency announcement (BAA) for the development and demonstration of mine safety and health technology. The objective of this announcement is to validate a sensor for the mine environment and test it in an actual working mine. The RSL FO sensor “OptoSniff” provided from this work is capable of hundreds of sensing points over distances of up to 20km, measurement range of 0.05% to 100%, senses in an oxygen deficient environment, and has no gas cross-sensitivity (RSL, 2014). The RSL system is totally electrically passive outside the central control unit (CCU) which can be housed in a MSHA approved XP enclosure, or in an outside control room outside of the permissive area. The sensor was tested in dusty and signal loss situations, showing it is tolerant of dust, functioned at signal losses up to 90%, and was successfully tested in a mine environment for a five month period (Walsh D. 2014).

In this paper the RSL FO sensor is used for testing using smoke and it’s contaminants for applicability in emergency situations. Testing investigates individual contaminants such as CO_2, temperature, and smoke. Each test was performed separately and methane, laser power, and response time data are collected.

4.2 Methods

4.2.1 Equipment

The fiber optic sensor system “OptoSniff” manufactured by RSL and OPtiSci, was used for testing. Figure 4.1 shows the OptoSniff system used, a sensor is shown in front of the central control unit (CCU) that houses the computer and laser components. The system supports three sensors through the ports shown in Figure 4.1. The OptoSniff system measures the methane in ppm up to 100% and also RSSI, or return signal strength indicator from the CCU.

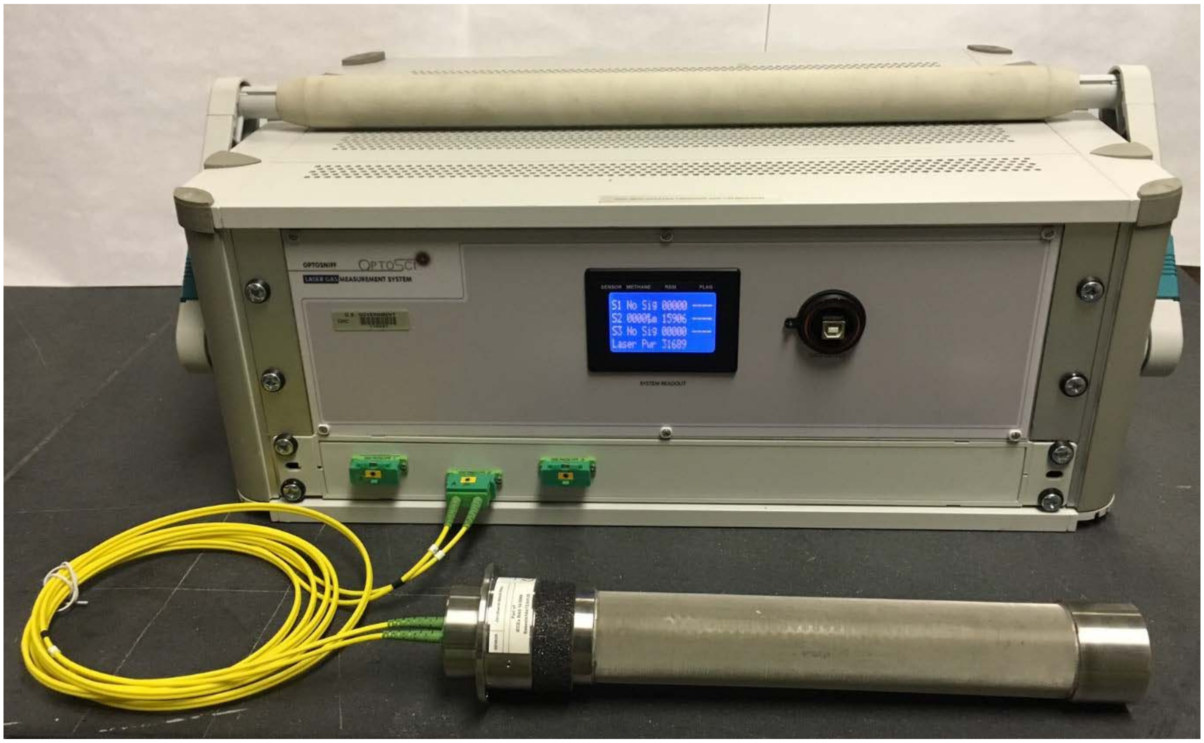

Figure 4.1: OptiSci OptoSniff fiber optic methane sensor head and CCU.

Optical powers were measured using a Keysight technologies 8163B lightwave multimeter which is primarily used for optical component tests. Two model 81623B Keysight optical heads were used for measuring the power throughput for the RSL sensor.

The power meter was used to measure the power throughput of the sensor for the wavelength of methane absorption line at 1651nm of the sensor. It measured the laser power sent from the CCU that enters the sensor and the return laser power to the CCU. The power throughput or power budget is the available optical power, after various loss mechanisms, that ensures sufficient signal strength is available at the receiver. A power ratio was calculated using the return power divided by the output power to the sensor to factor out fluctuations not due to sensor measurement. The meter was put into the system to measure power as seen in Figure 4.2. A splitter was used from the output of the RSL CCU FO cable, split to the power meter through a FO head to the power meter and also to the FO methane sensor. The return FO cable from the sensor also used a splitter to a second FO head and to the power meter and returns to the RSL CCU.

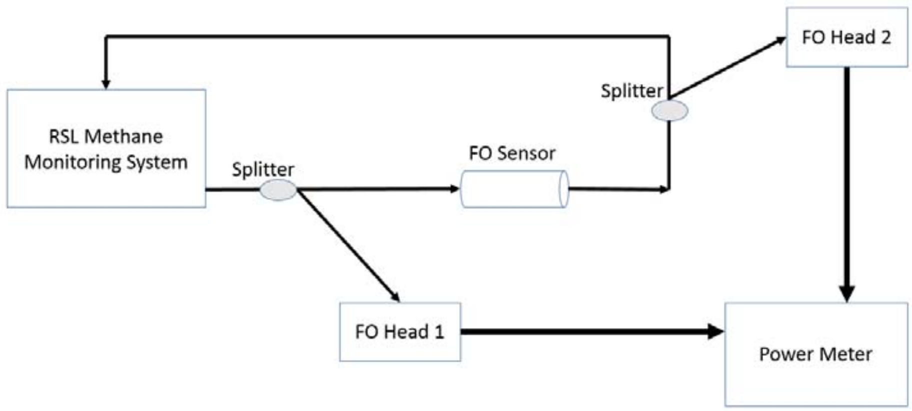

Figure 4.2: Optical power measurement diagram setup

4.2.2 Fiber optic sensor exposure test configurations

Four tests were run to determine if any of the fire contaminants disrupt or deteriorate the accuracy of the fiber optic sensor by measuring optical power and response time. Temperature was altered for increase in heat in an emergency fire situation. The FO sensor was then tested in a smoke box where smoke optical density and particulate concentration were recorded. An in mine coal fire test was conducted where airflow, CO, smoke, temperature and oxygen was monitored next to the FO sensor. After testing in these separate conditions, sensors were tested using a calibration cap to ascertain if there was a change in response time after the experiment.

4.2.3 Response time testing

Three sensor heads were used for this work along with the laser center control unit (CCU). Each sensor head was tested in a calibration cap (Figure 4.3) with 2.9% methane in air mixture at a flow rate of 400 mL/min. Time was recorded starting when an initial CH_4 concentration was detected by the monitor until the reading reached 90% (T90 test) value (2.61% CH_4). This test was run 15 times for each sensor to attain enough data for a statistical analysis of response time for comparison of sensors and for pre and post test comparisons. The mean response time in the calibration cap for the 6 sensors ranged from 56 seconds to 62 seconds. The calibration cap and a flow rate was chosen to produce a baseline response time of approximately one minute for a clean sensor. Fiber optic response is rapid when gas is exposed directly to the optic in the sensor. The calibration cap was used to test the sensor and its housing or filters consistently. Although a T90 test is used, the calibration cap is a restriction that does not allow this response time to be compared to other methane sensors, but it used to compare between tests.

4.2.4 Heat and CO_2 tests

Temperature and CO_2 tests were run separately in a 20 liter chamber within a laboratory hood (Figure 4.4). Temperature excursion was measured using a thermocouple, and increased with heat tape on the 20 liter chamber that was full of air. The thermocouple was placed close to the center of the 20 liter chamber, away from the sides. A maximum temperature of 40° C was attained within 45 minutes and sustained for 30 minutes. During CO_2 testing, a vacuum was drawn on the 20 liter chamber and pure 100% CO_2 was introduced once a negative vacuum of 0.47psi was reached. CO_2 was introduced at ambient temperature and was filled by allowing the chamber to attain an overpressure.

4.2.5 Smoke Box test

Tests were conducted in the PMRD Smoke chamber designed to meet Underwriters Laboratory Inc. standard (UL 268) that is connected to a combustion chamber. This combustion sample chamber contains a circular disk heater that was used to heat coal in a pan as seen in Figure 4.5 (Edwards, 1995). Pittsburgh coal was used as the combustible material for both flaming and smoldering tests. Once inside the smoke chamber, the smoke from the coal was mixed uniformly by two small circulating fans. A nephelometer was used to measure smoke through light scattering between 10º and 170º and a DustTrak aerosol monitor was used to monitor smoke.

Figure 4.3: Calibration cap and FO sensor head.

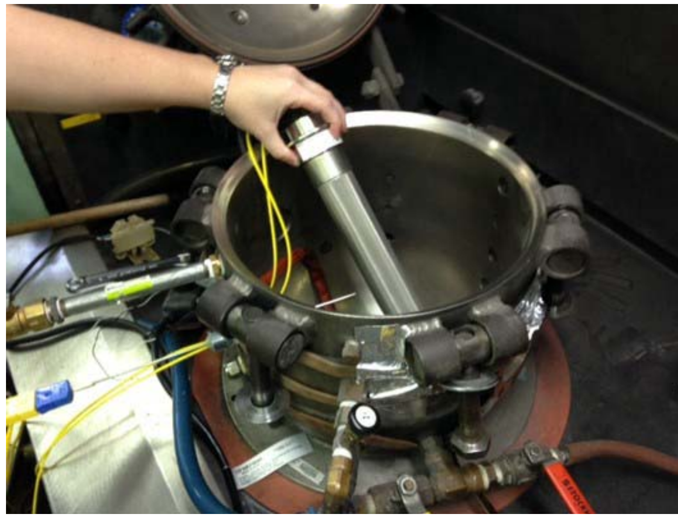

Figure 4.4: 20 liter chamber used for CO_2 and temperature testing, shown with fiber optic sensor inside an open chamber.

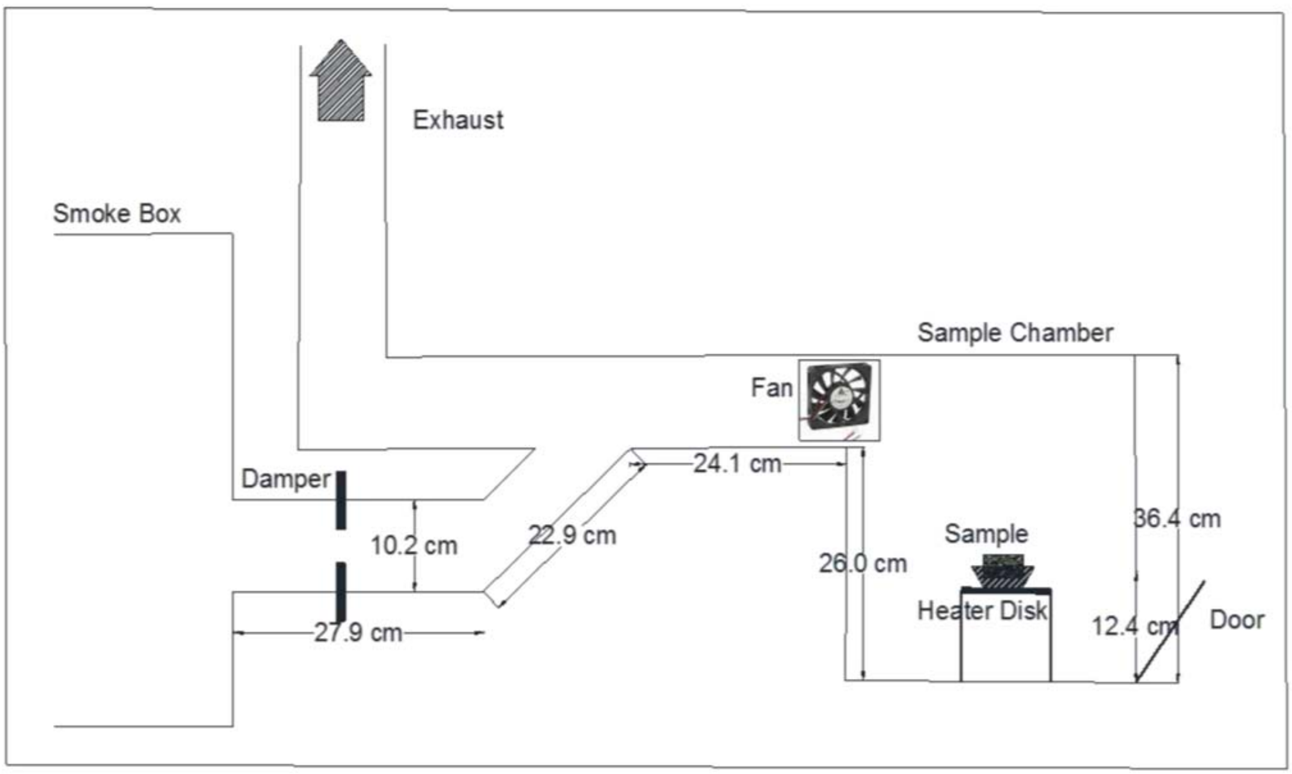

Figure 4.5: Schematic of sample chamber attached to smoke box. (Modified from Edwards, 1995)

A port in the side of the smoke box was used to insert the FO sensor in and out of the box during experimentation. The clean sensor was tested 15 times for response time under the calibration cap prior to smoke chamber testing for comparison to after smoke test response times. After each coal burn test of 1.05 oz (30 grams) of coal, which lasted approximately 30 minutes each, a calibration test was run on the sensor. These tests were conducted to determine if the sensor response time would change over time in a coal smoke fire.

Four coal burn tests were conducted using 1.05 oz (30 grams) of less than pea size coal in a 10 gram pan in the sample chamber (Figure 4.5). Airflow was set to approximately 100 feet per minute (fpm). The heater disk was turned on to start heating the coal, once the smoke was established in the chamber the sensor was placed in the smoke box. The first test was a flaming test lasting approximately 18 minutes, the last three tests were smoldering tests lasting approximately 30 minutes each for a total of 108 minutes of the sensor in the smoke. In between each test the calibration test was run on the sensor. After all the tests were run and methane calibration tests done, the sensor screen was cleaned. The screen was taken off the sensor frame (Figure 4.6), washed in a chemical bath then washed with soap and water and allowed to dry before reattaching to the FO frame. A calibration test was then run on the sensor.

Figure 4.6: Fiber Optic Methane sensor with screen slid off of the FO frame.

A research assumption prior to testing was that if CO_2 and heat had no effect, the barrier to accurate operation would be primarily the communication of airflow to the fiber optic sensing lens. The sensor would perform well when the laser could infiltrate the atmosphere it was testing, and the hurdle would be maintaining the filters around the FO portion of the sensor as can be seen in Figure 4.6.

4.2.6 In mine smoke test

Using PMRD Bruceton research mine, a coal burn test was performed. The coal burn test was conducted to indicate whether a real fire situation would impact the sensor, data, or laser power. During this testing a FO methane sensor was placed next to a row of sensors used for sensing airflow, CO, smoke, temperature and oxygen within one foot of the roof. The row of sensors was the first row of sensors, approximately 200 feet from the fire at the mouth of the mine. The fire consisted of approximately 39.5 lbs of coal. The laser CCU and power meter were placed outside of the mine with 656 feet (200 meters) of fiber optic line connecting the sensor to laser CCU and power meter. During this approximately 50 minute test, readings were taken from each piece of equipment every 60 seconds. These data were recorded, analyzed, and graphed.

4.3 Results

4.3.1 Calibration cap testing

All the sensors that could be used for experimentation were tested in the calibration cap for statistical comparison after testing comparison. Table 4.1 lists each sensor by its serial number and the mean T90 value time for each sensor and its standard deviation that was used for a clean response time. Table 4.1 shows the average 90% response time and standard deviation for the sensors that were used in testing; the response time per sensor for all the sensors averages between 55 and 62 seconds. A flow rate for these test of 400 ml/s was chosen to produce a target of approximately a 60 second response time for ease of testing and comparison.

Table 4.1: Response time for clean OptiSci methane sensors.

Sensor No.	390122	390110
Average/Mean (seconds)	57.9	56.1
Standard. Deviation (seconds)	2.1	2.3

4.3.2 Heat and CO_2 tests

During the CO_2 test there were 3 conditions, open to the air, closed and increase in pressure, CO_2 exposure, and then back to open to the ambient air. The optical power measured over time for the CO_2 exposure test is shown in Table 4.2. The ratio of output to input optical power stays constant when sensor exposed to pure air, vacuum, and CO_2. This indicates that the CO_2 and change in pressure tested has no impact on the power budget.

Table 4.2: Optical power when FO sensor is exposed to CO2

Gas exposed	**Pressure, psi**	**Input optical Power, µW**	**Output optical Power, µW**	**Output/input power ratio**
Pure air	12	3.000	0.327	0.11
Vacuum	0.47	3.069	0.339	0.11
Pure CO_2	21	3.088	0.315	0.10
Pure CO_2	14	3.011	0.320	0.11
Ambient air	12	3.029	0.335	0.11

During heat testing, the temperature in the 20 liter chamber was raised from approximately ambient (27.5° C) to 40° C. The temperature was then held consistent for 30 minutes at 40° C. Once the temperature was held constant for 30 minutes, the heat tape was turned off and the chamber and sensor were allowed to cool slowly. The maximum difference between power channels was 0.185 µW, with a steady power ratio of 0.19 to 0.21, showing little variability that would not affect the reliability of the sensor (Figure 4.6).

Table 4.3: Temperature test optical power and temperature

Time minutes	Temperature, °C	Input optical Power, µW	Output optical Power, µW	Output/input power ratio
0	27.5	2.950	0.610	0.21
45	40.0	2.950	0.595	0.20
47	40.2	3.100	0.575	0.19
75	40.0	3.030	0.575	0.19
77	36.0	3.000	0.575	0.19
112	33.0	3.000	0.585	0.20
152	30.6	3.000	0.580	0.19

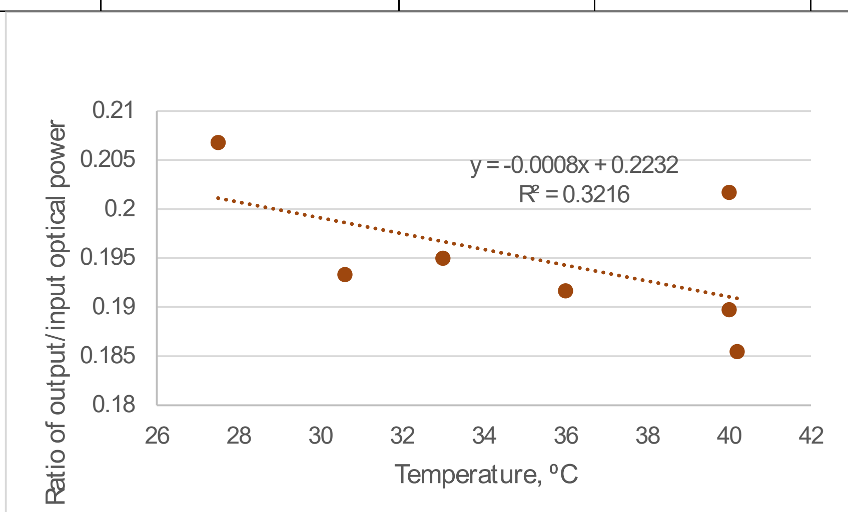

Figure 4.7: Optical power ratio by temperature.

4.3.3 Smoke Box test

The FO sensor responded throughout all of the smoke box testing without errors. The power ratio mean varied for each test from a minimum of 0.126 during the second test, to a maximum of 0.140 during the fourth smoke test (Figure 4.7). Figure 4.8 shows the cumulative dust concentration for each test in the smoke box and the sensor response time after each test. The mean smoke concentrations over the test time in the smoke box range from 24 mg/m3 for the first flaming test to 132 mg/m^3, 120 mg/m^3, and 130 mg/m^3 for each of the three smoldering coal tests.

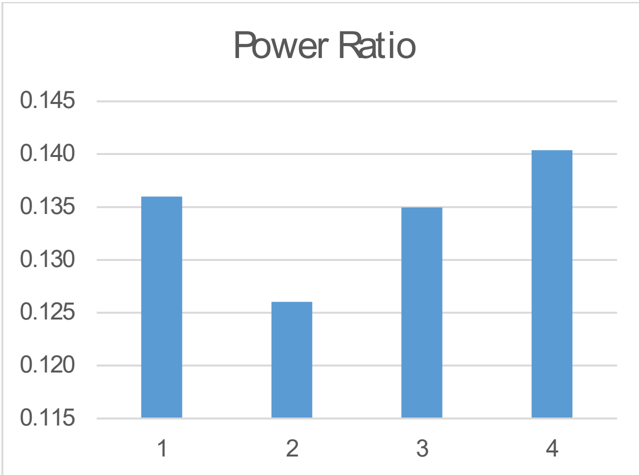

Figure 4.8: Power Ratio mean for each smoke test in the Smoke Box.

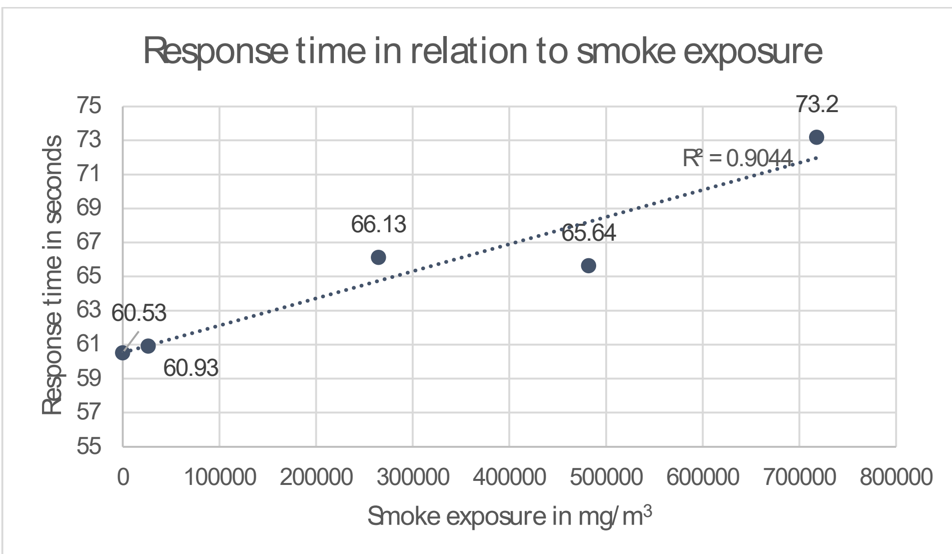

Figure 4.9: Response time in relation to cumulative smoke exposure.

When comparing a statistical analysis using Tukey's Studentized Range (HSD) test for response in the smoke box, only two time frames did not show significant differences in response time. These two time frames were between a clean sensor and the first flaming test (18 minutes of exposure) and the second (48 minutes) and third smoke test (78 minutes). There was a statistically significant time difference in calibration times for all other test pairs.

Once the testing was completed, the sensor was cleaned and calibration times were retested. Only the outside screen of the sensor was cleaned, leaving the inner fiber untouched. The mean for 90% full value for a cleaned screen after smoke box testing for the FO sensor was approximately 54 seconds. The difference from the initial clean sensor value of 60.5 seconds is a statistically significant difference.

4.3.4 *In mine smoke test*

Figure 4.10 shows the change in CO, CO_2, O_2, and smoke in relation to the change in power ratio over time. The smoke sensor used is just an alarm and shows a high number when it is exposed to smoke. The optical power ratio over time of smoke exposure for the in mine test is seen in Figure 4.10. No methane was detected during the in mine coal burn test. The ratio decreases in some degree as the sensor exposed to the coal fire smoke. Although this decreases over time, the difference is minimal and would not affect the reliability of the sensor for this test. Further long term testing would determine if the decrease in optical power budget would impact the sensor.

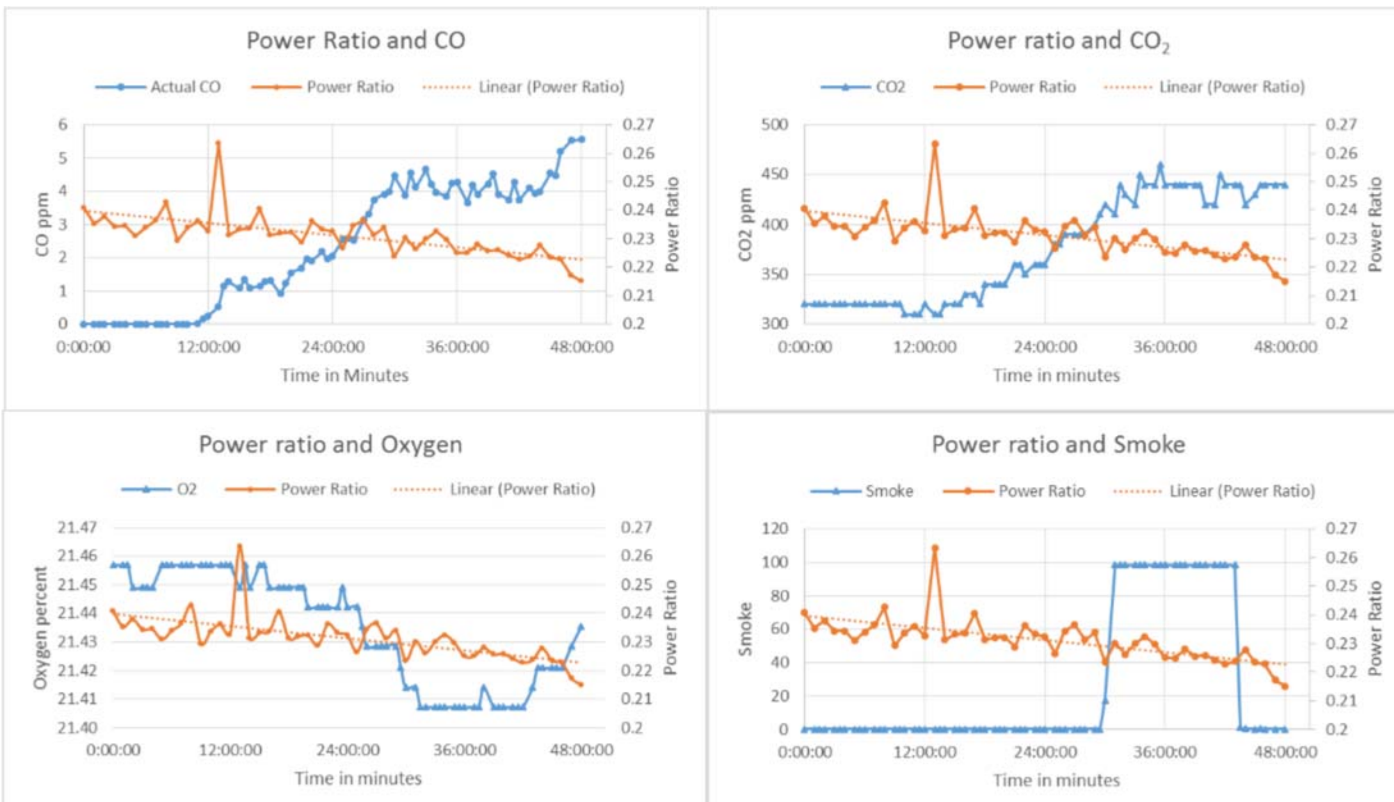

Figure 4.10: CO, CO2, Oxygen, and Smoke in relation to the power ratio from the power meter while testing.

4.4 *Discussion*

In the current configuration, the fiber optic cable, couplings, and sensor heads are the only fiber optic methane monitor components intended for exposure to methane or coal dust. The International Electrotechnical Commission (IEC) standard 60079-28 edition 2 describes precautions and requirements to be taken when using optical radiation transmitting equipment in explosive gas or dust atmospheres. One type of protection defined by the standard is inherently safe optical radiation, which is described as visible or infrared radiation that is incapable of producing sufficient energy under normal or specified fault conditions to ignite a specific explosive atmosphere. Per safe optical power limits listed in the standard, a maximum power of 35 mW would be considered inherently safe for the current configuration where the optical beam is exposed to methane or coal dust. The inherently safe concept also takes into consideration over-power fault protection for the optical source to prevent excessive beam strengths from being directed into the explosive atmosphere, as described in the standard (Dubaneiwicz 1999, Dubaniewicz Jr, Cashdollar et al. 2003, Taylor and Reid 2010).

The CO_2 and temperature tests showed that there was minimal change in the power budget and do not affect the reliability of the sensor. These tests determined that these contaminants would not affect the optical fiber in the sensor. Testing in both the smoke box and mine testing showed that there was no change in reliability of the sensor and little change in the power budget during these tests that would impact the sensor, but that there is a slowed response time. Longer term tests would indicate if the decrease in power budget seen in testing would decrease to a point that would impact the sensor response. Additional calibration cap testing after cleaning the sensor enclosure screen after smoke box testing showed us that there is a statically significant difference in calibration time. This indicates that the screen of the sensor is the component that would need the most care for maintenance and cleaning.

4.5 Conclusion

Fiber optics is the next generation for gas sensing in underground atmospheres. This FO sensor has the ability to be used in a wide range of areas within the mine due to its intrinsic properties. The sensors range of up to 100% methane, no cross-sensitivities, and no minimum oxygen content allows it to provide improved information in an emergency situation where concentrations could expand outside of the lower explosive limit (LEL) and atmospheres could be oxygen deficient. The sensor can tolerate up to a 90% signal loss, and the system signals if there is a loss in power that would affect sensing accuracy. This benefit allows mines to recognize if there is a signal issue and will not worry about that affecting accuracy of the sensor. The power supply and laser center (CCU) of this equipment can be kept on the surface while only fiber optic cabling (up to 20 km) and the sensor have to be in the underground atmosphere. This allows gas sensing to be continuous, and not influenced by power outages in the mine or power variations due to equipment or emergency situations. This laser system used for the sensor has a maximum 10 mW diode laser power, which is less than the standard recommendation of 35mW for atmospheres where methane is present. Using self-referencing, the sensor uses a gas cell within the CCU for calibration and does not need to be calibrated at the sensor head.

These benefits of fiber optic sensors allow there to be a wide range of uses for industrial and mining applications. This work highlights an enormous benefit for FO sensors, the use during an emergency situation, and after a fire or explosion. The sensor installed previously in the mine, and if not damaged by the emergency, will detect gases that can assist mine personnel in determining the extent of the situation. The power source can be on the surface, so this scenario is applicable in emergency situations, but also for situations where there is a planned or unplanned fan outage. FO sensors with their wide range, can also be used in post emergency situations, placed down boreholes, shafts, on robots, or with mine rescue teams. Walsh (2014) did tests of the sensors on mining equipment, and found the sensors suitable for this use.

The main barrier in these tests is the airflow around the sensor that can be inhabited by screen blockages, which can reduce response time. Regular checking and cleaning of the screen can insure that the sensor is reading at real time or near real time when in operation. In an emergency situation when the sensor cannot always be maintained, it is important to understand that the sensor may have a delayed response. Additional impacts to these sensors are that cables have to be maintained and may be damaged if exposed to an impact or explosion.

4.6 Disclaimer

The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health. Mention of any company or product does not constitute endorsement by the National Institute for Occupational Safety and Health (NIOSH).

Acknowledgement

Heather Dougherty is the lead author of this chapter and responsible for most of the orginial writing. She conceived and wrote the paper with editorial input from Thomas Dubaniewicz and MingMing Li. Dubaniewicz conceived the research motivation, research questions, and laboratory methods, although Dougherty had input in the experimental design and conducted the testing and analysis. Dubaniewicz compared the instrument laser power to provisions of IEC 60079-28 for inherently safe optical radiation.

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5. CHAPTER 5: INTERFACE DESIGN

5.1 Introduction

Underground coal mines predominantly collect atmospheric data by collecting measurements via hand held sensors, and recording data as required by law. With advances in technology and the need for complex mines to collect, trend, and predict changes there is a need for a tool to gather and share this data in a meaningful way. With the addition of continuous monitoring sensors there are massive amounts of data which need to be quickly processed and visualized to relay to miners.

For mine personnel the gathering, compiling, and interpreting of atmospheric data can be overwhelming for those that are not regularly immersed in this information. Atmospheric monitoring system (AMS) data are received in varying time frames, from a data point a second, per sensor, per gas, to multiple points per second. Information can also come from multiple systems, making it hard to put the information together to make meaningful sense of it, and how or if it interacts together. To assist in solving these issues, a database and interface for collection and display of atmospheric data is created.

The objective of creating an interface to display atmospheric data for miners and front line supervisors is to enable them to have access to useful information that will allow them to have a better understanding of their work environment. This AMS interface is intended to be readily accessible for all miners, allowing them to interact with and view the AMS information frequently. The AMS interface is intuitive, interactive, and consistently updating. Presenting AMS data in a way that assists the miner in synthesizing the information quickly can lead to better decision-making for their personal safety and health as well as an increase in operational safety and productivity.

Currently, many mine operations are reluctant to collect, store and share information beyond what is required by the regulations (30 CFR 75.351 (CFR, 2011)) for several reasons. First, significant time and expertise are required for data management and analysis, and off-the-shelf solutions are not readily available. Also operators may be concerned about increased regulatory enforcement and consistent interpretation.

Presently, atmospheric monitoring systems have the functionality to log and record data. When these data are combined together with other operational and environmental data, an abundance of information about the mine can be discovered. These data, if processed and presented, can assist in educating the miners and industry to be more knowledgeable of the atmospheric variations that can impact the production, safety, and health of the operation, as well as identify unusual or hazardous conditions earlier.

5.2 Background

Presently, mines, particularly underground coal mines, have a variety of ways and systems for data gathering and sharing. Much of the atmospheric data is collected by on-shift and pre-shift exams then recorded in a book for record keeping. Communication of data also occurs more informally, passing it on verbally on the section from person to person, shift to shift. Existing sensors, primarily carbon monoxide (CO) sensors on belt lines, are continuously monitored from a central computer or communications room and are typically recorded when in alarm status. Once the data is collected by a computer, sensor, hand held sensor, or recorded in a book, this information is of its greatest value if it can be rapidly conglomerated and shared with the workforce.

Other heavy industries are working with data bases and in-house human-machine interface (HMI) development. The natural gas industry has been working on a system to assist in data acquisition, transferring data to a central location, and displaying it for decision makers. Their system, similar to what we envision in mining, consists of a HMI, computer monitoring, data acquisition, processing and visualization (Abdi, Iqbal, & Ahmed, 2016). Abdi also notes that a well-managed interface results in business benefits and greater safety achievements. Power plants are also working on improving the control and communications system through graphical visualizations of the physical parts of the plant. Holzinger showed that users preferred to have visual data short and concise, so that they can be apprised of a situation at a glance. He also noted that more experienced users wanted less guidance from an interface, and the less experiences user wanted more guidance and direction (Holzinger, Popova, Peischl, & Ziefle, 2012).

Wang (2016) presents an case of an offline data integration and visualisation for maritime vessel operations. He uses data integration and visualisation techniques for monitoring sensor data on maritime vessels. He indicates that onshore operational centers manage fleets of maritime vessels in real time and that each vessel should be considered an individual data source. It is expected that in the future vessels will send data to these onshore centers in the form of real time streams. These data streams will go back and forth between the vessel and the operations center, and large amounts of data will be compiled to assist in detecting and preventing emergency situations with alarms in near-real-time.

In metal/non-metal mines a great progression has been made in Ventilation on Demand (VOD). Coal operations are more restrictive due to their regulations and intrinsic safety standards than metal/non-metal mines. Allen (2008) described a pilot test for the Coleman mine in 2008 that was carried out in phases due to the nature of the VOD dynamic system. This VOD system was implemented in stages, the first installing sensors, automated regulators, tracking systems, air quality and temperature monitors, and variable frequency drives. This first stage allowed a manual control of the VOD system. The next stage was to implement automated control systems. Allen (2011) later reports with full implementation of the Coleman VOD system and their control strategies which range from manual to fully automated operation has allowed them to reduce energy usage. She also notes that it has had secondary impact, increasing productivity, continuous monitoring of workplace environmental conditions, and a reduction in air heating fuel. The project has been a success and the company intends to expand it to other ore bodies and other operations.

Jahir (2011) points out that Conspec has been working on VOD technology for sensors and controls for over 40 years. Stating that using VOD, or ventilation when needed can save a company significantly since ventilation power can account for between 35-50% of the total mines energy consumption. The Centre for Excellence in Mining Innovation (CEMI) has also investigated VOD focusing on the financial, physical and equipment viability of utilizing these systems in mines (Lyle, G., Bullock, K., Dasys, A., Hardcastle, S. 2010). They developed an interactive system, using a rules engine, which links an event and ventilation simulator. The tool they created presents a dependable and quick appraisal of changing mining scenarios and how the ventilation system can be optimally adjusted to provide the best atmosphere. They continue to do work in this field, collecting data to provide insight for decreasing emissions and financial savings.

NIOSH Mining SMRD has also looked at decreasing short-term exposures to airborne contaminants when VOD systems more global influence is not applicable (Raj, KV., Jacksha, RD, Sunderman, C, Pritchard CJ, 2017). Using monitors, the automated system improved localized airflow and reduced contaminant levels.

All of these VOD systems are being implemented gradually into metal/non-metal mines due to their high cost and intricate backbone infrastructure. Companies are seeing how beneficial a well thought out and designed VOD system can be to their bottom line for energy savings, increased production and also reduced pollution. Equipment and sensor companies are quickly adapting to this changing focus to VOD. Interfaces and an important part of monitoring for VOD and companies such as Conspec and Howden are continually working to provide a connected interface for their equipment to the industry

5.2.1 End User – the Miner

Because the median age of the mining workforce is decreasing, todays younger mine workers are accustomed to multi-tasking and can absorb large quantities of information at once (L Mallett & Orr, 2008). Unfortunately, as older, more experienced miners retire, they take with them a large breadth of knowledge. To facilitate broader knowledge among newer, younger mine workers, computer-based virtual reality and virtual environment training methods are becoming more common in the mining field. Mallett and Reinke point out the importance of computer-based learning to young workers and find that one of the top choices for learning for many current miners surveyed was a simulation (2002). Computers and simulated trainings provide an opportunity to train individuals about emergency situations without exposing them to workplace hazards.

The US Census bureau reported that in 2013, 83.8% of all US households reported owning a computer, and 74.4% reported internet use. Even higher numbers of computer (92.1%) and internet (77.7%) use are attributed to 15-34 year olds (File & Ryan, 2013). These figures show a good connection between the growth in a younger mining workforce and their comfort with computer interaction in their daily lives.

5.2.2 Current mine practices

30 CFR §75.351 states that there must be a designated person (operator) to monitor any atmospheric monitoring system and their responsibility is to monitor and respond to an emergency. The AMS system must have a visual and audible signal in both the surface monitoring location and underground at the effected location for notification of those working in the area. The only mention of record keeping in the AMS law is that alerts, alarms, malfunctions, and tests must be recorded, no continuous data records are required. It is mandated that this information is to be kept in a "secure book that is not susceptible to alteration, or electronically in a computer system that is secure and not susceptible to alternation". Records, by law, are only retained for a year. Real time continuous remote atmospheric monitoring is most common for fire monitoring on belt lines using carbon monoxide (CO) sensors. Using CO sensors in a specific AMS allows operators to not need to continually walk beltlines for fire monitoring. (30 CFR §75.351, 2011)

These regulations give the minimum requirements but with the expansion of current sensor development a greater amount of monitoring data can be attained. This data is easily stored as digital storage capabilities increase and become less expensive. But there is a need to utilize this data in a meaningful way to advance mines and miners safety and health.

5.3 Preliminary design aspects

The main objective when planning the design of an AMS interface is to use visual communication cues to share collected data in an informative way. Making the data visually intuitive for miners is important for the quick transfer and understanding of this information. The focus on underground miners and supervisors, each having a limited amount of time to interact with the information, makes rapid communication of visual data essential to the value of this data.

A glaring point when looking to software development, and it is the power of simplicity (Kaulgud & Sharma, 2015). Creating a mental model, or "small scale" internal representation of a real-world AMS, in our case, a mine map, will assist in making this interface relatable to miners (Craik, 1967). Mines commonly use maps of their mined areas and display these maps in multiple locations throughout the facility. These maps showcase information including ventilation, sensors, safety, ground control, materials, and escapeways to name a few. Miners most likely have a good idea of their individual mines layout and would rapidly understand information displayed on this map.

The recommendation of a standard for symbols in all AMS interfaces to classify main identifiers has been suggested. These identifiers include the sensor bank and atmospheric indicators such as airflow direction and air classification. Figure 5.1 and Figure 5.2 provide suggested symbols for an AMS interface (Dougherty, Luxbacher, Ripepi, Karmis, & Agioutantis, 2015). Also to be considered is the level of miners' map-reading and interpreting abilities, which if utilized can assist in easy interpretation of relative location. The use of these symbols, along with consistency in the interface design, will allow an ease of understanding for miners, contractors, and regulators.

●	1-sensor	Circle
⬬	2-sensor	Ellipse
▲	3-sensor	Triangle
◆ ■	4-sensor	Quadrilateral
⬟	5-sensor	Pentagon
⬢	6-sensor	Hexagon

Figure 5.1: Suggested standard for monitors for a AMS interface(Dougherty et al., 2015)

	Symbol	
Intake	Solid blue arrow	(blue)
Neutral	Solid green arrow	(green)
Return	Solid red arrow with double head	(red)

Figure 5.2: Suggested atmospheric air flow symbols and colors(Dougherty et al., 2015)

5.4 Collecting Data

This interface will be created to present data of various gases and input locations from multiple units and areas of the mine. Along with this input data, data from other sources like weather stations could also be inputted into the interface database. Depending on the size of the mine and likely contaminants, atmospheric data that would be collected could include gasses (eg CO, CO_2, CH^4, O_2), wet and dry bulb temperature, air flow, barometric pressure, fan pressures, airflow pressures, humidity, etc. Two primary contaminants in underground coal mining, methane and carbon monoxide, are important to monitor and understand because increased concentrations of methane in the atmosphere can create an explosive mixture within a range of 5-15%, and increased concentrations of CO indicates combustion. The data collected will be computed and interpreted graphically, which will display changes in AMS data over time.

Three hurdles to overcome with a large quantity of information are data validation, storage, and processing. An application, Atmospheric Monitoring Analysis and Database Management (or AMANDA) was specifically designed for AMS data (Agioutantis, Luxbacher, Karmis, & Schafrik, 2014). With this data management resource for atmospheric data, much of the storage and processing is done within AMANDA. Figure 5.3, Figure 5.4, and Figure 5.5 are examples taken from the AMANDA software system and display some of the software's functionality. Figure 5.3 shows a single methane sensor over time, Figure 5.4 shows multiple methane sensors over time, and Figure 5.5 shows multiple sensors, methane, and barometric pressure over time. These charting functions are user-friendly and are created almost instantaneously, without the need for arduous processing of large data files.

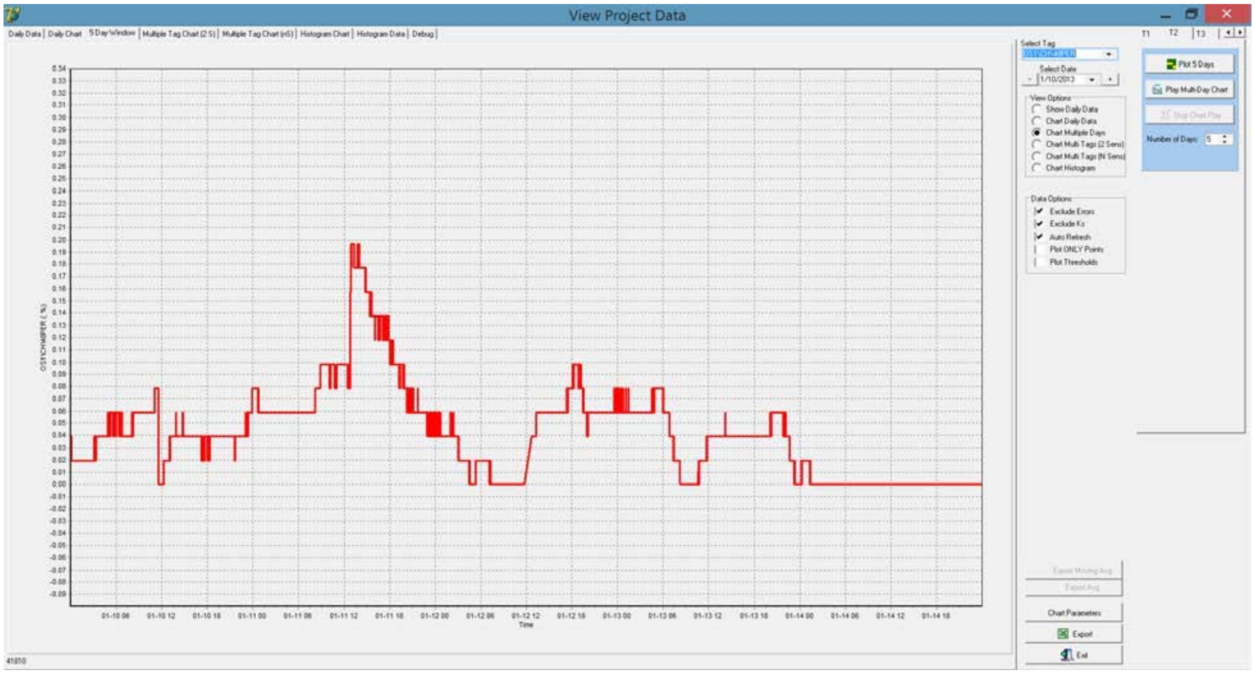

Figure 5.3: Example of AMANDA © software with one sensor (Methane) over a 5 day period.

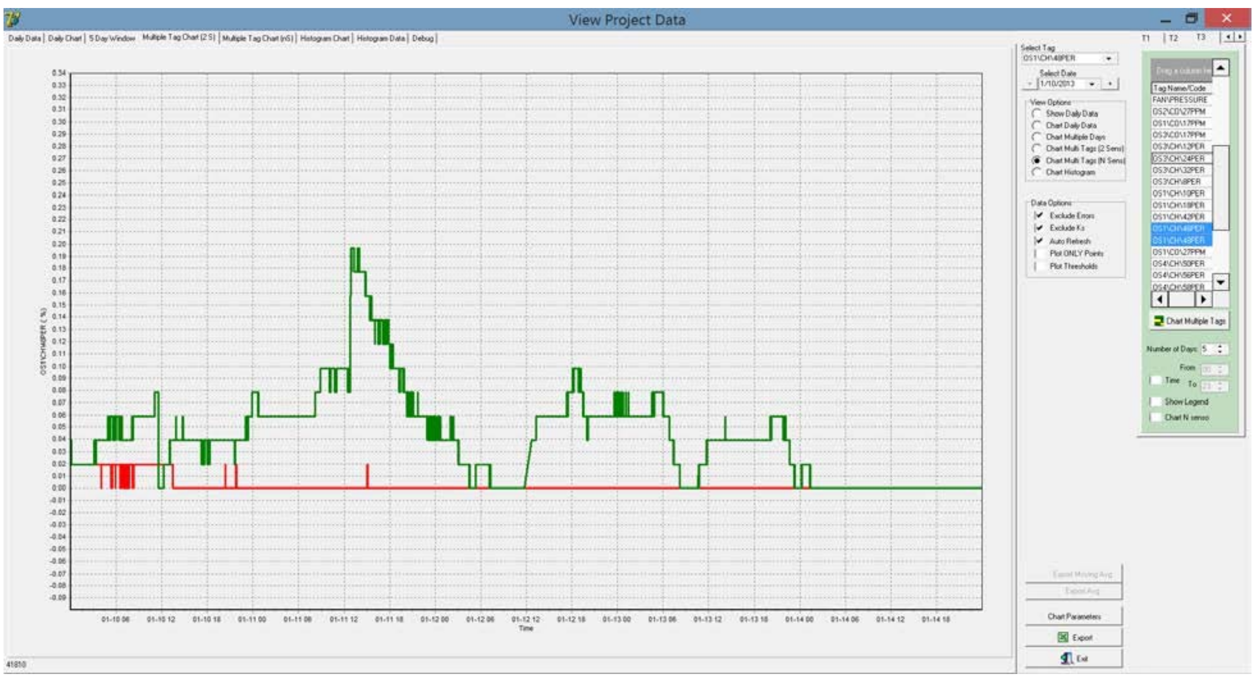

Figure 5.4: Example of AMANDA © software showing multiple sensors of the same type over time.

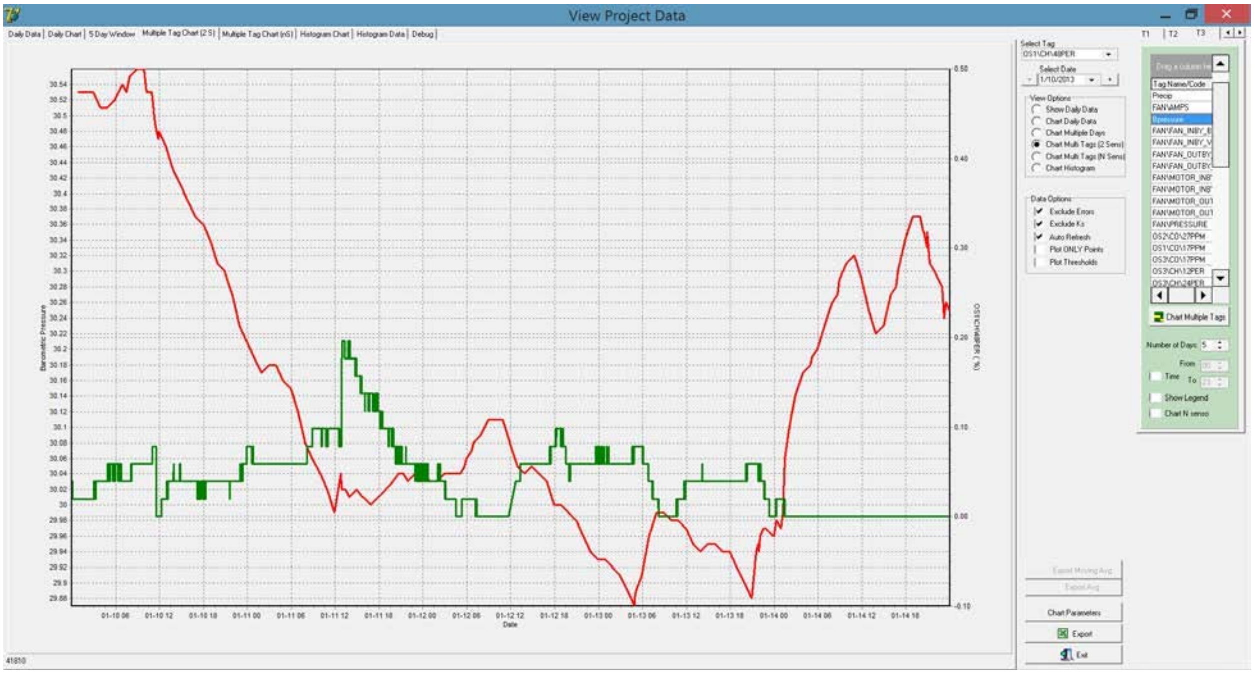

Figure 5.5: Example of AMANDA © software with multiple sensors, barometric pressure and methane over a 5 day period.

The collection of data within an AMS system permits additional functions and uses of this information. Not only can the data be viewed for current trends or occurrences, it also can be used to trend the past for seasonal differences as an example. As databases increase, with a minimum of approximately two years of information, assumptions can be made as to site and general mine variations for seasonal weather influences. This data may even be useful for predicting mine atmospheric changes due to other outside influences.

5.5 Human Computer Interface (HCI): design principles

It is essential when starting the design process to focus on the end user as well as their tasks, their goals, and the values that drive them. Driving factors to consider include the end user's environment, abilities, and situation. In this project, the focus is on the transfer and understanding of collected atmospheric monitoring data for the general underground workforce. Individual miner's tasks vary, but the atmosphere influences all of their work in varying capacities, and all miners are trained to recognize hazardous atmospheres.

Gaining insight from end users about their work habits and expectations is a large part in prototyping development. Collaborating with end users during prototyping allows the researchers to collect feedback and quickly develop ideas for improvement. The prototyping process helps answer questions about the interface such as:

- What is the end goal of this interface? (To convey AMS information)
- What information do we want it to convey? (Keep it simple and straight forward, Continuous Atmospheric Monitoring)
- What might this look and feel like? (Making sure it will be used and accepted by the work force)
- How might this work? (Consider mining constraints in technology)
- What might the experience be like? (how can we make it beneficial and attractive for both miners and management)
- Will it increase learning? Decrease production delays? (Benefit for industry)

Once there is a working interactive interface, the researchers evaluate the developing design by usability studies and surveys. The interface design needs to be compatible with the users' working environment; mining can be very different from other user environments.

5.6 Testing of interface to improve effectiveness

Testing the interface allows researchers to improve current aspects of the design, usability, and effectiveness. To help researchers quantify and examine differences between individuals and their opinions about the interface it is important to gather demographic, experience, and opinion about AMS, safety and health in the survey. This allows for a statistical analysis of the participants and their opinions. A qualitative examination of the interface will assist in assessing the quality uses and applications of the interface and specific user experiences.

5.6.1 Design of Testing

Testing allows miners and supervisors to interact with the interface, e.g. in training, when a good representative cross section of miners are available. This will be done using a testing framework that is meaningful to the miner, and comparable to the final interface, such as a touch screen tablet or touch screen TV. Both individuals and groups will be used for interface testing. Demographic, age, technology experience, education level, time in the industry, and certification information will be collected on each miner and will assist when quantitatively assessing the effectiveness of the interface.

The interface will be evaluated both quantitatively and qualitatively. During quantitation users will be asked prior to interaction their demographic information and their current feelings on safety culture and about atmospheric monitoring. During quantitation, users will be questioned on the ease of use of the interface and how they feel about various regulatory, safety and health topics related to increased AMS use. For the qualitative assessment, questions will be asked as to how users liked their experience, how easy the interface was to use and navigate, how it associates with what they do in their job, and how quickly and easily they understood or learned to use it. Observations and open comments will be recorded along with sections of the survey where participants can leave anonymous comments.

5.7 Initial Interface Prototype

Components for the interface were drafted to include (Figure 5.6).

- Background of a familiar format mine map, possibly in CAD or a map outline so there are reference points to the placement of sensors.
- The use of a touch screen, in Figure 5.6 the purple arrows show that could be touched and moved to put into a graph. Availability to touch to zoom for both mine area and charts.
- Legends so that unfamiliar users can interpret the information easily. Also legends for the charts to determine colors or characters for individual sensors.
- Use consistent symbols when possible; see Figure 5.1 and Figure 5.2.
- Various preset optimal time intervals, 1 shift (8 hours, standard), 24 hours, week, and month.
- Additional areas for information such as from a weather station, either on site or on a local public weather station.

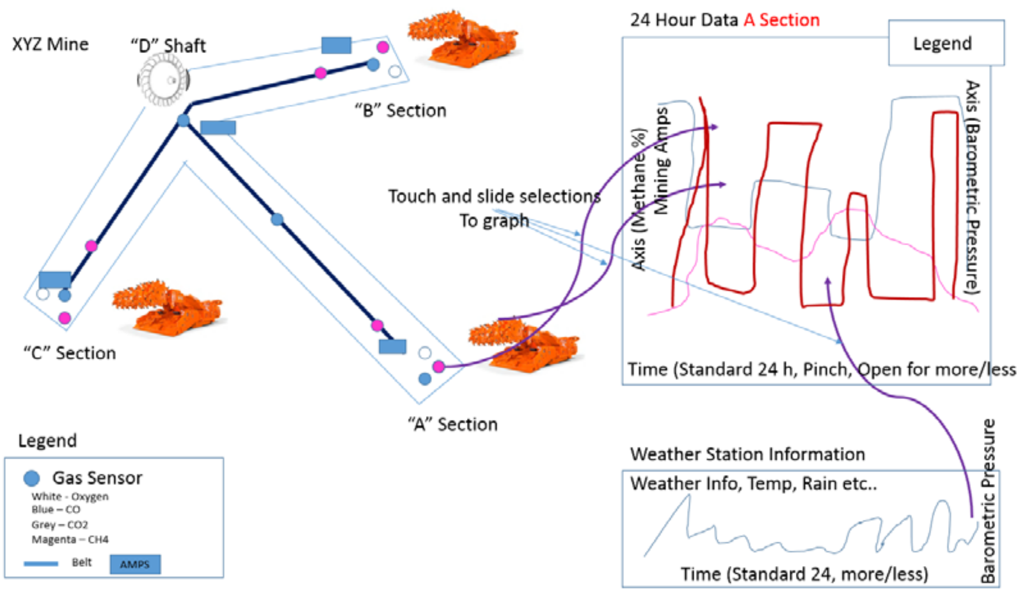

Figure 5.6: Initial visual aid for interface creation

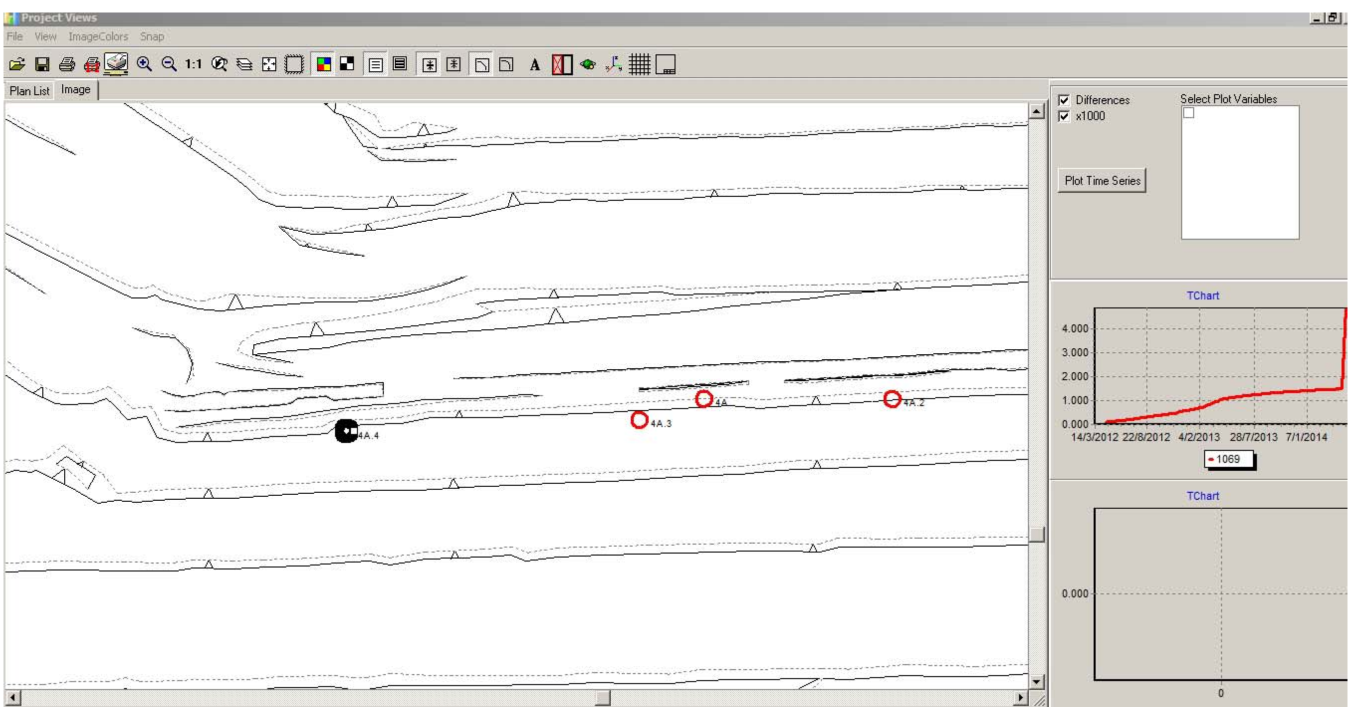

Figure 5.7:Screen shot of ground control interface. Agioutantis © Copyright 2014

Figure 5.7 is the first generation interface from Agioutantis for mine ground control that will be converted for an atmospheric monitoring interface. A zoomed CAD map is visible as the main part of the screen. The red circle dots or indicators on the screen are data points. These points contain large data files, once chosen, they can be graphed on the side of the screen, or the data can be graphed and "popped out" of the screen. The center CAD map is at a zoomed area currently, but can be zoomed out to encompass larger areas, and moved around within the mine map extents.

5.8 Developing data for test Interface

Using real data is important for an authentic experience and interpretation of the AMS interface and what it can do for the miners. Current regulation and company ideals make finding an up-to-date extensive data set challenging. However, a cooperating mine was identified that is collecting and storing expanded AMS data. Their AMS system went beyond normal underground coal regulatory standards, which mainly consist of CO monitoring on belts, to included oxygen (O2) and methane (CH4) at mutiple monitoring stations in the mine.

Due to confidentiality agreements, the mine will be referred to as the Virginia Tech (VT) mine. The VT mine is an underground coal mine located in the United States. The mine is above the water table and consists of multiple continuous miner (CM) sections, has sealed areas, and uses a surface fan for exhausting ventilation. The VT mine has a sealed abandoned CM mine above some of its current mining operations.

The VT mine started out with approximately 10 methane sensors in their returns in addition to their regular CO sensors on their belt lines. Partnered with the methane sensors were oxygen sensors. As the mine grew and faces progressed, additional sensors were added. The sensors are permissible, but are not intrinsically safe. The system was MSHA and state approved for the particular mine site. The sensors used were pellistor type for methane (0-100% of lower explosive limit, LEL) and electrochemical for carbon monoxide (ppm) and oxygen (percent) standardly used in mining applications. Due to compliance with CFR 30 §75.351(n) for calibration of sensors, the VT mine required a dedicated full time technician to maintain the AMS system. (Griffin, 2013)

VT mine installed extensive sensor banks in the mine intake and return as well as belt entries along with sensors at the belt loading point close to the face area. Due to the location and gas content of the coal, many sensors saw little, if any variation in concentrations. Figure 5.5 shows how a sensor that was charted had a maximum methane content of 0.2%. This methane content is very low and did not show any need for additional concern or observation. The data shown previously in Figure 5.5 demonstrate that there is a relationship between barometric pressure and methane released from the particular area of the mine. This is a good example of relational information that is important to use and show to miners for a realistic AMS interactive experience in the interface.

Barometric pressure is typically logged on the surface by local weather stations. The barometric pressure data in AMANDA was imported in from a local weather station in the approximate area of the mine site, and was found to be consistent with the sampling of the mine weather station. Experienced miners are aware that a fluctuation in barometric pressure can have a large influence on gas leakages in and out of sealed areas, gobs, and coal. In his two-year study of underground barometric pressure and methane concentrations Wasilewski (2014) found that this relationship is consistent. When barometric pressure drops, it assists in the release of gas from areas of the mine such as gob, sealed areas, or abandoned over or underlying mines.

5.8.1 Developing Dataset for VT mine

Using actual data from the VT mine, which was gathered and evaluated in AMANDA, a 30-day dataset was chosen for testing with the miner cohort. Important factors when choosing the data from the VT mine in AMANDA included:

- A complete data set, one that did not have holes or spans of equipment or sensor failure
- A time frame where fluctuating barometric pressure or other factors would show the influence on gas concentrations
- Only sensors that showed a variation in gas concentration (methane) were chosen (there were no variations in CO or O2 found)
- Fan amps, methane, barometric pressure, oxygen, and CO were chosen as parameters for the test AMS interface to show simple realistic variables that most all mines could easily monitor and collect and miners would recognize

Due to the low methane concentrations in the dataset from the VT mine, original methane datasets were chosen and then scaled in different ways for different sensors in the mine. Figure 5.8 shows the sensors that were chosen to be pulled from the mine data in AMANDA. This figure also displays an instance of a fan outage and the real impact of this type of mine event on gas concentrations within the mine environment.

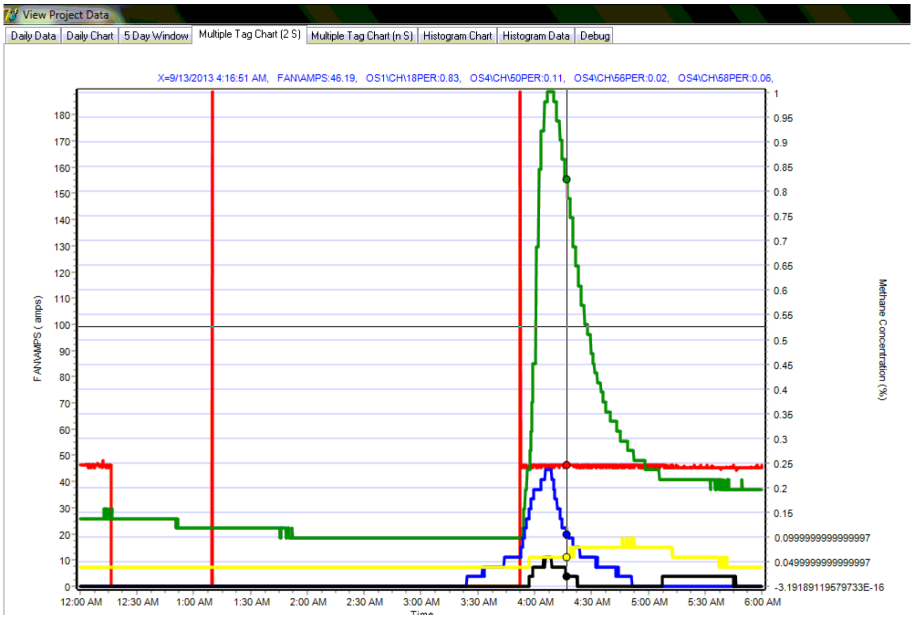

Figure 5.8: Screen Shot from AMANDA showing multiple methane sensors and fan amps.

Figure 5.8 shows that the maximum methane seen over this 6-hour period is 1%, which is within legal limits but quite high for this mine. To make a realistic but concerning scenario, the methane was scaled to a factor of 2 for a data point that shows a 1% maximum initially. These data now shows a 2% maximum which is at the highest legal limit for this type of entry. Using a scaling factor allows zero values to stay zero, and displays peaks within the proper time frame for other influencing factors (eg, barometric pressure changes) in the data.

The data set included some atmospheric changes that should stick out to the miners when viewing the data set. The first one was the interaction between the barometric pressure and the methane concentration in the mine. There was an individual sensor below and area that was previously mined that standardly indicated increased changes in methane, when compared to other mine methane monitors, when the barometric pressure changed. There was also a fan outage in the data set. This fan outage shows a prolonged time where the fan shows no amps (fan is off), and then when it increases to standard amps quickly (fan turned back on). Once the fan is turned back on, the methane sensor below the undermined section increases quickly due to the increased change in pressure. This fan outage and increased methane in the outby area is something that could commonly happen in underground areas that were under or over mined, or sealed areas. It is hopeful that this data assists the understanding of the workforce as to changes in the atmosphere that can occur when standard variations occur.

5.8.2 *Gains from data in the AMS interface*

Initially, a training session was planned for the miners, who would be asked about knowledge gains from the interface once they were given an opportunity to work with it. This was deemed to be an advanced testing technique to be used after a proven interface was developed. It will take time and training to assist the miners in understanding and connecting their hands-on experience with the interface data and graphs. Testing and feedback from the miners about their ease and understanding is the first step in this process. Training is the next step once the interface is in use.

5.9 *Conclusion*

A collection of atmospheric data can most easily be communicated by displaying it visually in a straightforward AMS. Combining data within an interface allows all the sensors and other atmospheric factors to be joined and displayed to communicate what is taking place in the mines atmosphere. This information can be used to educate the miners which increases the safety and health of the workforce and can ultimately increase safe production.

An interface was designed using actual mine data and a map for visual cues. Charting functions and indicators on maps allow for easy interpretation of miners to a "virtual mine map" interface. Using actual mine data to create the data set used in the tested interface creates a realistic test experience for miners, enhancing feedback for development.

It is expected that differences in miners education, experience, and technology know how will influence how they interact with and accept the interface. A straightforward, intuitive, and interactive interface, however, assist all miners in a better and safer understanding of the mine atmosphere.

Acknowledgement

Heather Dougherty is the lead author of this chapter and responsible for most of the original writing. She conceived and wrote the paper with editoral input from Kray Luxbacher and Zach Agioutantis. Agioutantis developed the referenced interface with minor design input from Dougherty.

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6. CHAPTER 6: TESTING INTERFACE, SURVEY, AND OUTCOME

6.1 Introduction

Modern coal mine ventilation systems have a myriad of requirements that make maintenance and monitoring of the system complex for the designer as well as the underground worker. Additional information analysis is needed for understanding, forecasting and prevention. As real-time atmospheric data are collected and analyzed it is must be conveyed to those who are impacted. Translating these data graphically and displaying them through an interface best accomplishes this aim. Determining design parameters for these displays to various cohorts of AMS data consumers a variety of displays were examined by several target populations. The researchers recognize positive outcomes and identify deficiencies within the interface, as well as report possible barriers to a successful implementation.

This interface was designed with respect to the practices and habits of underground miners, their knowledge of maps, and experience with mine gases and safety and health practices. Typical mine maps and atmospheric information were used to simulate a functional AMS interface experience for testing. The researchers collected a mine's atmospheric monitoring data and adapted this for the AMS interface simulation. Touchscreen tablets were used to assist in an interactive environment and allowed multiple participants to interact with the interface individually. Participants reported information regarding their demographics, AMS knowledge, and feelings about AMS and the interface. The information gathered from the cohort of miners tested helped us understand miners' understanding and perception of atmospheric monitoring and the AMS interface they tested.

6.2 Background

The target population for this interface is primarily miners and supervisors who work in underground coal mines. These specific mining personnel were chosen because they spend time underground daily and are most affected by atmospheric changes. They also often make rapid safety and operational decisions with only point measurements of atmospheric conditions. Access to comprehensive information is limited, and commonly not available. If it's presented correctly, this information is meaningful to engineering and management staff at most coal mines, but the focus of this work was to communicate atmospheric data with those who interact daily with the mine environment and can use the information to profoundly impact their daily tasks. Continuous atmospheric monitoring and communication of the corresponding data via touch interface can impact the health and overall safety of miners.

Underground coal mines in the U.S. commonly use continuous atmospheric monitoring for fire prevention, utilizing CO sensors along belt lines and other high-risk areas. Machine mounted monitoring and handheld sensors are also standard practices. Digital continuous monitoring of multiple gases (e.g., CO, CO_2, O_2, CH_4) are available, but uncommon.

Researchers went to mine sites and surveyed miners, both underground labor and management, during safety training. An overview of current atmospheric monitoring legal standards, atmospheric monitoring data, and the user interface was discussed with all miners. A description of how the interface could be used and a summary of the system was also given. Surveys were given prior to and after interface interaction to gather thoughts, ideas and input.

The developed interface is named ADAMAS, A DAta MAnagement System, pronounced a.da.ma:s (Agioutantis 2015). It is a database system used to store data and access it graphically using map locations as data points. An assumption we made about all miners is that they would have a spatial understanding of their mine and a familiarity with reading underground mine maps. This map interface allows mine maps to be used as a visual cue and the location of sensors associates the area of the mine and AMS data. This visual association allows the user to understand and relate the data to their work site more quickly.

6.3 Survey Design

Two surveys were designed to gather pertinent information in the following categories:

- Pre Interface Questionnaire
    - Demographic and training
    - Familiarity with technology
    - Familiarity and current opinion with AMS
- Post Interface Questionnaire
    - Feedback from ADAMAS interface interaction
    - Feelings on what is essential with AMS

Demographic and training information was modeled after The Office of Mine Safety and Health Research national survey of the mining population (McWilliams, Lenart, et al. 2012) for comparison purposes to the full coal mining population. Information in these categories assists in evaluating the interface by determining feelings, perceptions, and target populations for the most significant impact of ADAMAS interface.

6.3.1 IRB application and approval

The Institutional Review Board (IRB) of Virginia Tech requires submission of a protocol for approval before human participants are surveyed. The protocol was approved on March 30th, 2016. The following documents were included in the IRB application (Appendix A):

- Recruitment Materials
- Consent Document
- Data Collection Instruments – e.g., Interview questions, surveys (protecting confidentiality & anonymity)
- CV, resume, or biographical description for all investigators
- All investigators must also have proof of a completed human subject protections training.

Recruitment materials included a statement that safety managers and trainers at prospective survey sites (underground coal mines) would be contacted to inquire if they would be willing to participate. The goal when working with mines was to minimize disruption by participating in already scheduled meetings or training. We also proposed that engaging miners in such active techniques with atmospheric data and scenarios has a secondary benefit as a safety activity.

Every participant was informed of the following and consented to the testing:

- Title and investigators of the research project
- Purpose of the research project
- Procedures if they agree to participate
- Risks and benefits of the research project
- Extent of anonymity and confidentiality
- Compensation
- Freedom to withdraw
- Questions or concerns
- Final signature for consent

Before any surveys were conducted, the informed consent form was reviewed and signed by each participant and collected in a way that would preserve anonymity. Participants were informed that they were not required to complete the survey or to answer questions with which they were at all uncomfortable. No payment or benefit was received, and no perceived risk was present.

The survey was split into two parts. The first, labeled "Pre-Interface Questionnaire," was designed to collect demographic, opinion, and experience information from the miners. It was given before their interaction with the interface, although some of the participants may have received an introduction to atmospheric monitoring and background on the interface and data. The second portion of the survey was labeled "Post-Interface Questionnaire" and was given after the surveyed miners had the opportunity to be guided through and interact with the interface, individually or within a group. This part of the survey was designed for determining the ease or difficulty of working with the interface, the miners' feelings about its implications, and how it would be incorporated at their mine site.

6.4 Introduction and training of interface

The survey population was given a brief introduction to AMS and the interface prior to the survey. Using actual mine situations as examples of how the interface could be used, the researchers explained to the survey participants how collection and communication of additional atmospheric data can be beneficial. Next, each participant was given the Pre-Interface Questionnaire to complete. While the survey was being completed, the researcher passed out Surface tablets with the interface open to participants. This touchscreen tablet used was preloaded with the AMS interface software and a month of atmospheric data. There were approximately nine tablets with the interface that were used, which were shared when groups had more than nine participants (Figure 6.1).

Participants were informed that real data was used in a mock mine map of the "VT mine" and that a full month of data is available for viewing and interacting within the interface. Discussions were held about how this interface could benefit the miner, (e.g. knowledge of atmosphere prior to entering, especially in unfamiliar areas or those that are not inspected regularly). It was stated that the interface was for the miners' benefit and that the intention is to mount the interface on a large interactive screen in an easily accessible common area such as the lamp room. This would allow ease of view and interaction with the data for all miners.

To assist the participants in understanding the mine and the data they were observing, a large printed map of the VT mine was available. Figure 6.2 is the map of the VT coal mine used in the interface showing one active continuous miner section. It was also communicated that there is an overlying sealed mine and that the current mine was above the water table and contained a sealed area.

The VT mine, both in print form and on the interface, contained a substantial amount of atmospheric monitoring and ventilation information. These maps included ventilation controls, ventilation direction and type of airflow, sensor locations, fan location, belt lines, and a legend.

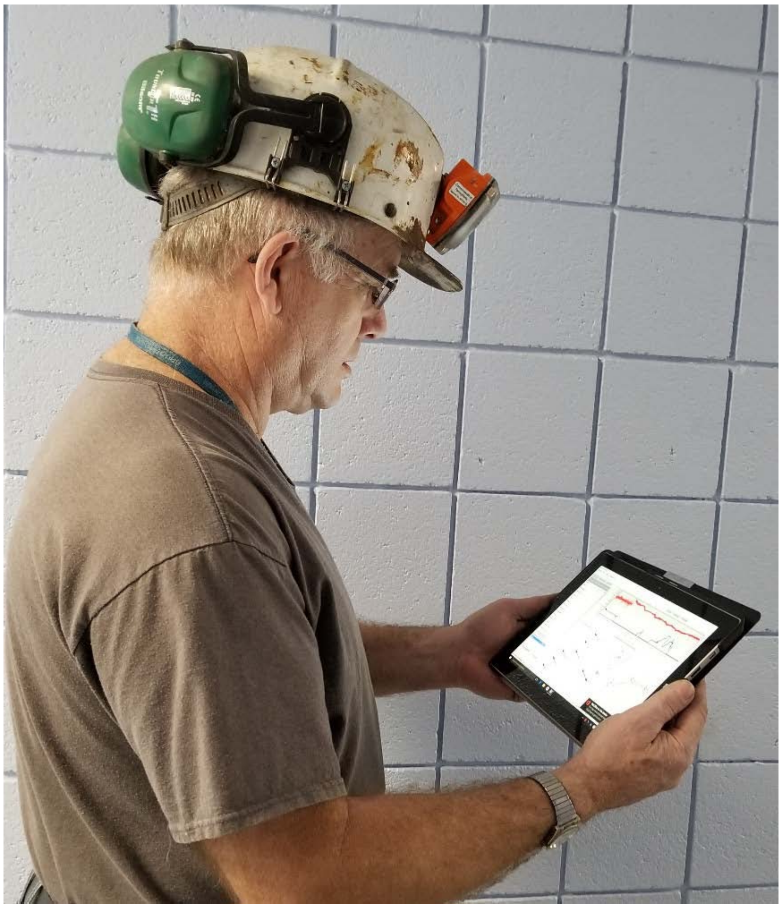

Figure 6.1: Miner interacting with ADAMAS interface on tablet

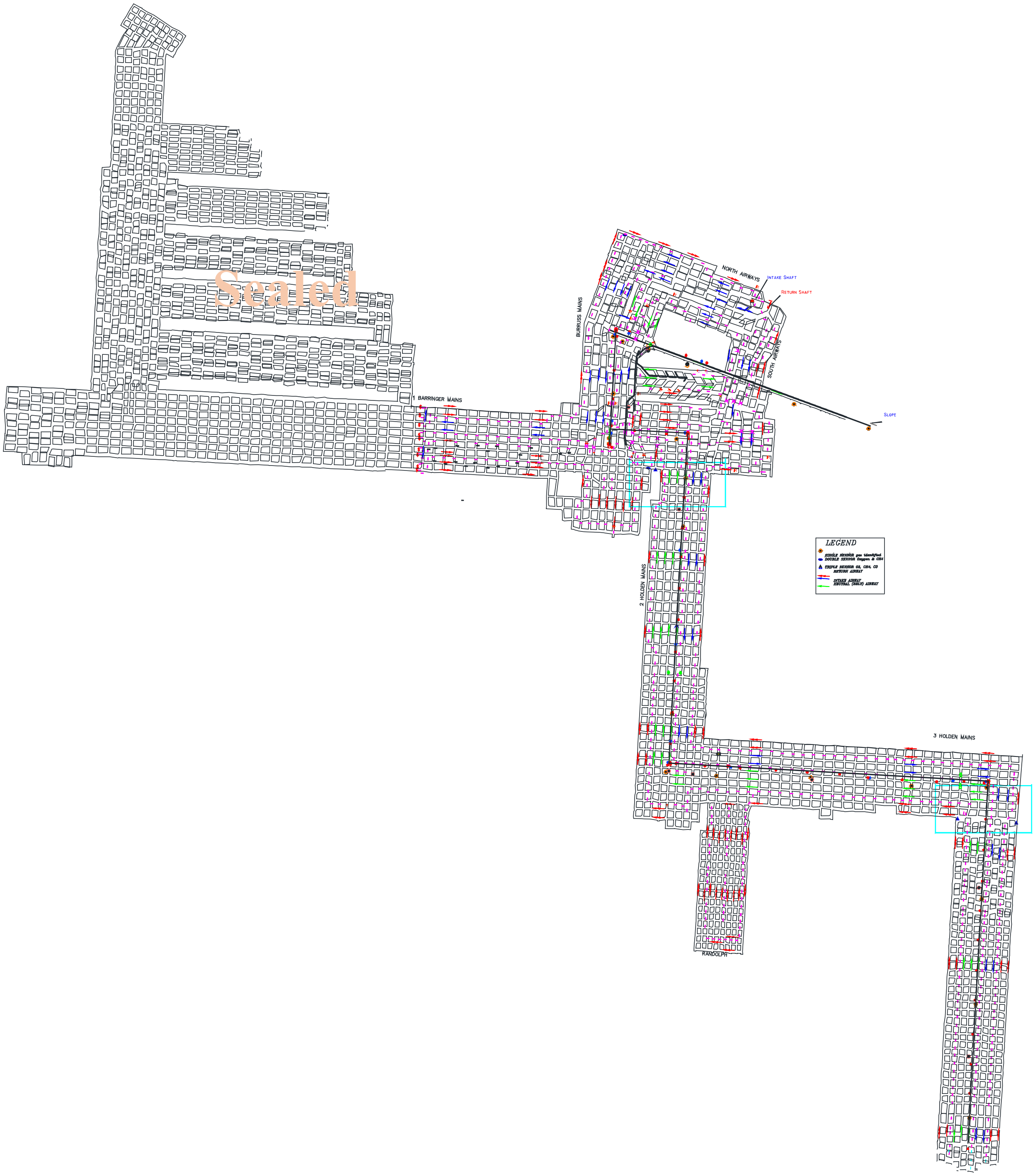

Figure 6.2: Virginia Tech (VT) full mine map

Figure 6.3: Screenshot of interface showing intake barometric pressure at the top (red box), sensor names on the left (green box) and the zoomed in mine map with the sensor location and label at the bottom (blue box).

Once the survey was complete, the tablets were distributed, and the researchers provided an overview of the information, an overview of the interface was initiated. The map, charts, and listing of sensors and gases was identified within the interface. A guided tutorial of the interface was given, which covered:

- Finding available sensors and gases (Figure 6.3, green box)
- Zooming into the map
- Changing the length of time of the data shown (last 24 hours, week, and month were options)
- Identifying sections on the map (Figure 6.3, blue box)
- Chart identification, including scales and legends (Figure 6.3, red box)
- Clearing the map and charts
- Turning on and off sensors, from the charting and the map areas (Figure 6.3, green box)

As a walk-through exercise, miners were shown how to use the interface by turning on barometric pressure and methane sensors. Three time frames were available for viewing in the interface:

the last 24 hours, last 7 days, and last month. A week time frame was chosen, barometric pressure and methane sensors within the mine were turned on and charted, after which the participants reviewed the data that was displayed. The participants were then asked what they identified in the charted information. Figure 6.4 shows an example from that exercise demonstrating a clear correlation between barometric pressure on the surface and methane release in the underground mine. Participants were then shown how to clear data from the map and charted area.

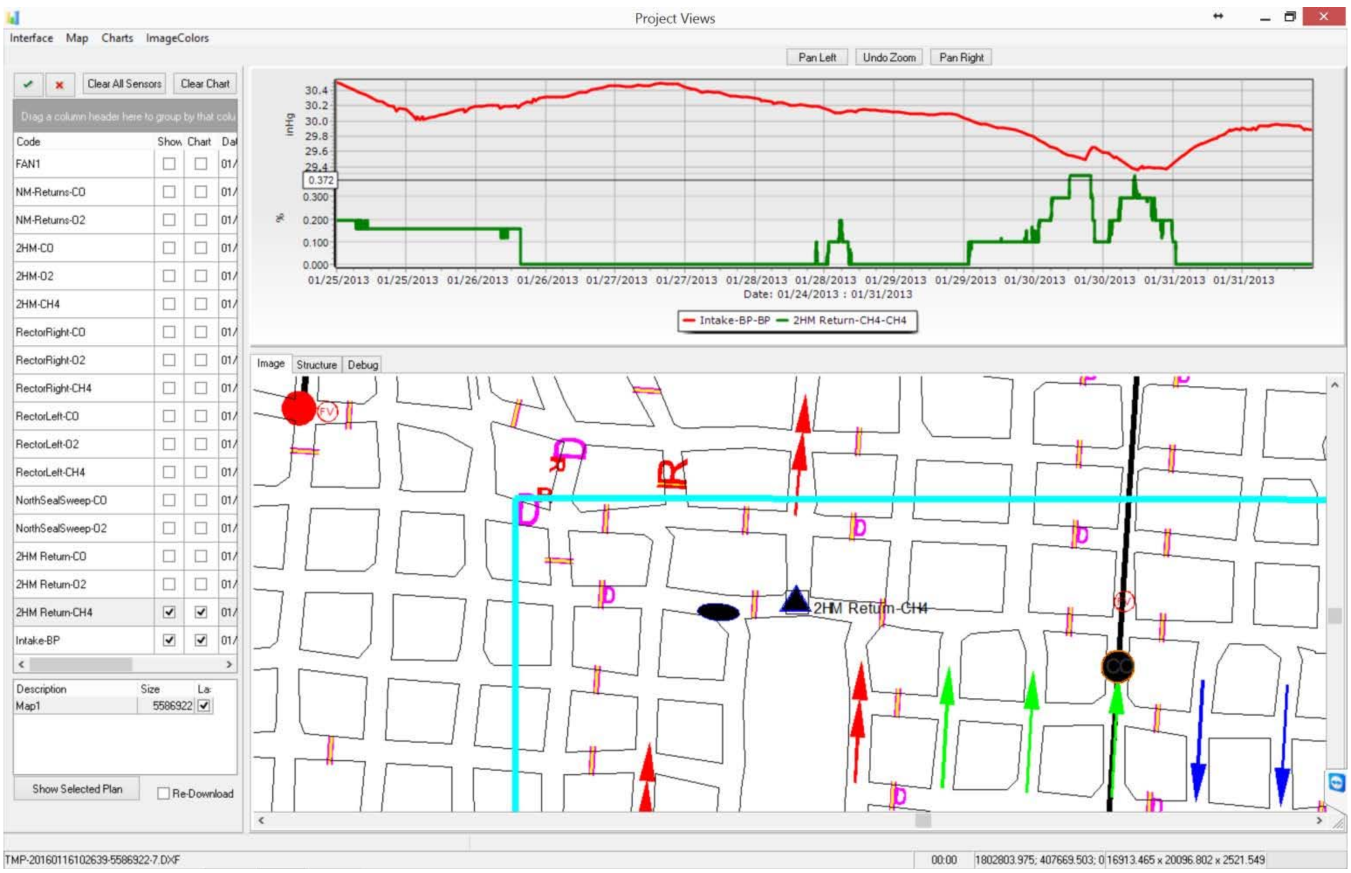

Figure 6.4: ADAMAS AMS interface showing a methane sensor and barometric pressure charted for a week time frame.

In a second scenario, the fan amp data and methane data in an outby area were turned on. After viewing the data generated over the course of a month, the miners were asked what they identified. As can be seen from Figure 6.5, the methane spiked in a location shown on the map after the fan was put back in service after an outage. Participants were shown how to zoom in on areas of the chart to better understand the data. After the guided scenarios the participants were then given approximately three to five minutes to explore the interface on their own or give another group member the opportunity to interact with the interface.

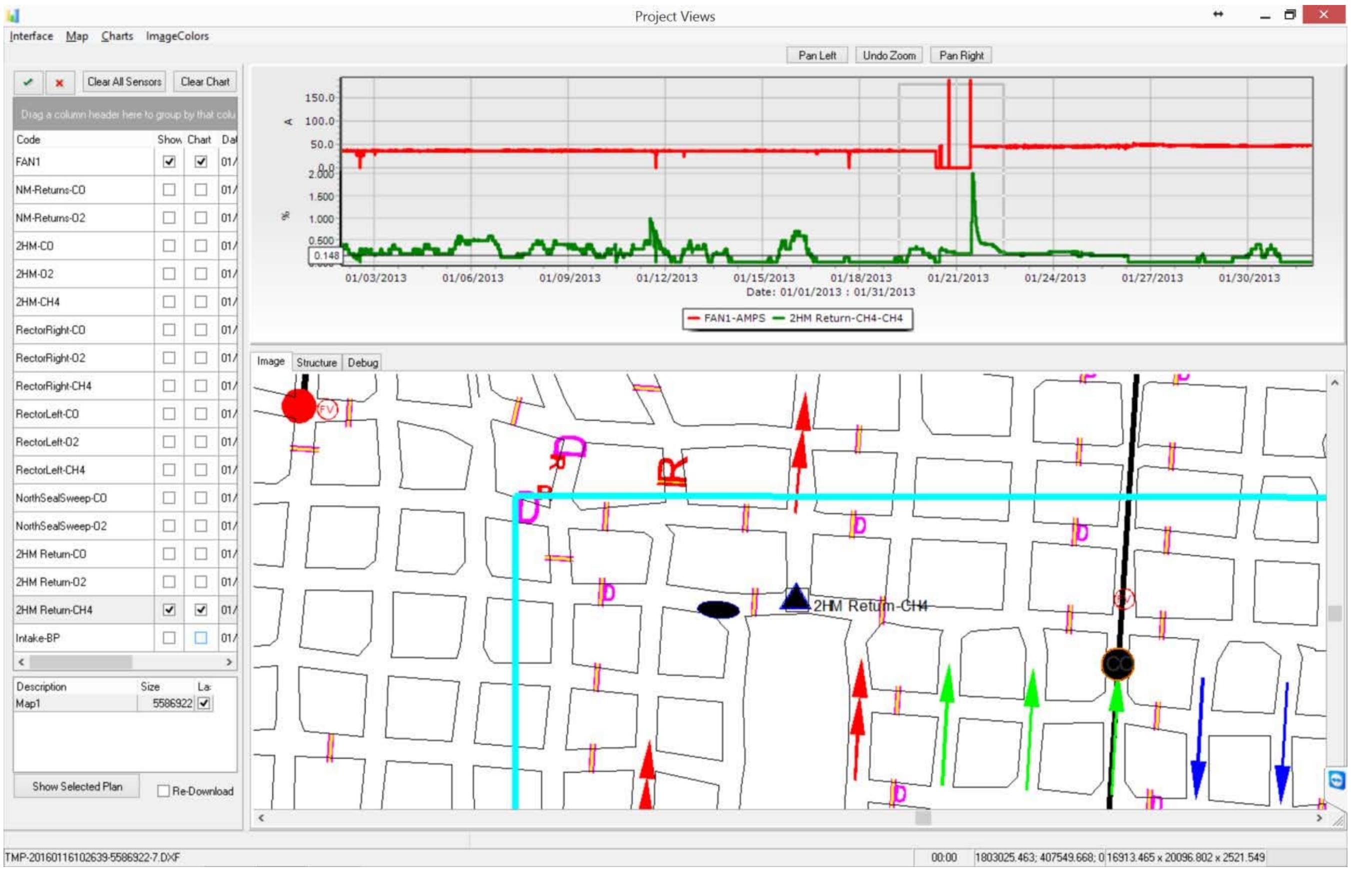

Figure 6.5: ADAMAS AMS interface showing Fan Amps, and methane data for a 30 day period.

The post-interface questionnaire was then distributed so participants could provide feedback on the interface and their experience interacting with it. The miners were asked to rate the interface as if the data were real-time, or almost real-time, information for their particular mine. Though only a small tablet was used for this study, the participants were told the system could be implemented on a large screen in common areas where miners were most likely to spend time pre- and post-shift.

6.5 *Collection of Survey data*

The survey was given in two locations: the Cumberland underground coal mine in Greene County, Pennsylvania and the MSHA Academy in Beckley, West Virginia. Testing was done during the Cumberland Mine's quarterly emergency response and preparedness (ERP) training, which consisted of water inundation, CPR and AED training, and ventilation. Cumberland mine is an underground longwall coal mine with approximately three continuous miner (CM) sections and one active longwall. The researcher communicated with approximately 400-500 miners, managers, union members, and contractors over a three-week period.

At the MSHA academy, the researcher interacted with two classes of approximately 15 MSHA surface metal/non-metal (M/NM) inspectors each. One class included novice inspectors, and the other was a group of experienced inspectors. Both groups had experience in various states across the country.

Participants occasionally skipped questions leaving portions of the surveys blank and with missing data. The researcher opted to exclude surveys where one full side or more of the survey was left blank. This occurred mostly when large classes were surveyed, which could have been because participants did not have an opportunity to work with the tablet, did not feel comfortable completing the survey, did not have the additional time to complete the survey, or simply because they chose not to complete the survey.

6.6 *Results*

Once surveys were completed, an Access database was set up to input all the data. This was done so that the information could easily be processed and separated for analyses. A data sheet was created with questions, and Access labels used for inputting data (Appendix B).

The targeted population for testing was underground coal miners. The majority of participating miners came from coal mines with a small population from metal/nonmetal mines.

6.6.1 *Pre-Interface Survey Data*

The Office of Mine Safety and Health Research released a national survey of the mining population (McWilliams, Lenart, et al. 2012) that was used to assist in determining demographic data so that the data could be compared to the general underground coal mine population. In the tables, the NIOSH title refers to this data, while "Survey" refers to the data collected during this research. Table 6.1 is a descriptive statistical data table of survey participants displaying age and mining experience. These data show that the surveyed population was younger than the median NIOSH population age of 43.8

years and had fewer years of experience than the NIOSH population (16.0 years). Table 6.2 indicates that the surveyed population was more educated than the NIOSH survey population. Table 6.3 displays the breakdown of the gender of the population (NIOSH data) and surveyed data, showing the large discrepancy in gender in the mining field, which is predominantly male.

Table 6.1: Descriptive Statistical Data of Age and Experience collected by Survey data. Age of workforce in years and experience as a miner in years.

Descriptive Statistical Data - Survey		
	Age (years)	Experience (years)
Mean	41.46	14.13
Standard Error	0.62	0.58
Median	40	10
Mode	39	6
Standard Deviation	11.25	10.44
Minimum	21	1
Maximum	68	44
Count	325	324
Confidence Level (95.0%)	1.23	1.14

Table 6.2: Comparison of Education for NIOSH population survey and Survey of participants.

Education	NIOSH	Survey
Some High School	6.5%	0.9%
High School	76.7%	46.1%
Some college, Associates	14.0%	37.0%
Bachelor’s degree or beyond	2.8%	16.0%

Table 6.3: Comparison of gender for NIOSH population survey and Survey of participants

Gender	NIOSH	Survey
Male	96.2%	97.9%
Female	3.8%	2.1%

Current job classifications, classifications performed in career, certifications, and job title (e.g., management, union, etc.) were surveyed. Within current job classification (Table 6.4), 48.2% of employees reported working as an outby laborer (utility) or inby machine operator. Utility workers may only work on a production section but usually are involved in jobs throughout the mine. Inby machine operators tend to be limited to a production section and do not spend time in multiple areas of the mine.

Table 6.5 indicates that more than 50% of the mine population (71.8%, 70.6%, and 67.9%, respectively) reported holding the job at one time of an outby laborer (utility), inby laborer, and inby machine operator. A large portion (40.2%) also reported being motorman/supply worker who moves throughout the mine and is familiar with working sections and outby areas. Table 6.6 displays the certifications of surveyed miners, showing that most survey participants (85.6%) reported having their underground miner certification, followed by a machine operator certification (67.3%). A combined total of 46.5% of surveyed miners reported having either an assistant mine foreman, fireboss, or mine foreman certification, showing that they have tested and are legally able to inspect the mine for dangerous conditions. Table 6.7 explores the job titles of the surveyed workforce, with the majority of the surveyed miners (66.2%) being union workers followed by management (23.9%) with a much smaller surveyed population of regulatory/government, contractors, or non-union workers.

Table 6.4: Current main job classification of surveyed miners

Job Classification	Percent total of workforce
Outby Laborer (Utility)	25.9%
Inby Machine Operator	22.3%
Mechanic/Electrician	8.4%
Management	7.8%
Regulator Agency/Government	7.5%
Underground Supervisor Face	5.4%
Inby Laborer	4.5%
Fireboss	4.2%
Engineer	3.6%
Safety	3.3%
Underground Supervisor Outby	3.3%
Motorman/Supply	2.7%
Maintenance Foreman	0.3%
Other	0.3%
Water technician	0.3%

Table 6.5: All job classifications performed in career for surveyed miners

All Job Classifications Performed	Percent of workforce
Outby Laborer (Utility)	71.8%
Inby Laborer	70.6%
Inby Machine Operator	67.9%
Motorman/Supply	40.2%
Fireboss	25.2%
Management	22.5%
Mechanic/Electrician	20.7%
Underground Supervisor Outby	19.8%
Underground Supervisor Face	18.6%
Safety	11.4%
Regulatory Agency/Government	7.2%
Engineer	5.7%
Other	2.4%

Table 6.6: Certification from surveyed miners

Certification	Percent of workforce
Underground Miner	85.60%
Machine Operator	67.30%
Underground Gas Check	52.00%
Assistant Mine Foreman	24.00%
Fireboss	16.20%
Mine Foreman	6.30%
None	4.20%

Table 6.7: Job Title classification from survey of miners

Job Title	Percent of Total
Union Worker	66.2%
Management	23.9%
Regulatory/Government	7.3%
Contractor	2.4%
Non-Union Worker	0.3%

The pre-interaction questionnaire also looked at familiarity and knowledge of computer systems, AMS, and awareness of other monitoring in the mine, such as weekly inspections and reviewing recorded "book" information (e.g., information that is recorded by law on a weekly, daily or shift basis). Table 6.8 indicates that miners have an 83.2% chance of interacting with a tablet or smartphone a few times a week or more and a 78.1% chance of interacting with a computer on the same time basis. Only 22% of the surveyed population used a video game system a few times a week or more.

Only 33% of the workforce reported examining log books, which report inspections throughout the mine, on a weekly or greater basis, but 78.1% of the population reported that additional monitoring of gases would be helpful. Of this additional monitoring, as indicated in Table 6.9, more than 50% of the miners surveyed found that the face, belt, bleeder, and outby areas (71.2%, 69.6%, 65.8%, and 58.5% respectively) being monitored would be helpful to them.

Table 6.8: Video game, Computer and Tablet/Phone use by surveyed miners

	Never	Monthly	Weekly	Few times a week	Daily
Video Game	59.00%	19.00%	8.00%	8.90%	5.20%
Computer	13.00%	9.00%	13.60%	17.30%	47.20%
Tablet/Phone	14.70%	2.10%	3.70%	9.50%	70.00%

Table 6.9: Additional continuous monitoring areas by surveyed population

Place to be monitored	Percent helpful
Face	71.2%
Belt	69.6%
Bleeder	65.8%
Outby	58.5%
Other	8.5%

When asking miners what AMS were available or used at their mines as seen in Table 6.10, 85.3% indicated that they had a belt CO system (carbon monoxide). Fewer indicated that they had an additional gas monitoring or another system (34.5% and 2.4%, respectively). A surprising number (11.7%) indicated they were unaware of the AMS system or type of system used at their mine. Of the surveyed mining population, 56.2% indicated that current AMS information was available in common areas and easily accessible.

Table 6.10: Current types of AMS available at the mine as reported by survey

AMS at current operation	
Belt CO System	85.3%
Additional gas monitoring system	34.5%
I don't know	11.7%
Other	2.4%

The survey population was asked "Why or why not is atmospheric monitoring beneficial to you?" on this portion of the survey. The response was generally positive, that they like it for its safety and they believe it would make the mine safer. That it can help in areas where they work when they are not inspected on a regular basis, and that the real time nature of the information allows for rapid mitigation of ventilation issues. A few concerns were raised that there is "enough monitoring" (e.g. too much currently) at their particular mine, that it did not affect their job or daily work, and that it would be beneficial for negative enforcement activities. There were also a few concerns about the feasibility of having additional monitors, calibration, and maintenance of a comprehensive AMS in the mine.

6.6.2 Post-Interface Survey Data

Once the interface was introduced to the tested population, at least one scenario was explored prior to the post-interface questionnaire being administered. As stated, the questionnaire had four main sections:

- Ease of use of the interface
- How they felt about AMS
- Who they felt an AMS would be useful for
- What type of AMS would be helpful to them

When exploring the ease of use of the current interface for the surveyed miners, the questionnaire asked if eight different aspects of the interface were *very hard, hard, neutral, easy*, or *very easy*. The data were recorded as a numerical value from 1-5, with 1 being *very hard* and 5 being *very easy* with 3 indicating *neutral*. The numerical system allowed for a conversion to more easily average and evaluate responses, quantitatively. Question 1 included the opening statement of "Working with this Atmospheric Monitoring Interface, how easy was it to" and followed by the a-h questions shown in Table 6.11. Table 6.11 also indicates the labels used in Access to identify each question, 1a-1h, and the average recorded value of all responses. Figure 6.6 displays the population percent of responses from *very hard* to *very easy* and uses the Access labels to identify questions. The survey found the interface for the population to be approximately "*neutral*" to "*easy*" in each category surveyed to operate with the majority of the responses indicating "*easy*." The two hardest interface operational areas were understanding the data presented and identifying the active working section (questions 1e and 1a). The easiest operational areas of the interface were identifying changes in gases at sensor locations and changing the gas chart data to different time frames (questions 1g and 1h).

Table 6.11: Post-Interface Questionnaire Question 1 data. Label, Question and Average answer value for data collected in survey population.

Label	Question	Average Value
a) Section	Identify the active working section?	3.53
b) Sensors	Identify the sensors in the active working section?	3.81
c) SensorLoc	Find the sensor locations throughout the mine?	3.78
d) SensorData	Access the data from the sensors?	3.72
e) data	Understand the data from the sensors?	3.38
f) SensorMove	Move to different sensors throughout the mine?	3.81
g) Gaschg	Identify changes in gases at sensor locations?	3.86
h)ChartTime	Change gas chart data to different time frames? (e.g., 24 hr, 1week, etc)	3.85

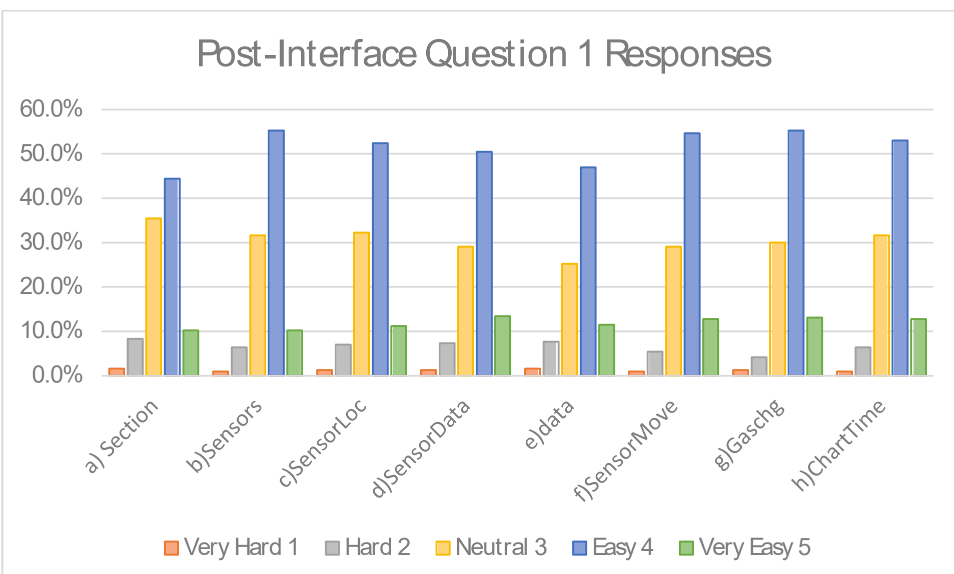

Figure 6.6: Post-Interface Question 1 responses in percent from entire survey population.

When exploring how surveyed miners felt about AMS in relation to their job and mine, the questionnaire asked six different opinion questions with response choices of *strongly disagree*, *disagree*, *neutral*, *agree*, or *strongly agree*. These data were recorded as a numerical value from 1-5, with 1 being *strongly disagree* and 5 being *strongly agree* and 3 indicating *neutral*. The numerical system allowed for a conversion to more easily average and evaluate responses. Question 2 included the opening statement of "Rate how you feel about," followed by a-f questions as shown in Table 6.12. Table 6.12 also indicates the labels used in Access to identify questions 2a-2f. The average recorded value of all responses is used in Figure 6.7 for ease of labeling questions. Figure 6.7 displays the population percent of responses from *strongly disagree* to *strongly agree*. The survey found the survey population feel about AMS to be approximately "*Neutral*" to "*Agree*" in each category surveyed. The majority of the responses indicating "*Agree*" for most questions, excluding miners opinion that the data would be used for increased or unfair oversight by regulatory agencies. This question (2c) was rated more "*Neutral*" than the others. The lowest AMS opinion rated question was the belief that by providing this information would lead to increased or unfair oversight from regulatory agencies (question 2c, 3.45). The highest rated AMS opinion area was that the safety and health of the miner and operation will be increased by having AMS data available with a very strong agree response (question 2d, 3.94).

Table 6.12: Post-Interface Questionnaire Question 2 data. Label, question, and average answer value for data collected in survey population.

Label	Question	Average Value
a) Decisions	Miners can make better decisions by having additional atmospheric monitoring data available.	3.88
b) ImpReg	Providing this information will lead to improved interactions with regulatory agencies?	3.66
c) UnfairOver	Providing this information will lead to increased or unfair oversight from regulatory agencies?	3.45
d) SHIncrease	The safety and health of the miner and operation will be increased by having atmospheric monitoring system data available.	3.94
e) EasyInter	It will be easy to interpret this information and make it useful for the miner?	3.69
F)Presenting	Presenting this information on a handheld device for use underground at my operation(s) would be useful.	3.76

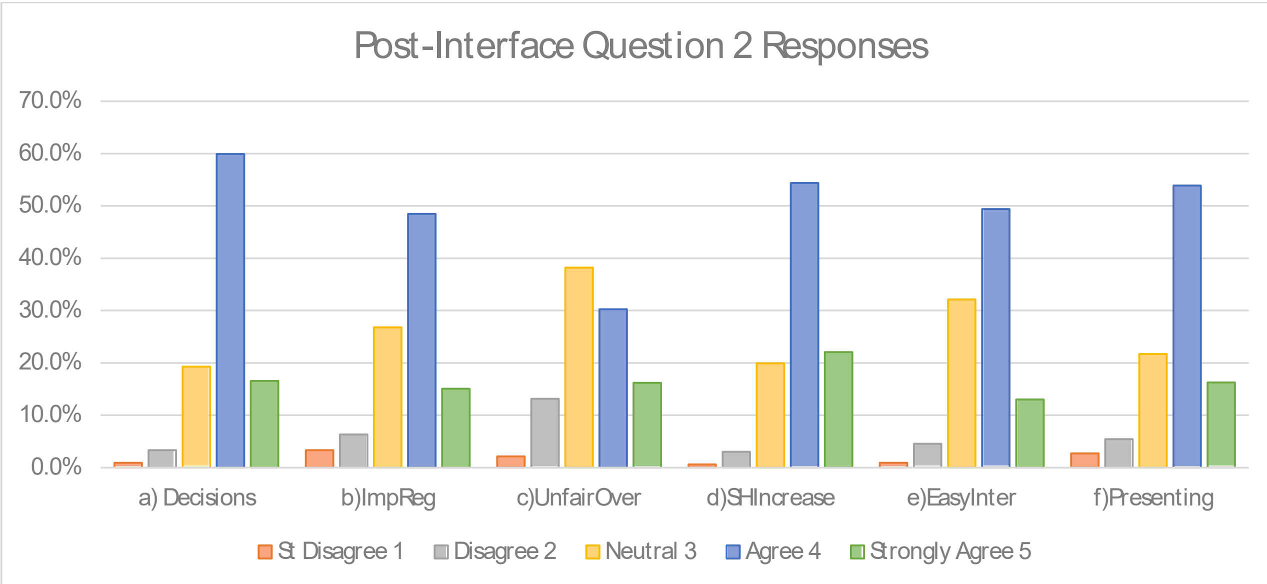

Figure 6.7: Post-Interface Question 2 responses in percent from entire survey population using labels from Table 6.12.

Question 3 relates to who the surveyed miners believed would use the AMS information and interface on a regular basis at work. They were asked if they would personally be more likely to use it, or if miners, supervisors, engineers, managers, or regulatory workers would be more likely to use the interface. Figure 6.8 displays the breakdown in percent of responses of the entire survey population. The highest perceived use by the surveyed population was for the engineers (87.4%) followed closely by supervisors (83.2%) and management (81.4%). The lowest perceived use by the surveyed population was by the miner at 49.8%.

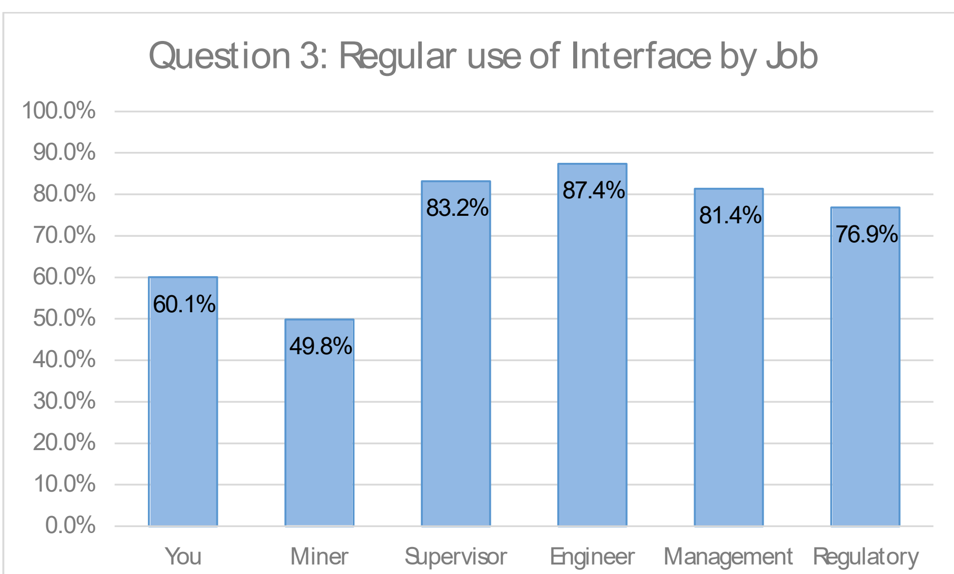

Figure 6.8: Post-Interface Question 3 responses in percent from entire survey population.

Question 4 relates to the areas of the mine that the surveyed population feels would be useful to monitor on a regular basis. Participants were instructed to select all that would apply to them. Figure 6.9 describes the breakdown of identified areas deemed useful for AMS monitoring as indicated by the entire surveyed population. The top three areas they feel would be useful to monitor are *all returns* (73.9%) with *seal lines* surveyed identically (73.9%), followed closely by *belts* (72.4%) that are currently monitored more frequently in underground AMS. The three lowest areas participants feel would be useful to monitor were the s*lope* or haulage shaft (49.8%), *shaft bottoms* (50.5%), and *outby section returns* (58.3%). A majority of listed areas showing greater than 50% agreement that it would be beneficial to monitor on a regular basis.

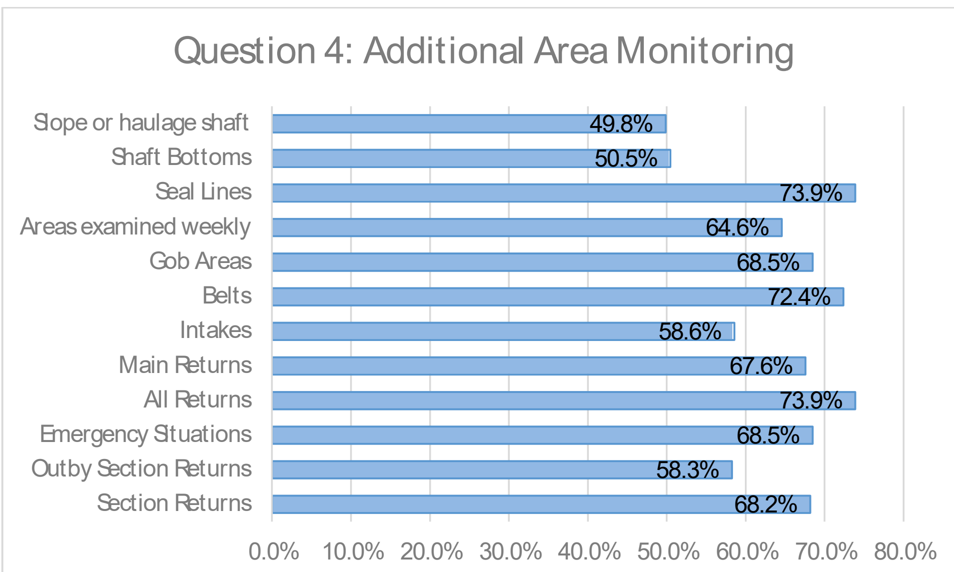

Figure 6.9: Post-Interface Question 4 responses in percent from entire survey population.

Question 5 relates to additional atmospheric parameters that miners would feel would be beneficial to monitor for underground coal mining operations. Figure 6.10 shows all the atmospheric data that were included on the survey along with the survey population percent that indicated which data would be beneficial to monitor. The three most chosen atmospheric data by the surveyed population were *methane* (82.0%), *carbon monoxide* (79.9%), and *oxygen* (76.0%). The three least chosen AMS information by the surveyed population were *belt amps* (36.0%), *weather* (40.5%), and *fan amps* (41.1%).

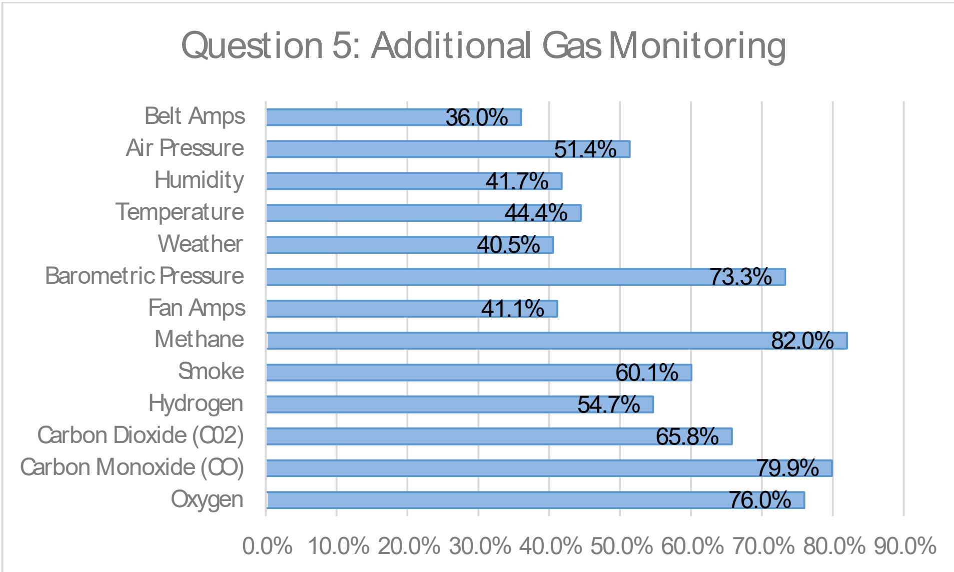

Figure 6.10: Post-Interface Question 5 responses in percent from entire survey population.

At the end of the survey it was asked "Do you identify any other opportunities for improvement in current atmospheric monitoring systems?" The responses to this written question were minimal. Most of the comments asked for the interface to be simple, easier to operate, more user-friendly, mainly within the map, additional training, and larger buttons. All of these represent easily adaptable solutions within the software. Some of these issues were caused by the small screen that was used for testing. In a real mine case, this would be on a much larger screen and scale in a common area, which would eliminate some of the requests to enlarge figures and information. The occasional negative comment centered on systems like this being a job killer, saying it would negatively affect jobs at the operation. Other comments had ideas for improvement, adding that a handheld device would be valuable for miners. Researcher notes from the survey conversations found that management found this system could be beneficial for multiple systems within the mine. Adding information to a common system that could be accessed could be used for communication, e.g., an "internet" of the mine operation. Management and union both had concerns that this information could be misused by regulatory agencies to regulate operations unfairly.

6.7 Hypotheses

Initial hypotheses were made from researcher experience and stakeholder input. Initial hypotheses for interface acceptance investigated:

- Inby machine operators and mine inspection personnel will value and understand data better due to their interactions with the data and work with the atmospheric interactions on a regular basis (Investigation by job).
- Management, the workforce (union), and regulatory personnel will have different views on the interface, specifically on oversight and usefulness. (Investigation by classification)
- Due to more familiarity with computers and technology, the younger generation will be more accepting and they may more easily understand and operate the interface than the older generation. (Investigation by age)
- The higher the computer/tablet/phone/video game knowledge and competence, the higher the acceptance of the interface and use. (Investigation by computer and tablet/phone use)
- The higher the experience/education of the workforce (or group) the more likely they will be to find the data useful. (Investigation by experience and education)

6.8 Investigation by Job

An initial hypothesis stated that job classification and certification would influence individuals' opinions on the AMS and its perceived usefulness. Those classified as a machine operator or certified as a fireboss (which includes both assistant mine foreman and mine foreman certification) will have a better understanding of underground atmospheric changes due to their frequent hands-on interaction with atmospheric data. Inby machine operators take methane, multigas, airflow, and possibly pressure readings on their sections. They pass on pertinent information from shift to shift to help prepare the next machine operator for what to expect and to enhance safety for the next shift or crew. Firebosses are responsible for daily inspections of a section of the mine and for taking methane, multigas, and airflow readings in both working section and outby areas. Because they regularly examine logs that have atmospheric information they may see long-term trends in the data.

When analyzing Fireboss' and Foreman compared to the rest of the sampled population, a noticeable number of questions had p-values indicating them to be statistically significant. This population found all aspects of the interface use (Question 1) easier than the rest of the population, and all but 1f and 1g were significant (Table 6.13a). When asked how they feel about aspects of the AMS (Question 2) two questions stood out as statistically significant, 2b and 2c. Fireboss and Foreman rated 2b with a lower mean, and 2c with a higher mean than the rest of the population. This stated that Fireboss' and Foreman do not agree as strongly that increased AMS and information sharing will lead to improved interactions with regulators. They do believe more strongly that providing this information will lead to an increase or unfair oversight by regulators.

When performing the analysis, there was a concern that a significant number of the population of fireboss and foreman would also be management and could skew the statistics (47 of the 101 were foreman). An additional analysis of current fireboss' only was done to determine if this was an issue. Table 6.13b shows statistics for the fireboss only population. This population indicated, as did the fireboss and foreman population a higher mean in all of question 1 subparts about the interface ease, but this population showed 1a and 1c not to be considered significant. The other difference was in question 2, where the fireboss rated 2b lower than the other population, indicating that they believe more strongly that providing this information will not lead to improved interactions with regulatory agencies. However, they did not have a statistically different opinion than the other population that providing this information would lead to increased or unfair oversight from regulatory agencies (although their mean was higher).

Current inby machine operators work closely at the face, mining coal, and are continually monitoring for atmospheric indicators to increase the safety of their work area. It is believed that these operators would feel more strongly about a greater ability to monitor and share this information. The analysis shown in Table 6.13c does not show this hypothesis was correct. There was no statistically significant differences in question 1 and only one significant difference for question 2. They actually showed a lower mean rating for 2d, they believe less strongly than the other population that the safety and health of the miner will be increased by having AMS data available.

Table 6.13: Classification by Job P-values (highlighted rows are statistically significant)

13a Fireboss and Foreman Only			
Question	P-value	Question	P-value
1a.Section	0.0270	2a.Decisions	0.3260
1b.Sensors	0.0078	2b.ImpReg	0.0002
1c.SensorLov	0.0195	2c.UnfairOver	0.0004
1d.SensorData	0.0008	2d.SHIncrease	0.9019
1e.Data	0.0028	2e.EasyInter	0.2136
1f.SensorMove	0.1112	2f.Presenting	0.8253
1g.GasChg	0.1553		
1h.CharTime	0.0081		

13b Current Fire Boss Only			
Question	P-value	Question	P-value
1a.Section	0.0873	2a.Decisions	0.3711
1b.Sensors	0.0224	2b.ImpReg	0.0048
1c.SensorLov	0.0780	2c.UnfairOver	0.0569
1d.SensorData	0.0008	2d.SHIncrease	0.9847
1e.Data	0.0136	2e.EasyInter	0.3767
1f.SensorMove	0.0344	2f.Presenting	0.7154
1g.GasChg	0.0274		
1h.CharTime	0.0117		

13c Current Machine Operator			
Question	P-value	Question	P-value
1a.Section	0.4546	2a.Decisions	0.0988
1b.Sensors	0.4545	2b.ImpReg	0.6663
1c.SensorLov	0.5726	2c.UnfairOver	0.3972
1d.SensorData	0.1931	2d.SHIncrease	0.0115
1e.Data	0.1788	2e.EasyInter	0.2608
1f.SensorMove	0.5252	2f.Presenting	0.0751
1g.GasChg	0.9747		
1h.CharTime	0.8825		

Figure 6.11 shows the differences in opinion on AMS usefulness from all survey participants, firebosses, and inby machine operators. Firebosses were more likely to quickly determine that AMS interfaces are useful to them. After interaction with a more comprehensive AMS, they were much more likely to find the AMS interface was more useful to them than for miners and supervisors. Firebosses are also more likely than the survey population and inby machine operators to agree that the AMS interface is good for engineers, supervisors and regulators.

Figure 6.12 displays the differences in opinion between the total survey population, certified miners, and operators as to regulatory oversight. Operators were more likely than all and certified miners to more highly rate that they believed sharing this information will lead to improved relationships with regulatory agencies and rated lower that they believed it would lead to increased or unfair oversight. Certified miners (Firebosses) had the opposite belief of the operators; rating improved relationship lower and increased or unfair oversight higher than the operators and all survey participants.

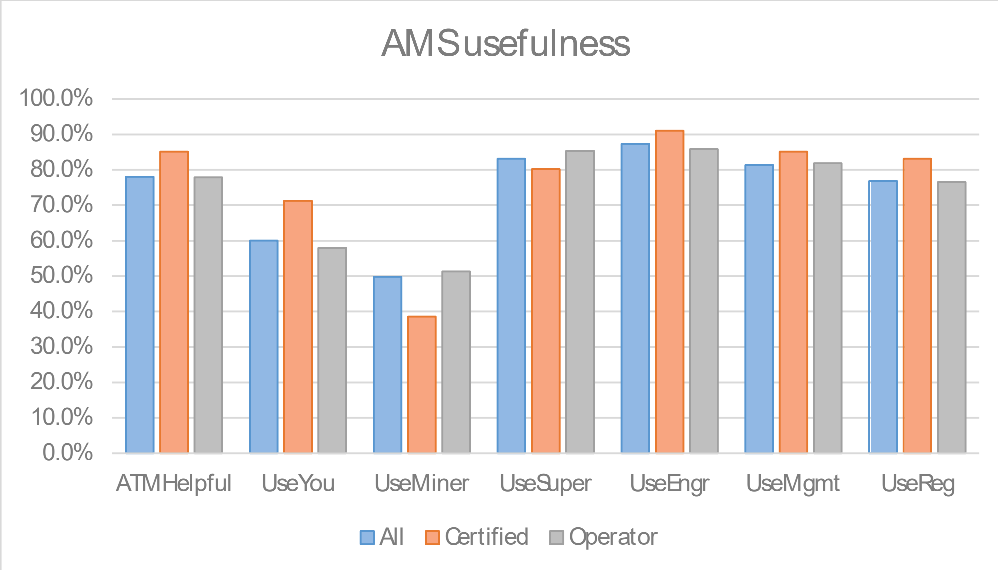

Figure 6.11: AMS usefulness for All survey participants, Certified persons (Fireboss, Foreman), and Inby Machine Operators.

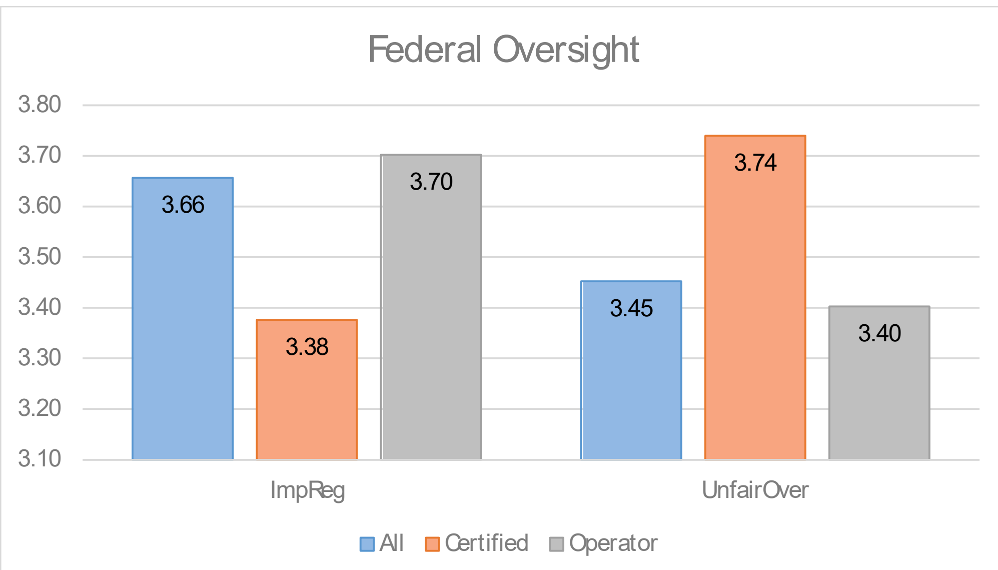

Figure 6.12: Opinion on Federal oversight by All survey participants, Certified persons (Fireboss, Foreman), and Inby Machine Operators.

6.9 Investigation by Classification

Prior to collecting survey data, it was hypothesized that those with a classification of management and the workforce (union) might have a difference in demographics (age, experience, and education), which would influence their opinions on the AMS system and perceptions as to who will benefit from AMS. They may also have a difference in viewpoint due to job responsibilities and experiences between management and union about oversight. Management (23.9%) and union (66.2%)

represent the most significant segments of the population surveyed (Table 6.4). When separated from the whole survey population, the responses of these two classifications vary significantly. Also, because the union workforce responses were nearly three times those of the management workforce (approximately 217 versus approximately 79), the union workforce opinion has higher weight on the total survey population response.

Education, age, and experience were extracted by classification (management and union only) and compared to the NIOSH National Survey of the Mining Population, Coal (McWilliams, Lenart, et al. 2012) and the survey population. Figure 6.13 displays the breakdown of education from NIOSH data, survey population data, and management, and union classifications. Members of the survey population, which include the management and union classification, all have significantly higher education rates (more than high school completion) than the National NIOSH survey of the same population. The survey population also shows a much lower reported rate of less than high school education. An initial theory was that management would have more education than the underground (union) workforce, which was confirmed by the data. The management population has a higher rate of bachelor's degree and beyond education (38.0%) than do the other three categories of populations.

Age and mine experience statistics are described in Table 6.13. Management populations' average age (41.89 years) is slightly higher than the survey population (41.46 years), while the union average age is slightly lower (40.92 years). It is notable that the mode of management was 58, much higher than the median of 39. Mine experience also varied between the survey population, management, and union populations. Management had a higher length of experience (15.88 years) than did union members (13.24 years) when compared to the survey population (14.12 years).

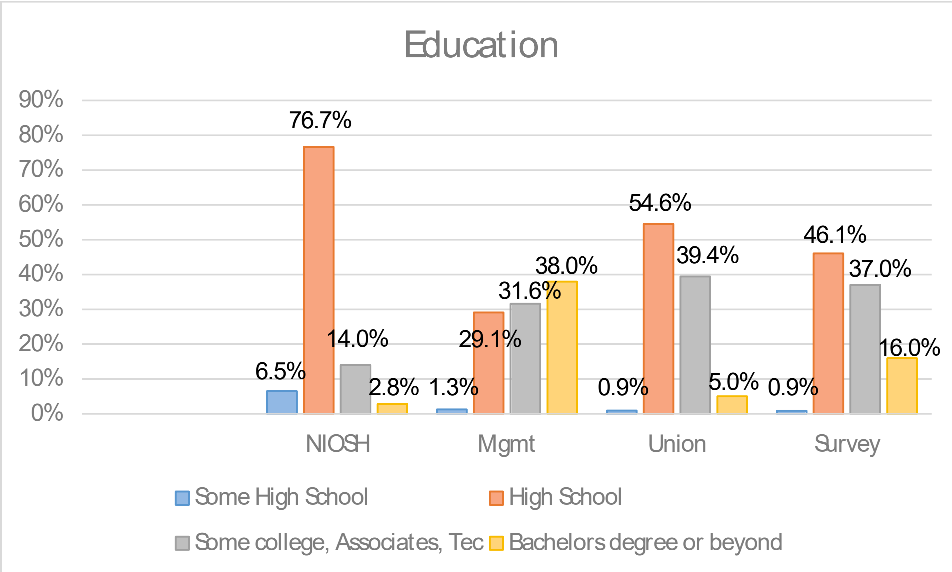

Figure 6.13: Education by percent of the population for NIOSH data, Management (Mgmt), Union, and Survey population.

Table 6.14: Descriptive Statistics of Mine Experience and Age for the entire survey population (Survey), Management (Mgmt), and Union populations.

	Mine Experience (years)			Age (years)		
	Mgmt	Union	Survey	Mgmt	Union	Survey
Mean	15.88	13.24	14.13	41.89	40.92	41.46
Standard Error	1.40	0.67	0.58	1.35	0.77	0.62
Median	11	10	10	39	39	40
Mode	10	6	6	58	39	39
Standard Deviation	12.27	9.88	10.44	12.02	11.15	11.25
Minimum	1	3	1	23	21	21
Maximum	44	44	44	66	68	68
Count	77	217	324	79	212	325
Confidence Level(95.0%)	2.78	1.32	1.14	2.69	1.51	1.23

Figure 6.14 shows diversity of opinions about AMS usefulness for management, union (underground workforce), regulatory, and all survey participants. While each classification appears to strongly agree that additional AMS is helpful to them, management reports an even stronger opinion. Management reported that this AMS interface system is more useful for them (you, 68.4%), engineers (94.9%), management (88.6%), and regulatory agencies (79.7%) than the union workers do. The union employees reported more strongly than management that the AMS interface is more useful for the miner

(55.3%) and the underground supervisor (85.4%). Regulatory personnel felt more strongly that the interface would be useful for them (regulatory, 86.4%) than for other job categories at the mine.

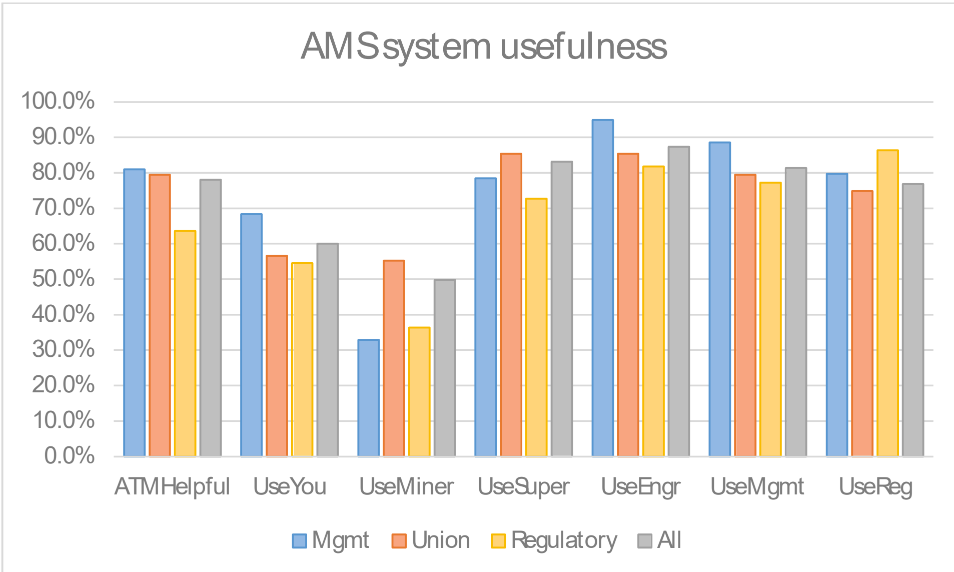

Figure 6.14: AMS usefulness as reported by survey population (All), Union survey population (Union), Regulatory, and Management (Mgmt) population in percent.

When asking survey respondents their opinions about the safety and health aspects of the AMS interface after the interaction, there was a hypothesized difference in opinion between management and the union. Statistical analysis was conducted, and the p-value was calculated for both question 1 and 2 in the post-interface questionnaire. Analyzing with three groups (Management, Union, and Regulatory) and two groups (Management and Union) returned the same statistically significant responses (Table 6.15). When asked about the ease of the AMS interface (Question 1), the Management group consistently had the higher mean of the groups, each part of this question indicating a statistically significant difference excluding 1c and 1g.

This analysis of question 2 showed that there were only two areas where the classifications differed in opinion on the interface: 2b (about improved interactions with regulatory agencies) and 2c (increased or unfair oversight from regulatory agencies). The null hypothesis for all of the statements was that the two groups would have no statistical difference of opinion; the p-values reject the null hypothesis for 2b and 2c. Showing management and workforce (union) differ on whether they will have improved interactions with regulatory and whether they feel they will have increased oversight. Management mean values for these questions indicated that they disagree more that there will be improved interactions with regulators, and agree more that there will be increased or unfair oversight from regulatory agencies due to the availability of increased AMS information for their mine.

Table 6.15: P-values for Classification of survey participants

Union, Management, and Regulatory				Union and Management			
Question	P-value	Question	P-value	Question	P-value	Question	P-value
1a.Section	0.0226	2a.Decisions	0.3657	1a.Section	0.0096	2a.Decisions	0.1468
1b.Sensors	0.0007	2b.ImpReg	0.0267	1b.Sensors	0.0002	2b.ImpReg	0.0070
1c.SensorLov	0.0622	2c.UnfairOver	0.0001	1c.SensorLov	0.0856	2c.UnfairOver	0.0050
1d.SensorData	0.0004	2d.SHIncrease	0.1031	1d.SensorData	0.0001	2d.SHIncrease	0.1369
1e.Data	0.0022	2e.EasyInter	0.5874	1e.Data	0.0006	2e.EasyInter	0.3084
1f.SensorMove	0.0015	2f.Presenting	0.5528	1f.SensorMove	0.0010	2f.Presenting	0.4349
1g.GasChg	0.0721			1g.GasChg	0.0245		
1h.CharTime	0.0012			1h.CharTime	0.0002		

Looking more deeply into questions 2b/c about regulatory oversight, the data are examined by job classifications. An inspection of the difference in opinion between the union workforce, management, regulatory personnel, and the total survey population on oversight found some differences in opinion about regulatory oversight (Figure 6.15). Figure 6.17 indicates that at a rate of more than twice their union counterparts (28.2% versus 14.0%), management reported they strongly agreed there would be increased or unfair oversight by regulatory agencies. The union workforce reported believing more strongly that there is an increased chance of improved interactions with regulatory agencies by providing AMS information. Figure 6.16 shows that a similar percentage of union and management (13.8% and 13.9% respectively) strongly agreed that AMS information would lead to improved interactions with regulatory agencies. A much higher percentage of union workers agreed (54.1%) than did management (39.2%), and a much greater percentage of management workers disagreed (11.4% vs Union at 5.0%) and strongly disagreed (7.6% vs. union at 1.8%), which signals a difference in opinion between management and union employees about regulatory enforcement (Figure 6.16). Regulatory survey respondents showed a higher positive response rate than management but less than union on the opinion that there would be an improved interaction due to AMS data being available. Regulatory survey respondents also had a much higher neutral and disagree response to the idea that there would be increased or unfair oversight due to the AMS information being available. In discussions, management voiced a concern that additional non-regulated information gathering may affect their operation negatively when shared with regulatory agencies. The union underground workforce more strongly agreed that sharing AMS information openly with regulatory agencies will lead to improved interactions with these agencies than did management, showing a different type of relationship with regulatory agencies.

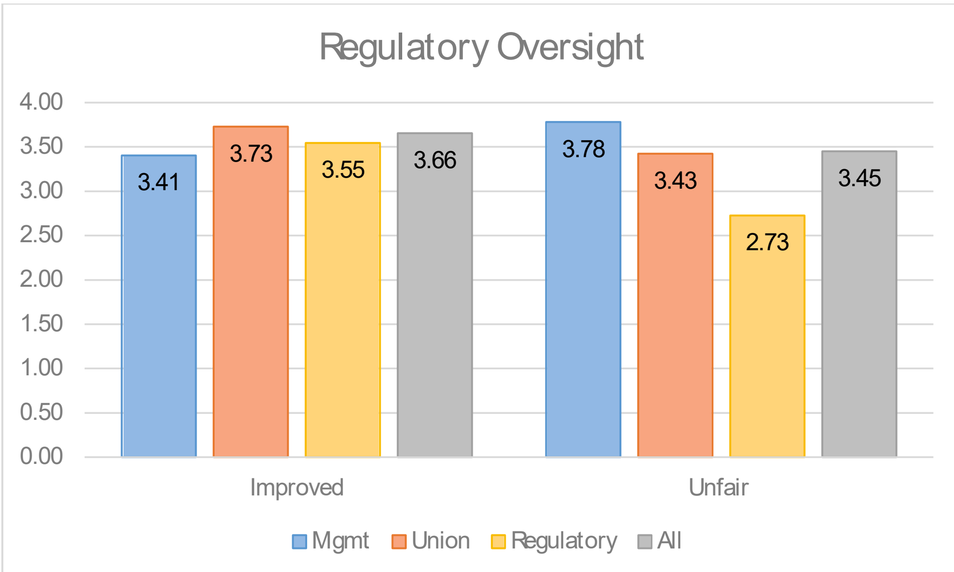

Figure 6.15: Regulatory oversight opinion as per Survey population (All), Management surveyed population (Mgmt), Regulatory, and Union surveyed population.

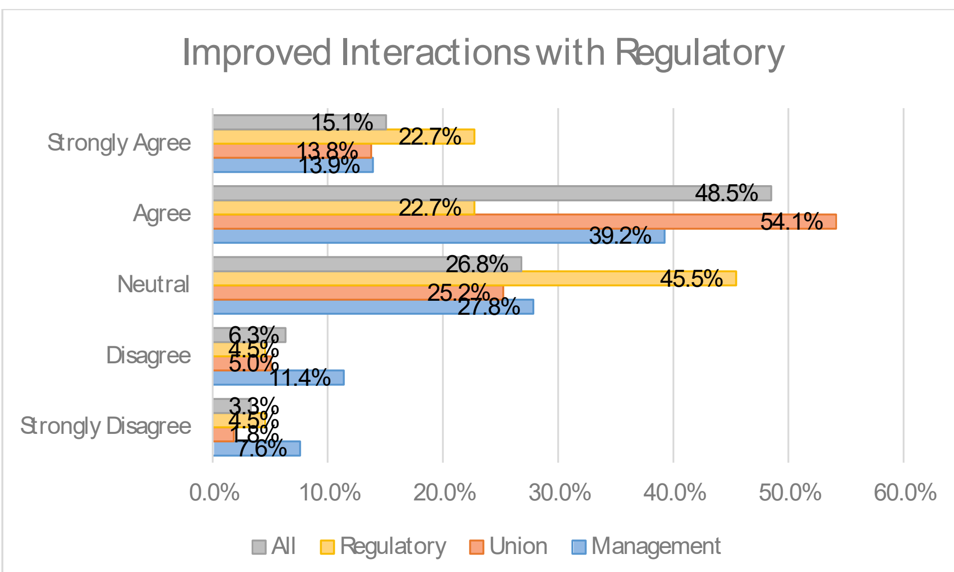

Figure 6.16: Figure of responses to "Providing this information will lead to improved interactions with regulatory agencies?" Broken down by All survey respondents, Regulatory, Union, and Management respondents in percent of that survey population.

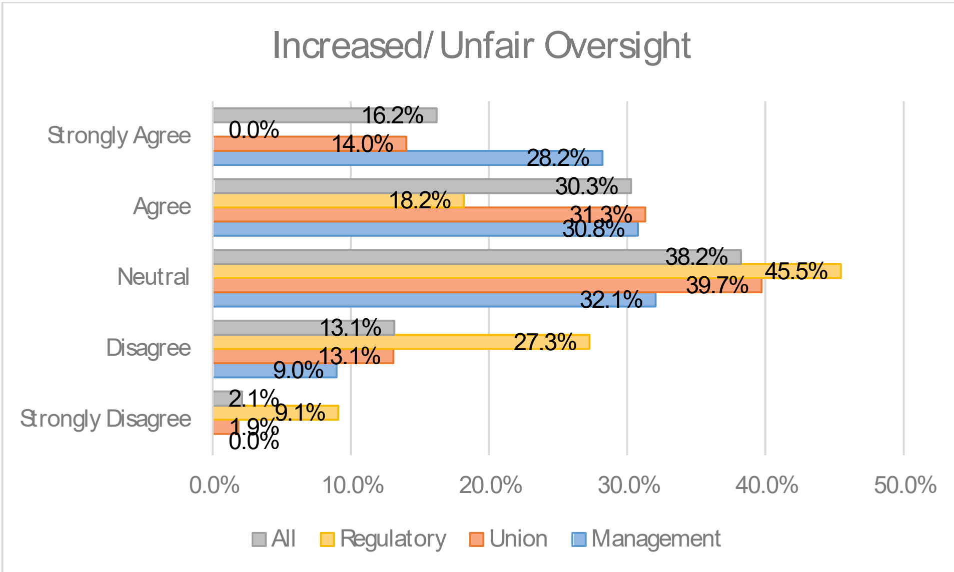

Figure 6.17: Figure of the question "Providing this information will lead to increased or unfair oversight from regulatory agencies?" broken down by All survey respondents, Regulatory respondents, Union respondents, and Management respondents in percent of that survey population.

6.10 Investigation by Age

Initial theories stated that younger miners would be more responsive and open to computer-based systems, in this case, AMS. Age groups from the surveyed population were broken up into 10-year increments: 20-29, 30-39, 40-49, 50-59, and 60-69 years. Within these age groups, mine experience, thoughts on AMS and regulations, and the usefulness of AMS to groups were analyzed.

Mine experience means within an age group were much more tightly grouped within that age group, as can be seen in Table 6.15 by the small standard error. The standard error only increases as age increases, with the maximum being 2.1 years by participants in their 60's. Average experience steadily increases in years from 6, 9, 12 23 and 35 for miners in their 20's, through 60's, respectively. The average experience tells us that miners in their 20's, 50's, and 60's all started their careers on average at a very young age. Miners in their 30's and 40's mean experience indicate they started their mining career at an older age, we can infer that mining may have been a second career. This demonstrates how the economy of the coal industry has influenced workers, showing a gap in hiring miners in the 1990's by highlighting a difference in experiences in age groups.

When survey participants' answers as to whether the interface is useful to different groups the most optimistic are the 30 and 40 year old miners (Figure 6.18). A point of interest from the young and older miners are that the younger miners find AMS less helpful to them and other miners, but more useful for supervisors, managers and engineers. Older miners find the interface most helpful for themselves and miners but feel it less helpful than the other survey population for other types of employees. When questioned how they felt about oversight, if there would be improved relations with regulators or unfair oversight, the age groups ranged in belief. Only the younger miners, in their 20's had a larger population that thought that there would be more unfair regulation due to this information being available (Figure 6.17). The rest of the population more generally believes that there would be an improved relationship with regulators with the availability of this information than an increased oversight (Figure 6.16).

Table 6.16: Mine Experience in years separated by 10 year age increments from survey respondents.

Mine Experience (years)					
	20's	30's	40's	50's	60's
Mean	6.00	9.25	13.11	23.82	35.40
Standard Error	0.29	0.37	0.75	1.39	2.14
Median	6	9	12	26	39.5
Mode	5	10	8	30	44
Standard Deviation	2.00	3.78	6.70	10.93	9.58
Minimum	2	1	3	5	10
Maximum	10	19	31	41	44
Count	47	106	79	62	20
Confidence Level(95.0%)	0.59	0.73	1.50	2.78	4.48

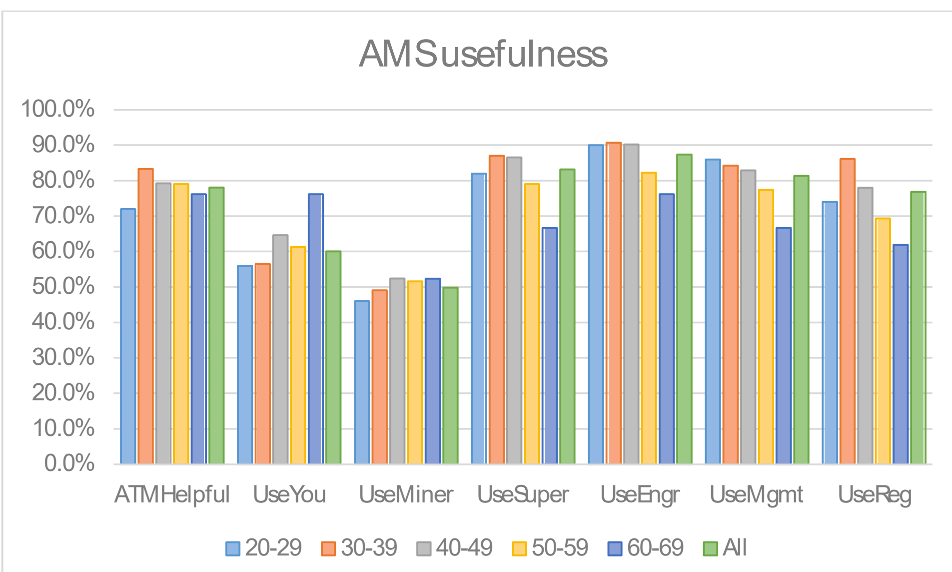

Figure 6.18: AMS usefulness from survey of respondents, separated by age group compared to all survey respondents.

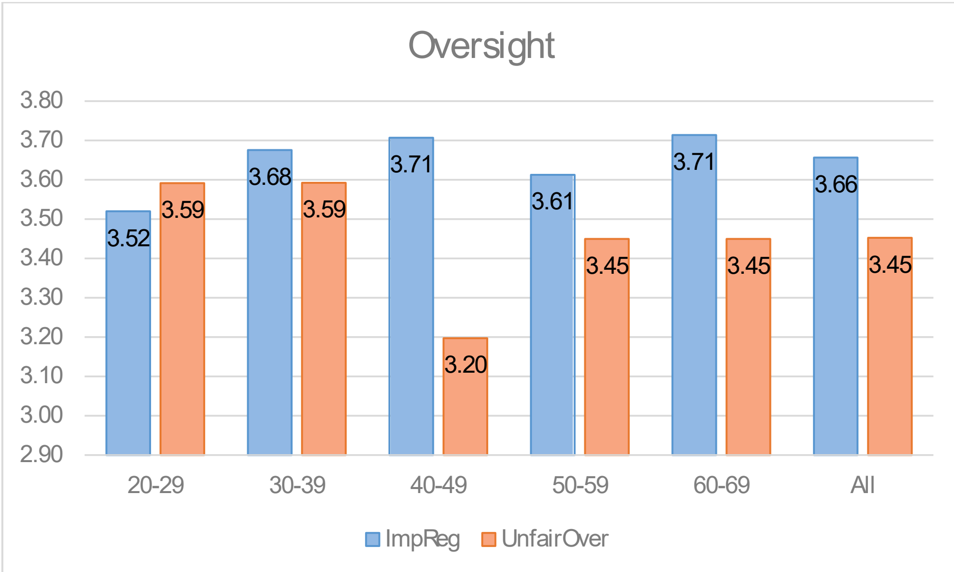

Figure 6.19: Oversight opinion from survey respondents separated by age group in comparison with all survey respondents (mean value).

When statistically analyzing question 1 and 2 of the Post-Interface questionnaire it was unanticipated to see that there were no significant difference in the populations (Table 6.17). When doing the analysis, and additional Tukey's HSD analysis was done to determine if there was any difference between groups. Only one question, 2c, inquiring about the feeling of unfair oversight by regulatory agencies indicated a difference for the 40-49 year old group. This group's mean was significantly lower than the other groups, making them disagree more than the other populations that this information would lead to increased or unfair oversight from regulatory agencies.

Table 6.17: P-values for Age of surveyed miners

Question	P-value	Question	P-value
1a.Section	0.4239	2a.Decisions	0.6190
1b.Sensors	0.1604	2b.ImpReg	0.8173
1c.SensorLov	0.1302	2c.UnfairOver	0.0650
1d.SensorData	0.5157	2d.SHIncrease	0.3458
1e.Data	0.8465	2e.EasyInter	0.0992
1f.SensorMove	0.3344	2f.Presenting	0.3530
1g.GasChg	0.4628		
1h.CharTime	0.6431		

6.11 Investigation by Computer and Tablet/Phone familiarity

The initial hypothesis as we examine technology familiarity was that the more comfortable users are with digital forms of communicating and interacting (e.g., video games, computer, tablet, and smartphone), the more comfortable they will be working with a digital AMS interface. High usage is determined by using either the computer, tablet or phone a few times a week or more. Low usage is identified as weekly or less usage of the computer, tablet, or phone. Data was pulled from the entire survey, because time spent on the computer is a separate question from the tablet and smartphone question, participants can be included in both groups, they are not mutually exclusive. The survey showed low use of video games, (86% once a week or less, with most of the total, 59.0% never playing video games) therefore applying video game usage as a factor to look at variances was excluded. Computer, tablet, and smartphone use was much more common within the population and chosen as a greater factor when looking at variances in opinion.

Tablet and smartphone users mean age and experience for low usage users are 50 and 20 years respectively. For regular tablet and phone users, mean age and experience is 30 and 13 years, respectively. There was less of a difference for computer users than tablet and phone users. Low computer users mean age and experience is 40 and 12 years, while high users is 42 and 15 years, respectively.

Both low and high tablet and computer use seemed to trend together in their opinions of AMS usefulness and who it is helpful for (Figure 6.20). The only one that differs from this trend is the low computer use respondents trended with the high users for AMS usefulness for supervisors.

Figure 6.20 shows the differences in beliefs about regulatory enforcement between the different use categories. Both tablet and computer high users think it is more likely that regulatory agencies will increase unfair oversight. The respondents that use computer and tablets less believe more strongly that there will be a better relationship between the regulatory agencies and the mine with more atmospheric monitoring information available.

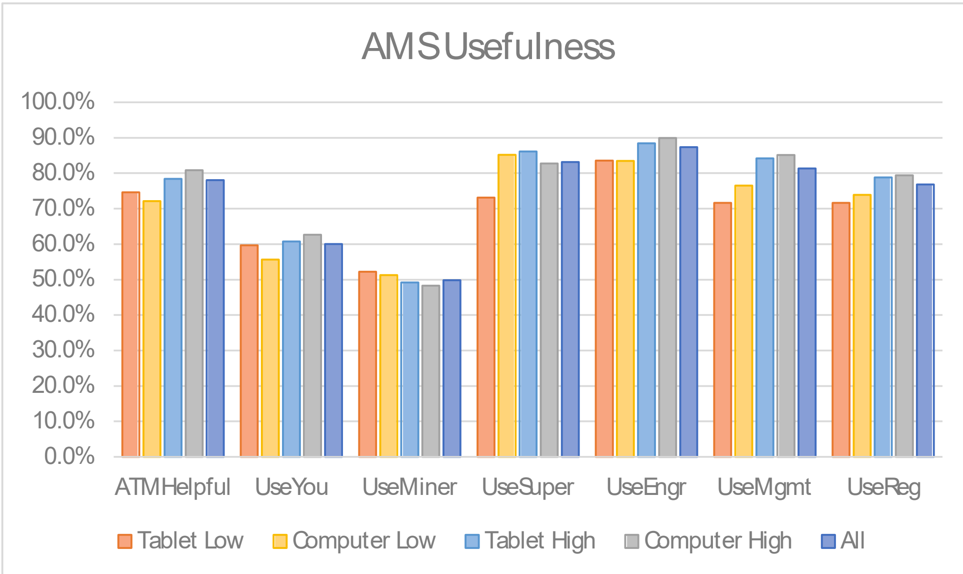

Figure 6.20: AMS helpful, and usefulness for type of job from survey results broken down by tablet or computer usage.

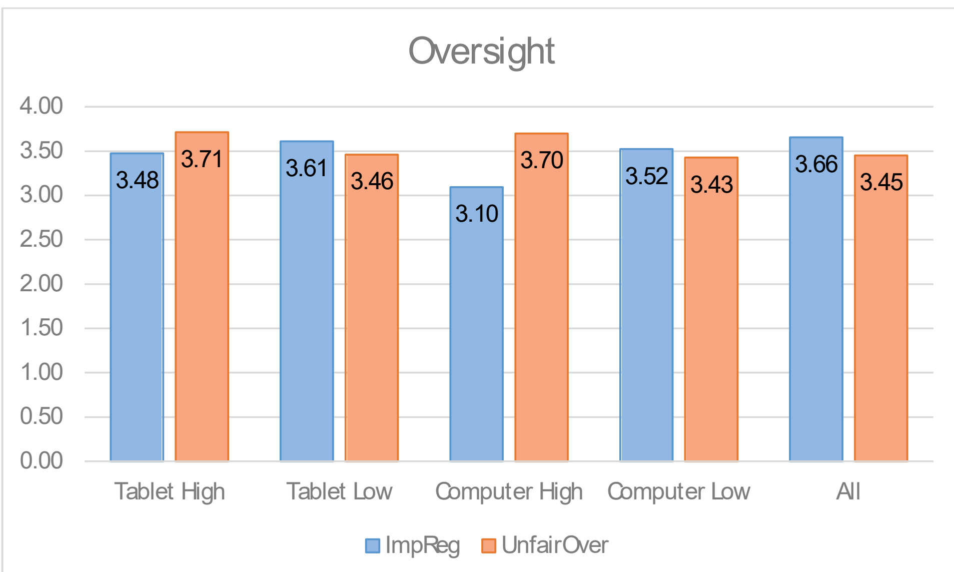

Figure 6.21: Oversight opinion from survey respondents separated by computer and tablet usage in comparison with all survey respondents (mean value)

Statistically analyzing phone/tablet and computer use against answers to questions 1 and 2 from the post –interface questionnaire p-values are in Table 6.18. There is not much difference in the populations in both the phone/tablet and computer use categories. The only statistically significant differences came out for question 1 in both technology use populations. 1h, the use of the time frames for the gas charting was the question that both phone/tablet and computer use populations differed in their opinion of use, both having higher means for the high users. The phone/tablet high users found it easier to move to different sensors throughout the mine than did the low users. The high computer users found it easier to understand the data from the sensors than the low computer users.

Table 6.18: P-values for phone/tablet and computer use

Phone/Tablet Use				Computer Use			
Question	P-value	Question	P-value	Question	P-value	Question	P-value
1a.Section	0.0546	2a.Decisions	0.4571	1a.Section	0.5425	2a.Decisions	0.5261
1b.Sensors	0.4447	2b.ImpReg	0.9924	1b.Sensors	0.9156	2b.ImpReg	0.2569
1c.SensorLov	0.4258	2c.UnfairOver	0.9854	1c.SensorLov	0.7679	2c.UnfairOver	0.9782
1d.SensorData	0.4408	2d.SHIncrease	0.6208	1d.SensorData	0.2008	2d.SHIncrease	0.1396
1e.Data	0.3545	2e.EasyInter	0.8999	1e.Data	0.0369	2e.EasyInter	0.7712
1f.SensorMove	0.0088	2f.Presenting	0.2823	1f.SensorMove	0.0794	2f.Presenting	0.3055
1g.GasChg	0.1630			1g.GasChg	0.2961		
1h.CharTime	0.0269			1h.CharTime	0.0345		

6.12 Investigation by Mine Experience and Education

It was hypothesized that the more experience a miner had, his opinions would differ from those miners with less experience. Education was also thought to be a factor in varied opinions within the survey population. Miner experience ranged from 1 year to 44 years, with a mean of a little over 14 years, median of 10 and mode of 6 (Table 6.1). The survey participants were also well educated, with more than 46% with a high school diploma, 37% with some college or an Associates, and 16% with a Bachelor’s degree or more (Table 6.2). A breakdown of education by classification (Figure 6.13) showed us that the survey population is more educated than the NIOSH population, and that Management is more educated than the Union population.

Experience was broken down into 10 year increments, participants with zero to 10 years’ experience are marked as 10, 11-20 as 20 and so on. Analyzing who the survey respondents believe the AMS interface will be best for, we can see that the lowest category is for the miner (Figure 6.22). The 10 group was less likely to choose themselves and miners and more likely to choose all the management roles. Although the population for the 50 group was only 9 people, it was surprising to see that all of those participants choose that the AMS interface is useful for them.

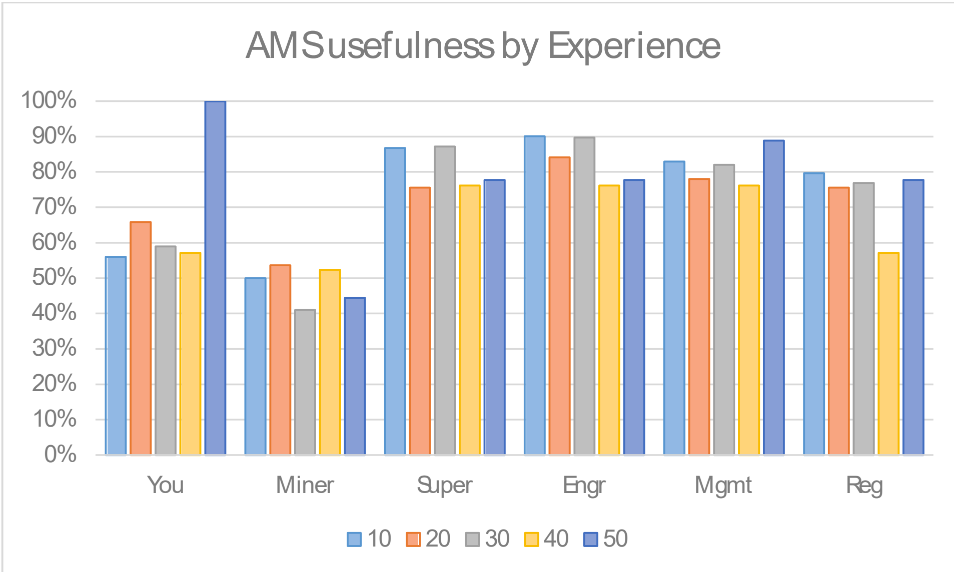

Figure 6.22: AMS usefulness by experience

Only one question from the post interface questionnaire flagged as statistically significant when analyzing by experience. Table 6.19 indicates the p-values for these questions and only 2b, the belief that there would be improved interactions with regulators with the availability of this information. The linear fit of the data indicates that with increased experience the rating for 2b decreases. With increased experience, there is a decreased belief that there will be an improved relationship with regulators if this data were to be available. Figure 6.23 presents the breakdown in percent of each population response for question 2b.

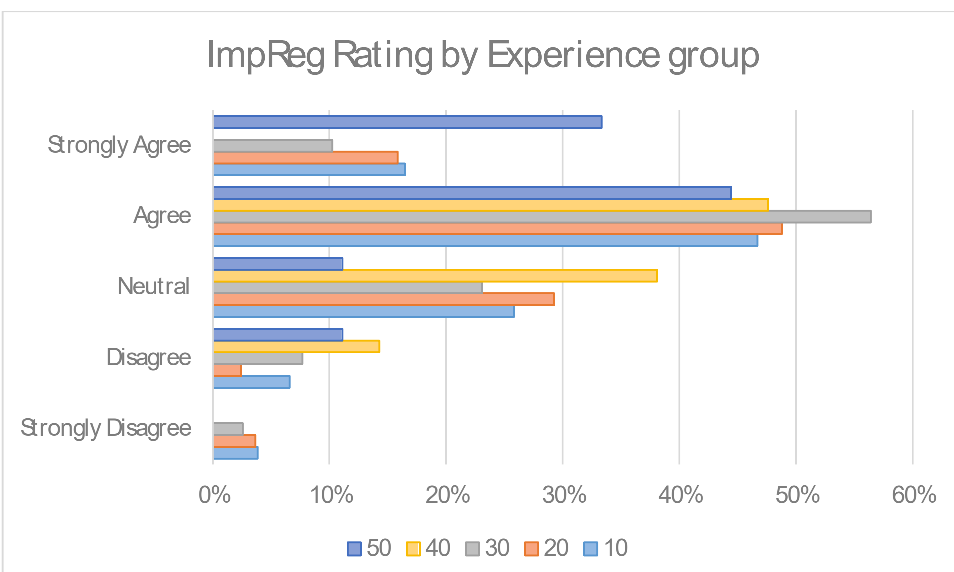

Figure 6.23: Response for ImpReg question by experience

Education was also hypothesized to influence opinion in the survey. As with the current mine experience, education only showed one statistically significant question, 2b, ImpReg (Table 6.19). There should also be noted when evaluating responses in Figure 6.24, that there were only three "Some high school" responses with the majority of the population responding with High school and Some College. It should also be noted that 57% of the College and beyond responses are Management. The responses show that the higher the education the lower the response when asking if they believed that there would be a better relationship with regulatory agencies if this information was available. Responses are broken down in Figure 6.24.

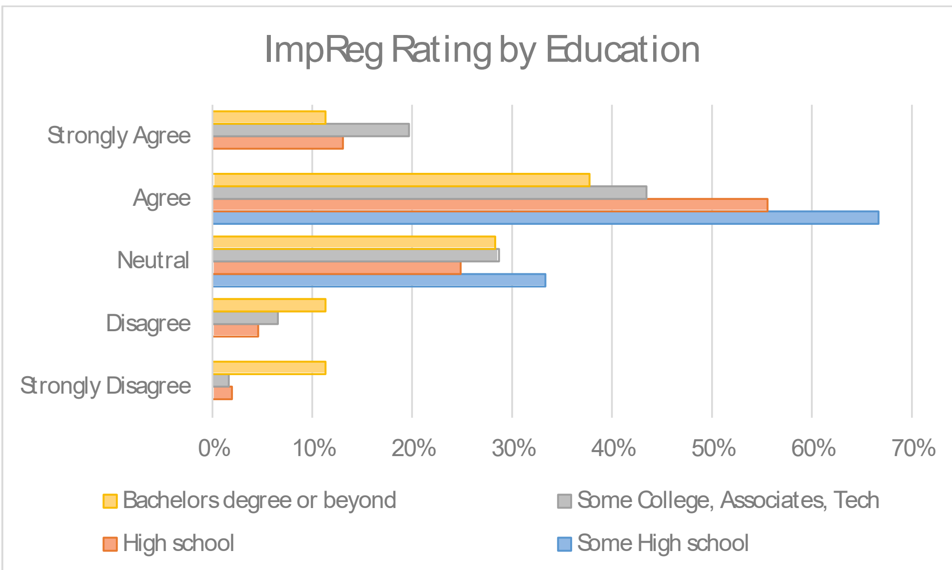

Figure 6.24: Response for ImpReg question by Education

Table 6.19: P-values for current mine experience and education

Current Mine Experience				Education			
Question	P-value	Question	P-value	Question	P-value	Question	P-value
1a.Section	0.6002	2a.Decisions	0.9632	1a.Section	0.8117	2a.Decisions	0.5180
1b.Sensors	0.5280	2b.ImpReg	0.0103	1b.Sensors	0.2241	2b.ImpReg	0.0034
1c.SensorLov	0.1370	2c.UnfairOver	0.5825	1c.SensorLov	0.6288	2c.UnfairOver	0.5749
1d.SensorData	0.9625	2d.SHIncrease	0.4832	1d.SensorData	0.0630	2d.SHIncrease	0.9323
1e.Data	0.3655	2e.EasyInter	0.9750	1e.Data	0.1370	2e.EasyInter	0.4694
1f.SensorMove	0.8386	2f.Presenting	0.3830	1f.SensorMove	0.1336	2f.Presenting	0.5435
1g.GasChg	0.4524			1g.GasChg	0.5218		
1h.CharTime	0.9372			1h.CharTime	0.2071		

6.13 Discussion

The Pre-interface survey found a few statistics from the general population; the primarily male surveyed population was younger, had less experience, and was more educated than the NIOSH survey coal population information from 2012. Almost 50% of the survey population reported as their main job classification being utility or inby machine operator. Additionally, almost 50% of this population reported of having fireboss or higher certifications. The largest portion, more than 66.2% are union workers, followed by over 23.9% management, these two groups representing more than 90% of the surveyed population. The most frequently used technology, a tablet or phone, was used frequently by over 83% of the population. In all, the survey population is young, well educated, have a high rate of certification, is familiar with technology, and is primarily union and management. Over 77% of the surveyed population felt that additional AMS would be beneficial, and almost 90% were familiar with some sort of AMS system at their current operation. This showing that the survey population was familiar with AMS and was open to additional monitoring.

After testing the entire survey population felt the interface was generally easy to use, and had a positive response for a more open and extensive atmospheric monitoring program at their operation. They felt that AMS would lead to a higher standard of safety and that miners would make better decisions by having this data available. They also felt more positively that they would have improved relationships with regulators, but also felt that this may lead to an increased or unfair oversight from regulatory agencies. It was surprising to see that only approximately 50% of the surveyed population thought that miners would use this data and interface on a regular basis. This could be due to the reliance of miners on their supervisors and firebosses to perform much of the underground safety inspections. They may also view it as an additional responsibility on top of their existing duties. A much higher percentage of this population thought the AMS would be most beneficial for supervisors, engineers, management, and regulatory. A high percent of this population designated multiple additional areas and atmospheric information as beneficial to them for monitoring.

The hypothesis were broken down into five different areas of detailed examination:

- Investigation by job
- Investigation by classification
- Investigation by age
- Investigation by computer and tablet/phone familiarity
- Investigation by mine experience and education

Investigation by job looks further into how the job classifications influence the miners' thoughts, opinions and outlook on atmospheric monitoring. Fireboss, machine operator, and all were pulled from the survey data and related to each other to see if there were differences. Fireboss job classification thought that atmospheric information was more helpful, and found AMS more useful for all categories of individuals with the exception of miners and supervisors. They may be expressing their viewpoint that miners and supervisors do not have the need to have a picture of the entire mines AMS for their daily work, while firebosses, engineers, management and regulatory representatives would more likely want and need this information. Operators' thoughts are similar with the survey population for usefulness of atmospheric information and who AMS is most helpful for. This shows that the hypothesis was wrong for operators, showing that they trend with the entire population and do not find atmospheric information more helpful or AMS more useful for any variety of the population. Firebosses thoughts did trend differently, they found the ADAMS system and AMS idea generally more useful. Firebosses high use and understanding of this information for their daily job working around the entire mine would most likely contribute to their opinion.

Firebosses and foreman were less likely to think that this system would lead to improved interaction with regulators and more likely to think it would lead to increased or unfair oversight than are operators or the entire population. These thoughts are more likely due to the fireboss and foreman's increased time spent with regulators and expanded responsibilities due to inspection of the mine. Operators generally thought the opposite of the firebosses, and trended with the general survey population, finding that they more strongly felt that they would have a better relationship with regulators and there was less likely to be increased or unfair oversight. Again showing the hypothesis more strongly aligning with firebosses and foreman and less with machine operators. This may be due to the fact that operators concentrate their effort on atmosphere in their section and are not as concerned with the changes in the whole mine atmosphere. They may think this system would be more helpful in the mine wide scale and not the section.

P-values calculated show many statistically significant differences between the populations (Table 6.13). The fireboss and foreman found everything easier (mean higher) but found six out of the eight questions about operating the interface statistically significant. The current firebosses means were higher and also six out of eight questions on the ease of the interface statistically significant when compared to the rest of the population. The current machine operators did not find any of questions about the ease of use of the interface statistically significant. Showing us that there was a difference with the Fireboss and foreman but not the machine operators that we hypothesized there would be. The firebosses and foreman have a higher chance of moving around and having a feel for the entire mine, possibly leading them to find the interface more helpful and significant to their everyday work.

Analyzing the data by job classification, e.g., management or union does indicate differences in opinions and outlooks in atmospheric monitoring. The population was well educated (Figure 6.13), but the survey found that those classified has management had a higher percent of bachelor's degree or beyond than the other populations (Figure 6.13). Management also had more years of experience and a higher age (mean) than the union or the general survey population (Table 6.14). Management found the AMS most helpful for all the populations but least so for miners. Union miners found AMS mostly helpful for all of the populations, but least so for miners, although they had a much higher percent believing it was helpful for miners than the other populations. Regulators found this type of system most helpful for regulators (Figure 6.14). It was expected to see that management was more inclined to presume that they would not have improved interactions with regulators and that they would have increased or unfair oversight with union feeling the opposite. This was presumed due to their relationships with regulatory agencies. The union standardly feels that the regulatory agency is there to help them and uphold the federal and state regulations, and the union commonly has less interest in the economics of the mine than does management. Management can sometimes feel that the regulatory agencies are there to make running a safe and economical operation more difficult and expensive. The concerns of management and union differ due to their current and past interactions, relationship, and culture with regulatory agencies.

It was unanticipated to see regulators feeling less strongly than the union and the entire population that having and sharing AMS information will lead to improved interactions with regulatory agencies (Figure 6.15). When looking at the breakdown from this question (Figure 6.16), a higher percent of regulatory participants choose *strongly agree* for this question. There was also a percentage of regulatory, similar to the entire population, which *strongly disagreed* that there would be improved interactions with regulatory. There was a very strong *neutral* response to this question from regulators. I believe the high percent *neutral* response and low total number of regulatory participants lead to the lower mean response rate amount regulators. It is apparent by their responses that regulators understand what this could do to operators if the information is used in the wrong way.

When analyzing the question of increased or unfair oversight by regulators (Figure 6.17), it was expected to see the regulatory population have no one that *strongly agreed*, and a larger percent *strongly* *disagree* with a high *neutral* response. The data showed that no regulatory responded *strongly agree*, and a much smaller percentage choose *agree*, there was a larger percent that chose *neutral*, almost double the percent chose *disagree* and a much larger percent chose *strongly disagree* than the other populations. These responses from regulatory trended well with the thought that regulatory would not believe this would lead to increased or unfair oversight. It was surprising to see 18.2% of the regulatory population, did choose *agree* to this question, which is a sign from the previous question of the higher mean response to question of improved interaction. Showing that there is a portion of the regulatory population that believes this may cause unfair or increased oversight.

Examining the investigation by age survey data it seems that the younger workers tend to think an AMS is more helpful for supervisors and management and less for miners and themselves. While the older workforce seems to think more strongly that the AMS is best for themselves, and less helpful for supervisors, engineers, management and regulators than did the other age groups and survey population. Leading to the younger workers possibly being more reliant on supervisors and management while the older, more experienced workers more reliant on themselves. The younger miners also had a higher tendency to believe that there would be increased or unfair oversight with increased AMS data available than did the miners over 40. This could be due to the changes in the regulatory atmosphere and laws due to high profile mining disasters in the past 10 years. The older generation has a higher positive opinion that more AMS will lead to better relationships with regulatory agencies. They have had a longer and more cooperative relationship between the miners (union) and regulatory during their time as a miner. The 40-49 population stood out by being statistically different for the question of unfair oversight. The data was looked into to see if there was a significant portion of the population that was contrasting that may explain this one age groups different opinion. Education and classification were looked into and the percentage of each population was not vastly different from the others (Table 6.20). One indicator from this is the larger proportion of “Other” classification, which is primarily regulatory who had a strong *disagree* answer to this question. Also noted was the trend of the 40 year old miners experience with the 20 and 30 year old miners (Figure 6.25), this is possibly a second career for many of them, which may influence their opinion. Other than the one question of unfair oversight in the one age group (40’s) there were no statistically significant differences for ease of use or feelings about the AMS interface proving our hypothesis incorrect for that age group.

Table 6.20: Age by group, Education percentage by age group, and Classification percentage by age group.

Education	Age by group, by Education, % by age group				
	20	30	40	50	60
Some High School	0%	0%	1%	2%	5%
High School	54%	37%	49%	55%	43%
Some College	28%	41%	38%	31%	43%
College and beyond	18%	22%	12%	13%	10%

	Age by group, by Management, % by age group				
	20	30	40	50	60
Management	24%	26%	20%	25%	33%
Other	6%	6%	20%	13%	5%
Union	70%	69%	61%	62%	62%

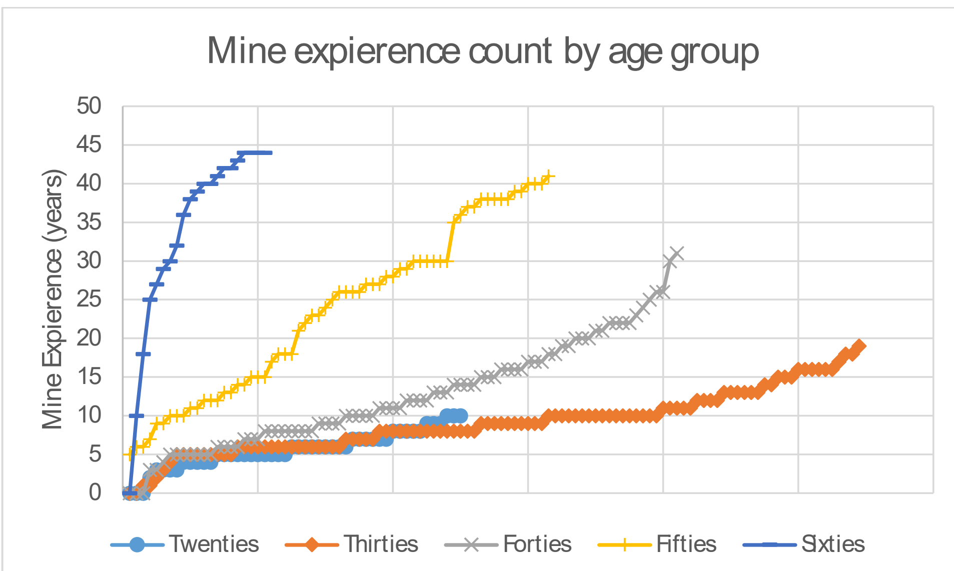

Figure 6.25: Mine experience in years, count by age group

Investigation by computer and tablet/phone use was also surprising. Although we identified trends in low and high users of these devices, there were very few statistically significant indicators for questions 1 and 2. The trends we identified are that higher users found using the interface easier (they identified this by having a higher mean than did the lower users), but they had only two of the eight questions as significant. They all identified similarly for their feelings on the interface (question 2,

Table 6.18). Although there are some differing opinions, without any statistically significant differences, the computer and tablet/phone use was not an indicator of differences. The entire population whether a technology user or not found the interface rather easy to use. There was also no divide on thoughts and feelings about the interface (question 2).

In both education and experience, only one statistically significant difference was found, their opinion on whether there will be improved relationships with regulatory agencies. The more educated the individual, the more likely they were to rate this item lower, this is possibly due to their higher chance of being management. The more experience the individual has, the more likely they are to rate this item lower. The higher the education or experience, the less the individual believes that there will be improved interaction with regulatory agencies.

Comments both in the form of the survey and researcher interaction with the groups found primarily positive feedback. The criticisms of the interface its self were easily adaptable solutions within the software or would not be an issue if it were a full scale mine implementation. Opinions that this type of system would have a negative impact on jobs were very minimal and unfounded. Management found that the system could be very beneficial to the mine as a whole for more data than just an AMS system. The largest concern discussed was how this would be implemented and its regulatory impact.

Management, firebosses, and foreman found the interface easier to use than the other groups. Management, foreman and firebosses also believed that there would not be improved relationships with regulators and thought there was a higher likelihood that there would be unfair oversight with additional AMS monitoring and data available. Education and experience indicated one difference, the more educated or experience a miner had, the more likely they were to believe that there would not be an improved relationship with regulators with this data available. Age and technology familiarity did not have a statistically significant difference in most areas, although they did show trends in the data as to what we expected for these indicators in the mining population.

A disadvantage of the experiment is that the test interface used a created mine foreign to survey participants. This would instantly make the use of it less intuitive for miners because they are not as familiar with the areas, methods or map indicators. The atmospheric data was also not similar to what they would experience in their particular mine. There were also comments because they interacted on a tablet and it was small, hard to see and move throughout. The intention is to have the interface on a large “smart” type of large interactive screen in a public, well-trafficked area. Even with these disadvantages, there was still positive responses for the use of the interface and participants were excited about the technology and information that could be available.

There are many indicators of opportunities for improvement from this data. Additional continuous monitoring that miners thought would be helpful was highly recommended by a large portion of the population (Table 6.9). There are also many areas that were thought to be good additional monitoring areas (Figure 6.9). A significant number of survey respondents said they did not know what type of AMS system was currently at their operation (Table 6.10). This figure could be inflated because contractors and regulatory agencies were surveyed and do not have a "current operation." However, this leads to us having an opportunity to inform and teach miners about AMS and the impact they can have to make operations safer.

6.14 Conclusion

Gathering and displaying AMS information can lead to a safer, healthier, and more productive mines and workforces. Targeted training of the AMS interface and atmospheric information for the miner can make him or her a safer and more proactive employee. Both miners, regulatory, and management see value in this system for themselves and the operation. This system is an opportunity to enhance communication of technical data, safety, and decision making, ultimately impacting safety.

A limitation of this work is that a high percentage of the survey population was from a single mine. Although all employees from the mine were surveyed the concentration is primarily a specific sample size of one mine, a single mining region, a particular safety culture, and it is likely a high percentage of this population has limited experience at other mines. The regulatory population surveyed was very diverse in region, experience, and culture. Although the entire surveyed population was focused, it is large and compares well with the NIOSH coal population (McWilliams, Lenart, et al. 2012). Another drawback is that miners may not be as spatially familiar with the simulated mine than they would their mine and work areas. The miners had little time to explore the interface individually, and most chose to move into the second survey after the guided scenarios.

A significant outcome of this undertaking is that miners, management, and regulatory personnel are open to and even like the idea of having additional monitoring. They see the value and the increased safety and health that would result from additional monitoring and the sharing of this information via an interface. It was hypothesized that age, experience, job classification, and computer skill would indicate differences in the thoughts and answers in the population. Although some of these aspects did influence differences in opinion, the data indicated that these variables influenced the population less than expected. The most surprising outcomes were that regulatory survey respondents indicated that they rated lower than the union but higher than management, in that they believed sharing a comprehensive atmospheric monitoring system would lead to improved relationships between mine operators and regulators. This may be an indicator of the current climate between operators and regulators. It was also unanticipated to see that all respondents indicated that they saw an AMS interface least likely to help miners. The AMS interface intends to empower miners in their daily decision making. AMS information has been something that is not actively communicated to miners throughout the work day unless conditions become hazardous. The idea of a comprehensive AMS system and interface is a new idea and may be overwhelming to most miners. Further exposure and interaction might be required for more miners to see the value.

Other issues arose during this research that may require further study. First, additional monitoring is beneficial in countless ways to mines, miners and regulators. However, with additional monitoring comes additional burden on operators for calibration, regulation, and maintenance of currently available sensors. Current technologies that are common in other industries may apply to mining applications. An example is fiber optic gas, pressure, and temperature monitoring, proven in other industries as well as mining, but yet to be used long-term in a mine. With the implementation of a database structure for the monitoring of atmospheres, this system could be used to integrate other regulatory or mine systems (e.g., tracking system for both miners and equipment, maintenance, supplies, to name a few). Also, sophisticated ventilation planning software is widely used for underground mining; additional continuous atmospheric monitoring systems could interact with this software and create a real-time ventilation model. One of the more controversial issues of such a system is regulatory oversight. With new technology, new approaches for regulation may also be required. Current regulatory instruments are not adapted to this type of new and emerging technology and information.

Concerns became apparent about regulatory oversight of such a vast atmospheric monitoring system and the availability of detailed data. This can be a stepping point for a collaborative learning relationship between mine operators and regulators. Any regulation proposed for supplementary monitoring systems should be considered to increase the health and safety of the miner and to understand underground atmospheres more fully. A comprehensive AMS can be a tool for interaction between mines and regulatory agencies. An excellent approach to regulation of supplementary monitoring would be to allow the operator to collect data and define to regulators what a baseline standard operating atmosphere is for a given mine, create thresholds, and develop plans that are operation specific. This path can take a significant amount of time and might include determination of trends for weather, seasonality, and other influencing factors. A safe operation is a productive one, and working together to find the safest solution for the operation is beneficial to everyone.

Acknowledgement

Heather Dougherty is the lead author of this chapter and responsible for most of the original writing. She conceived and wrote the paper with editorial input from Dr. Kray Luxbacher, Dr. Zach Agioutantis, and Dr. Steven Schafrik. Dougherty conceived the experimental work and wrote the corresponding IRB. She also conducted the field work and the data analysis.

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Agioutantis, Z. S., C.; Papavgeri, G.; Schilizzi, P. (2015). Development of a geotechnical data management system for mining operations. SOMP Conference, Freiberg, Germany.

McWilliams, L., P. Lenart, J. Lancaster and J. Zeiner Jr (2012). "National Survey of the Mining Population Part 1: Employees." Office of Mine Safety and Health Research, Information Circular, IC **9527**: 252.

CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

The ever changing workings and atmosphere of a mine create a dynamic working environment. Every operation faces its own ventilation challenges due to the different geology, mining conditions, surface conditions, weather, and climate. Considering these variables it is important to monitor, evaluate and interpret mine conditions to make improved decisions for both safety and production. An AMS system deploying current and emerging technologies can be promoted to collect current atmospheric data and report, via an interactive atmospheric monitoring interface. This interface, displaying graphs of the AMS data will assist in the transfer of this information and understanding of the association of this data to daily safety, health, and production of the mine and miners.

The recommendation is made for an intuitive interactive atmospheric monitoring interface that will create and display graphs and or graphics of the data to assist in the transfer of knowledge and understanding of this information. Additional functionality and tools for use to trend collected data and create reports may be investigated and recommended for multiple layers of data examination by different levels of miners and management. Increased monitoring and data gathering will increase the breadth of knowledge within the field of underground mining about underground atmospheres.

7.1. Impact

Meaningful transfer of atmospheric monitoring data is currently lacking in the underground coal industry. An interface was used to assist in the transfer of what can be large amounts of data to miners in a visual fashion. This transfer of information to the front line underground miners leads to increased knowledge of their atmosphere and to increased safety, health and production of the workforce and mine. A recommendation of standards for consistence in atmospheric monitoring systems was established. These standards will make communication and understanding of atmospheric data easer to process for miners, management, visitors, and regulatory agencies.

Current technologies can be adapted to the mining field and increase safety, health, and production. Fiber optic sensing, in this case methane, although not new, is novel in underground mining. The aspects that make fiber optic sensing desirable are their range of gas detection (0-100%), operation in oxygen deficient atmospheres, and intrinsic safety. These factors make fiber optic sensors a good fit for underground operations, especially in areas where intrinsic safety is a component, and also for post disaster monitoring. In post disaster monitoring fiber optic sensors if not already installed with power sources on the surface, can be deployed for atmospheric monitoring. Smoke box testing showed that the smoke did not interfere with the light in the sensor (power ratio), only a lag in sensing response due to soot accumulation on the screen of the sensor. Fiber optic sensing is a much needed addition to sensing in underground atmospheres where intrinsic safety is necessary.

An interface is badly needed in the industry but with permissibility requirements and a small market there has been little motivation or development. AMS interactions can be very site specific, the development of a data set at a particular site is important to determining what impacts different factors have at that site. Many miners don't understand all of the interactions at their mine site and there is little real data to show the intercommunication of atmospheric factors. Providing this data, in a visual, easy to understand way is conducive to new miners and employees at the operation. Miners who would not be in front of the screen or data for their entire shift, have to digest and make rapid decisions with the information they have at the time when working underground. An AMS interface available to miners showing atmospheric changes graphically informs them and assists them in making better, safer decisions rapidly. AMS provides a mechanism for improved decision making for safety, health and production for all miners, along with a pathway to greater understanding of atmosphere at their specific mine for the operation and with regulatory agencies.

The AMS interface was tested with miners and a survey was administered. What was found is that both regulatory and miners found the AMS interface to be valuable for themselves and the operation, enhancing communication of technical data, safety, and decision making. It was expected that age, experience, job classification, or technology skill would influence feedback from the population, the data indicated that they did not influence the population as expected. The most unanticipated outcome is the difference between the regulatory, union, and management belief that sharing a comprehensive atmospheric monitoring system would lead to improved relationships between mine operators and regulators. Management rated this the least likely, Union miners the most likely, and regulatory employees rated in between the two, indicating the current climate between operators, the union, and regulatory agencies. It became apparent that there is apprehension between regulatory agencies and mines of the availability of such a vast atmospheric monitoring system. This can be a stepping point for a collaborative learning relationship between mine operators and regulators. Any regulation proposed using AMS data, or for supplementary monitoring systems should be considered to increase health and safety of the miners and to understand underground mine atmospheres more thoroughly.

7.2. Future work

This research presents the idea of using a visual interface for communicating atmospheric monitoring data in underground coal mines. The study provides compelling evidence that miners would accept and utilize such an interface. It also presents apprehension from miners, operators and regulatory personnel about how this data will be used and if it would strengthen relationships between these groups.

Fiber optic sensors in underground mining are novel. Although research has been done on the sensors, it has yet to be proven long term underground or accepted by MSHA as a proven sensor for application in coal mines. There is apprehension to using additional sensors in areas that previously they were not used, an example is bleeder entries. A fiber optic sensor would have to be utilized in a mine atmosphere for a prolonged period of time or used in an emergency situation. Although fiber optics have been proven to be accurate in laboratory experiments, it would be valuable to have an in mine comparisons to current methane sensing technologies.

When collecting large amounts of atmospheric monitoring information, it is important to present and share this data so that it will be rapidly understood and utilized by miners as well as management. This data, once collected can be a catalyst for the ability to trend, anticipate, forecast and mediate atmospheric hazards in advance of a situation arising. Additional analysis can be performed and simulations can be executed to assist in investigations to better understand, predict, and prevent future disasters. Proactive management, on both operators and regulators can lead to heightened health, safety, and increased production.

This additional monitoring and collecting and sharing of the data will allow research on the effect of various atmospheric changes and variations, and their interactions with each other and outside factors, including but not limited to: seasonal variations, weather influences, water infiltrations, sealing, idle studies, moving of large materials and equipment, air change alterations, timeliness of changes within the system when a change is made, the extent that situation will progress (e.g., how far of an influence does the change in the cut through of a section have?), over and undermining, rock temperature, depth, roughness factors, to name a few. Although it is recommended each mine, with their own ventilation factors, monitor to find out these influences in their operation, a database of data can lead to a more active or expeditious interpretation of influencing factors. These are interests for the mining industry, educational institutions, government and regulators and will lead to heightened safety and health, and production planning.

APPENDIX A

IRB Application/ Research Protocol

VirginiaTech

Institutional Review Board
Research Protocol

Once complete, upload this form as a Word document to the IRB Protocol Management System: https://secure.research.vt.edu/irb

Section 1: General Information

1.1 DO ANY OF THE INVESTIGATORS OF THIS PROJECT HAVE A REPORTABLE CONFLICT OF INTEREST? (http://www.irb.vt.edu/pages/researchers.htm#conflict)

☒ No

☐ Yes, explain:

1.2 IS THIS RESEARCH SPONSORED OR SEEKING SPONSORED FUNDS?

☐ No, go to question 2.1

☒ Yes, answer questions within table

IF YES

Provide the name of the sponsor [if NIH, specify department]: Evan Energy Investments, 441644

Is this project receiving or seeking federal funds?

☐ No

☒ Yes

If yes,

Does the grant application, OSP proposal, or "statement of work" related to this project include activities involving human subjects that are <u>not</u> covered within this IRB application?

☒ No, all human subject activities are covered in this IRB application

☐ Yes, however these activities will be covered in future VT IRB applications, these activities include:

☐ Yes, however these activities have been covered in past VT IRB applications, the IRB number(s) are as follows:

☐ Yes, however these activities have been or will be reviewed by another institution's IRB, the name of this institution is as follows:

☐ Other, explain:

Is Virginia Tech the primary awardee or the coordinating center of this grant?

☐ No, provide the name of the primary institution:

☒ Yes

Section 2: Justification

2.1 DESCRIBE THE BACKGROUND, PURPOSE, AND ANTICIPATED FINDINGS OF THIS STUDY:

In the United States, continuous atmospheric monitoring of gassy, underground coal mines has yet to be fully implemented in a meaningful and accessible manner. Many mining operations do not provide a continual or continuous means by which ventilation parameters including gasses like methane, oxygen, and CO can be measured and recorded. Subsequently, these measurements could be used to determine trends and instances of changing atmospheric conditions that indicate the presence of potential ventilation hazards. Additionally, existing mine interfaces are simplistic, out of date and do not have the capabilities to convey important atmospheric information to the miner. Recent and emerging technologies including interactive applications, touch screen, etc., offer the possibility for improved mine interface systems. This research identifies the need for the integration of atmospheric monitoring systems with more accessible, user-friendly interfaces. Anticipated findings of this research will assist in the progression of and information gathering to further atmospheric monitoring, attitudes of miners about atmospheric monitoring, and help create and evaluate user-friendly, accessable and usable interface designs.

2.2 EXPLAIN WHAT THE RESEARCH TEAM PLANS TO DO WITH THE STUDY RESULTS:

For example - publish or use for dissertation

Publish in peer review publications and use for dissertation.

Section 3: Recruitment

3.1 DESCRIBE THE SUBJECT POOL, INCLUDING INCLUSION AND EXCLUSION CRITERIA AND NUMBER OF SUBJECTS:

Examples of inclusion/exclusion criteria - gender, age, health status, ethnicity

The sample pool will include currently employed underground coal miners, all over the age of consent (>18) No minors. We seek a minimum of 50 participants.

3.2 WILL EXISTING RECORDS BE USED TO IDENTIFY AND CONTACT / RECRUIT SUBJECTS?

Examples of existing records - directories, class roster, university records, educational records

☒ No, go to question 3.3

☐ Yes, answer questions within table

IF YES
Are these records private or public? ☐ Public ☐ Private, describe the researcher's privilege to the records:
Will student, faculty, and/or staff records or contact information be requested from the University?

☐ No

☐ Yes, provide a description under Section 14 (Research Involving Existing Data) below.

3.3 DESCRIBE RECRUITMENT METHODS, INCLUDING HOW THE STUDY WILL BE ADVERTISED OR INTRODUCED TO SUBJECTS:

Recuritment will be done via training or requesting a meeting with a group of employees. Researchers will reach out to coal companies asking for approximately an hour of time during annual training or suggest a meeting of a group of employees. Once the subjects are gathered, the study is totally voluntary, and it will be stated that if anyone chooses, they do not have to participate.

3.4 PROVIDE AN EXPLANATION FOR CHOOSING THIS POPULATION:

Note: the IRB must ensure that the risks and benefits of participating in a study are distributed equitably among the general population and that a specific population is not targeted because of ease of recruitment.

This population was chosen because the research focuses on atmospheric monitoring in underground coal. We hope to include all job classifications within underground coal mining.

Section 4: Consent Process

For more information about consent process and consent forms visit the following link: http://www.irb.vt.edu/pages/consent.htm

If feasible, researchers are advised and may be required to obtain signed consent from each participant unless obtaining signatures leads to an increase of risk (e.g., the only record linking the subject and the research would be the consent document and the principal risk would be potential harm resulting in a breach of confidentiality). Signed consent is typically not required for low risk questionnaires (consent is implied) unless audio/video recording or an in-person interview is involved. If researchers will not be obtaining signed consent, participants must, in most cases, be supplied with consent information in a different format (e.g., in recruitment document, at the beginning of survey instrument, read to participant over the phone, information sheet physically or verbally provided to participant).

4.1 CHECK ALL OF THE FOLLOWING THAT APPLY TO THIS STUDY'S CONSENT PROCESS:

☐ Verbal consent will be obtained from participants

☒ Signed consent will be obtained from participants

☐ Consent will be implied from the return of completed questionnaire. Note: The IRB recommends providing consent information in a recruitment document or at the beginning of the questionnaire (if the study only involves implied consent, skip to Section 5 below)

☐ Other, describe:

4.2 PROVIDE A GENERAL DESCRIPTION OF THE PROCESS THE RESEARCH TEAM WILL USE TO OBTAIN AND MAINTAIN INFORMED CONSENT:

4.3 WHO, FROM THE RESEARCH TEAM, WILL BE OVERSEEING THE PROCESS AND OBTAINING CONSENT FROM SUBJECTS?

4.4 WHERE WILL THE CONSENT PROCESS TAKE PLACE?

4.5 DURING WHAT POINT IN THE STUDY PROCESS WILL CONSENTING OCCUR?

Note: unless waived by the IRB, participants must be consented before completing any study procedure, including screening questionnaires.

4.6 IF APPLICABLE, DESCRIBE HOW THE RESEARCHERS WILL GIVE SUBJECTS AMPLE TIME TO REVIEW THE CONSENT DOCUMENT BEFORE SIGNING:

Note: typically applicable for complex studies, studies involving more than one session, or studies involving more of a risk to subjects.

☐ Not applicable

Section 5: Procedures

5.1 PROVIDE A STEP-BY-STEP THOROUGH EXPLANATION OF ALL STUDY PROCEDURES EXPECTED FROM STUDY PARTICIPANTS, INCLUDING TIME COMMITMENT & LOCATION:

A presentation of atmospheric monitoring and a review of the prototype interface showing this information will be given. The participants will be asked to fill out a general survey of their background and expierence. The atmopsheric monitoring interface will be given to the miners (possibly to work with in groups) and they will be asked some questions to help guide them through the interface. There will be guidance from a researcher if there are questions or concerns. They will be then asked to complete a questionaire about what they thought and learned from the interface. There may also be some group discussions that will be recorded by notes. This will all take approximately 1 hour of time and will mostly likely be done at their place of work in person.

5.2 DESCRIBE HOW DATA WILL BE COLLECTED AND RECORDED:

The surveys will be in paper form and will be collected and then recorded digitally for stastical evaluation.

5.3 DOES THE PROJECT INVOLVE ONLINE RESEARCH ACTIVITES (INCLUDES ENROLLMENT, RECRUITMENT, SURVEYS)?

View the "Policy for Online Research Data Collection Activities Involving Human Subjects" at http://www.irb.vt.edu/documents/onlinepolicy.pdf

☒ No, go to question 6.1

☐ Yes, answer questions within table

IF YES
Identify the service / program that will be used: ☐ www.survey.vt.edu, go to question 6.1 ☐ SONA, go to question 6.1

☐ Qualtrics, go to question 6.1

☐ Center for Survey Research, go to question 6.1

☐ Other

IF OTHER:

Name of service / program:

URL:

This service is…

☐ Included on the list found at: http://www.irb.vt.edu/pages/validated.htm

☐ Approved by VT IT Security

☐ An external service with proper SSL or similar encryption (https://) on the login (if applicable) and all other data collection pages.

☐ None of the above (note: only permissible if this is a collaborative project in which VT individuals are only responsible for data analysis, consulting, or recruitment)

Section 6: Risks and Benefits

6.1 WHAT ARE THE POTENTIAL RISKS (E.G., EMOTIONAL, PHYSICAL, SOCIAL, LEGAL, ECONOMIC, OR DIGNITY) TO STUDY PARTICIPANTS?

The participants may feel uncomfortable answering questions.

6.2 EXPLAIN THE STUDY'S EFFORTS TO REDUCE POTENTIAL RISKS TO SUBJECTS:

The study is voluntary and it will be stated that if they feel uncomfortable answering questions they can skip them.

6.3 WHAT ARE THE DIRECT OR INDIRECT ANTICIPATED BENEFITS TO STUDY PARTICIPANTS AND/OR SOCIETY?

A better understanding of how coal miners feel about atmospheric monitoring, atmospheric data, and the availability of this data to a larger group. This will be helpful in education and training of miners.

Section 7: Full Board Assessment

7.1 DOES THE RESEARCH INVOLVE MICROWAVES/X-RAYS, OR GENERAL ANESTHESIA OR SEDATION?

☒ No

☐ Yes

7.2 DO RESEARCH ACTIVITIES INVOLVE PRISONERS, PREGNANT WOMEN, FETUSES, HUMAN IN VITRO FERTILIZATION, OR INDIVIDUALS WITH MENTAL DISORDERS?

☒ No, go to question 7.3

☐ Yes, answer questions within table

IF YES
This research involves: ☐ Prisoners ☐ Pregnant women ☐ Fetuses ☐ Human in vitro fertilization ☐ Individuals with a mental disorder

7.3 DOES THIS STUDY INVOLVE MORE THAN MINIMAL RISK TO STUDY PARTICIPANTS?

Minimal risk means that the probability and magnitude of harm or discomfort anticipated in the research are not greater in and of themselves than those ordinarily encountered in daily activities or during the performance of routine physical or psychological examinations or tests. Examples of research involving greater than minimal risk include collecting data about abuse or illegal activities. Note: if the project qualifies for Exempt review (http://www.irb.vt.edu/pages/categories.htm), it will not need to go to the Full Board.

☒ No

☐ Yes

IF YOU ANSWERED "YES" TO ANY ONE OF THE ABOVE QUESTIONS, 7.1, 7.2, OR 7.3, THE BOARD MAY REVIEW THE PROJECT'S APPLICATION MATERIALS AT ITS MONTHLY MEETING. VIEW THE FOLLOWING LINK FOR DEADLINES AND ADDITIONAL INFORMATION: http://www.irb.vt.edu/pages/deadlines.htm

Section 8: Confidentiality / Anonymity

For more information about confidentiality and anonymity visit the following link: http://www.irb.vt.edu/pages/confidentiality.htm

8.1 WILL PERSONALLY IDENTIFYING STUDY RESULTS OR DATA BE RELEASED TO ANYONE OUTSIDE OF THE RESEARCH TEAM?

For example – to the funding agency or outside data analyst, or participants identified in publications with individual consent

☒ No

☐ Yes, to whom will identifying data be released?

8.2 WILL THE RESEARCH TEAM COLLECT AND/OR RECORD PARTICIPANT IDENTIFYING INFORMATION (E.G., NAME, CONTACT INFORMATION, VIDEO/AUDIO RECORDINGS)?

Note: if collecting signatures on a consent form, select " Yes."

☒ No, go to question 8.3

☒ Yes, answer questions within table

IF YES

Describe if/how the study will utilize study codes: Only the consent form will contain identifying information. This will be kept, and collected seperately so that no identifying informaiton is kept with the surveys.
If applicable, where will the key [i.e., linked code and identifying information document (for instance, John Doe = study ID 001)] be stored and who will have access? N/A Note: the key should be stored separately from subjects' completed data documents and accessibility should be limited.
The IRB strongly suggests and may require that all data documents (e.g., questionnaire responses, interview responses, etc.) do not include or request identifying information (e.g., name, contact information, etc.) from participants. If you need to link subjects' identifying information to subjects' data documents, use a study ID/code on all data documents.

8.3 HOW WILL DATA BE STORED TO ENSURE SECURITY (E.G., PASSWORD PROTECTED COMPUTERS, ENCRYPTION) AND LIMITED ACCESS?

Examples of data - questionnaire, interview responses, downloaded online survey data, observation recordings, biological samples

Questionnaire, Interview responses, observations written will be stored on a password protected computer with limited access.

8.4 WHO WILL HAVE ACCESS TO STUDY DATA?

Research team who were identified (Luxbacher, Jong, Schlossler, Dougherty)

8.5 DESCRIBE THE PLANS FOR RETAINING OR DESTROYING STUDY DATA:

Once all the data is retained digitally (inputted into an excel or access database) and publications are written, thehand written documents will be destroyed.

8.6 DOES THIS STUDY REQUEST INFORMATION FROM PARTICIPANTS REGARDING ILLEGAL BEHAVIOR?

☒ No, go to question 9.1

☐ Yes, answer questions within table

IF YES
Does the study plan to obtain a Certificate of Confidentiality? ☐ No ☐ Yes (Note: participants must be fully informed of the conditions of the Certificate of Confidentiality within the consent process and form) For more information about Certificates of Confidentiality, visit the following link: http://www.irb.vt.edu/pages/coc.htm

Section 9: Compensation

For more information about compensating subjects, visit the following link:
http://www.irb.vt.edu/pages/compensation.htm

9.1 WILL SUBJECTS BE COMPENSATED FOR THEIR PARTICIPATION?

☒ No, go to question 10.1

☐ Yes, answer questions within table

IF YES
What is the amount of compensation?
Will compensation be prorated? ☐ Yes, please describe: ☐ No, explain why and clarify whether subjects will receive full compensation if they withdraw from the study? Unless justified by the researcher, compensation should be prorated based on duration of study participation. Payment must <u>not</u> be contingent upon completion of study procedures. In other words, even if the subject decides to withdraw from the study, he/she should be compensated, at least partially, based on what study procedures he/she has completed.

Section 10: Audio / Video Recording

For more information about audio/video recording participants, visit the following link: http://www.irb.vt.edu/pages/recordings.htm

10.1 WILL YOUR STUDY INVOLVE VIDEO AND/OR AUDIO RECORDING?

☒ No, go to question 11.1

☐ Yes, answer questions within table

IF YES
This project involves: ☐ Audio recordings only ☐ Video recordings only ☐ Both video and audio recordings
Provide compelling justification for the use of audio/video recording:
How will data within the recordings be retrieved / transcribed?
How and where will recordings (e.g., tapes, digital data, data backups) be stored to ensure security?
Who will have access to the recordings?

Who will transcribe the recordings?
When will the recordings be erased / destroyed?

Section 11: Research Involving Students

11.1 DOES THIS PROJECT INCLUDE STUDENTS AS PARTICIPANTS?

☒ No, go to question 12.1

☐ Yes, answer questions within table

IF YES
Does this study involve conducting research with students of the researcher? ☐ No ☐ Yes, describe safeguards the study will implement to protect against coercion or undue influence for participation: Note: if it is feasible to use students from a class of students not under the instruction of the researcher, the IRB recommends and may require doing so.

Will the study need to access student records (e.g., SAT, GPA, or GRE scores)? ☐ No ☐ Yes

11.2 DOES THIS PROJECT INCLUDE ELEMENTARY, JUNIOR, OR HIGH SCHOOL STUDENTS?

☒ No, go to question 11.3

☐ Yes, answer questions within table

IF YES
Will study procedures be completed during school hours? ☐ No ☐ Yes If yes, Students not included in the study may view other students' involvement with the research during school time as unfair. Address this issue and how the study will reduce this outcome: Missing out on regular class time or seeing other students participate may influence a student's decision to participate. Address how the study will reduce this outcome:

Is the school's approval letter(s) attached to this submission?

☐ Yes

☐ No, project involves Montgomery County Public Schools (MCPS)

☐ No, explain why:

You will need to obtain school approval (if involving MCPS, click here: http://www.irb.vt.edu/pages/mcps.htm). Approval is typically granted by the superintendent, principal, and classroom teacher (in that order). Approval by an individual teacher is insufficient. School approval, in the form of a letter or a memorandum should accompany the approval request to the IRB.

11.3 DOES THIS PROJECT INCLUDE COLLEGE STUDENTS?

☒ No, go to question 12.1

☐ Yes, answer questions within table

IF YES

Some college students might be minors. Indicate whether these minors will be included in the research or actively excluded:

☐ Included

☐ Actively excluded, describe how the study will ensure that minors will not be included:

Will extra credit be offered to subjects?

☐ No

☐ Yes

If yes,

What will be offered to subjects as an equal alternative to receiving extra credit without participating in this study?

Include a description of the extra credit (e.g., amount) to be provided within question 9.1 ("IF YES" table)

Section 12: Research Involving Minors

12.1 DOES THIS PROJECT INVOLVE MINORS (UNDER THE AGE OF 18 IN VIRGINIA)?

Note: age constituting a minor may differ in other States.

☒ No, go to question 13.1

☐ Yes, answer questions within table

IF YES

Does the project reasonably pose a risk of reports of current threats of abuse and/or suicide?

☐ No

☐ Yes, thoroughly explain how the study will react to such reports:

Note: subjects and parents must be fully informed of the fact that researchers must report threats of suicide or suspected/reported abuse to the appropriate authorities within the Confidentiality section of the Consent, Assent, and/or Permission documents.

Are you requesting a waiver of parental permission (i.e., parent uninformed of child's involvement)?

☐ No, both parents/guardians will provide their permission, if possible.

☐ No, only one parent/guardian will provide permission.

☐ Yes, describe below how your research meets <u>all</u> of the following criteria (A-D):

Criteria A - The research involves no more than minimal risk to the subjects:

Criteria B - The waiver will not adversely affect the rights and welfare of the subjects:

Criteria C - The research could not practicably be carried out without the waiver:

Criteria D - (Optional) Parents will be provided with additional pertinent information after

participation:

Is it possible that minor research participants will reach the legal age of consent (18 in Virginia) while enrolled in this study?

☐ No

☐ Yes, will the investigators seek and obtain the legally effective informed consent (in place of the minors' previously provided assent and parents' permission) for the now-adult subjects for any ongoing interactions with the subjects, or analysis of subjects' data? If yes, explain how: For more information about minors reaching legal age during enrollment, visit the following link: http://www.irb.vt.edu/pages/assent.htm
The procedure for obtaining assent from minors and permission from the minor's guardian(s) must be described in Section 4 (Consent Process) of this form.

Section 13: Research Involving Deception

For more information about involving deception in research and for assistance with developing your debriefing form, visit our website at http://www.irb.vt.edu/pages/deception.htm

13.1 DOES THIS PROJECT INVOLVE DECEPTION?

☒ No, go to question 14.1

☐ Yes, answer questions ~~within table~~

IF YES
Describe the deception:

Why is the use of deception necessary for this project?
Describe the debriefing process:
Provide an explanation of how the study meets <u>all</u> the following criteria (A-D) for an alteration of consent: Criteria A - The research involves no more than minimal risk to the subjects: Criteria B - The alteration will not adversely affect the rights and welfare of the subjects: Criteria C - The research could not practicably be carried out without the alteration: Criteria D - (Optional) Subjects will be provided with additional pertinent information after participation (i.e., debriefing for studies involving deception): By nature, studies involving deception cannot provide subjects with a complete description of the study during the consent process; therefore, the IRB must allow (by granting an alteration of consent) a consent process which does not include, or which alters, some or all of the elements of informed consent.
The IRB requests that the researcher use the title "Information Sheet" instead of "Consent Form" on the document used to obtain subjects' signatures to participate in the research. This will adequately reflect the fact that the subject cannot fully consent to the research without the researcher fully disclosing the true intent of the research.

Section 14: Research Involving Existing Data

14.1 WILL THIS PROJECT INVOLVE THE COLLECTION OR STUDY/ANALYSIS OF EXISTING DATA DOCUMENTS, RECORDS, PATHOLOGICAL SPECIMENS, OR DIAGNOSTIC SPECIMENS?

Please note: it is not considered existing data if a researcher transfers to Virginia Tech from another institution and will be conducting data analysis of an on-going study.

☒ No, you are finished with the application

☐ Yes, answer questions ~~within table~~

IF YES
From where does the existing data originate?
Provide a detailed description of the existing data that will be collected or studied/analyzed:
Is the source of the data public? ☐ No, continue with the next question ☐ Yes, you are finished with this application
Will any individual associated with this project (internal or external) have access to or be provided with existing data containing information which would enable the identification of subjects: ☐ Directly (e.g., by name, phone number, address, email address, social security number, student ID number), or

☐ Indirectly through study codes even if the researcher or research team does not have access to the master list linking study codes to identifiable information such as name, student ID number, etc

or

☐ Indirectly through the use of information that could reasonably be used in combination to identify an individual (e.g., demographics)

☐ No, collected/analyzed data will be completely de-identified

☐ Yes,

If yes,

Research will not qualify for exempt review; therefore, if feasible, written consent must be obtained from individuals whose data will be collected / analyzed, unless this requirement is waived by the IRB.

Will written/signed or verbal consent be obtained from participants prior to the analysis of collected data? -select one-

This research protocol represents a contract between all research personnel associated with the project, the University, and federal government; therefore, must be followed accordingly and kept current.

Proposed modifications must be approved by the IRB prior to implementation except where necessary to eliminate apparent immediate hazards to the human subjects.

Do not begin human subjects activities until you receive an IRB approval letter via email.

It is the Principal Investigator's responsibility to ensure all members of the research team who interact with research subjects, or collect or handle human subjects data have completed human subjects protection training prior to interacting with subjects, or handling or collecting the data.

----------END----------

Recruitment materials

Contacts will be made with safety managers or trainers at major underground coal mine sites. We will ask if we can have an hour of time to discuss atmospheric monitoring with a range of miners to get their anonymous feedback for our research project. Detail about the surveys and interface will be provided upon request. A meeting prior to the research meeting will also be made if requested.

Consent

Consent Script

Hello my name is Heather Dougherty (or other researcher) and I am a graduate student at Virginia Tech studying, researching, and writing my dissertation focus on atmospheric monitoring in underground coal. I am here to research and talk to you about atmospheric monitoring, show you an interface to convey this information and gather your thoughts and opinions on this topic.

This survey is totally voluntary. Aside from your consent form your personal identifying information will not be collected or stored. The consent forms will be kept separately and not collected or stored with the surveys. If you agree to participate, I will give you two surveys, show you this interface and will give you time to interact with it. I may also collect notes from conversations to better understand your (and group) thoughts and feelings on the topic and interface.

The research project poses no physical or financial risks to you, no identifying information will be collected. Although this research provides no direct benefits to you, it will help the researchers better understand atmospheric monitoring in underground coal and may help improve health and safety.

You will receive no compensation for participating in this project. Your participation in this research project is entirely voluntary. You are free to withdraw from this study at any time without penalty. You are also free to refuse to answer any question at your discretion without penalty.

Do you have any questions about me, my research, or our interview before we begin?

Contact information will be provided and you are welcome to ask questions at any time during the study. Thank you in advance for your time and attention for this research.

Consent form

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Informed Consent for Participants

in Research Projects Involving Human Subjects

Title of Project: __Atmospheric monitoring interface in underground coal mines___

Investigator(s): _Heather Dougherty_________ _hndoug@vt.edu______

Name E-mail / Phone number

_Dr. Kray Luxbacher_________ _kraylux@vt.edu______

Name E-mail / Phone number

I. Purpose of this Research Project

In the United States, continuous atmospheric monitoring of gassy, underground coal mines has yet to be fully implemented in a meaningful and accessible manner. Many mining operations do not provide a continual or continuous means by which ventilation parameters including gasses like methane, oxygen, and CO can be measured and recorded. Subsequently, these measurements could be used to determine trends and instances of changing atmospheric conditions that indicate the presence of potential ventilation hazards. Additionally, existing mine interfaces are simplistic, out of date and do not have the capabilities to convey important atmospheric information to the miner. Recent and emerging technologies including interactive applications, touch screen, etc., offer the possibility for improved mine interface systems. This research identifies the need for the integration of atmospheric monitoring systems with more accessible, user-friendly interfaces. Anticipated findings of this research will assist in the progression of and information gathering to further atmospheric monitoring, attitudes of miners about atmospheric monitoring, and help create and evaluate user-friendly, accessible and usable interface designs.

Anonymous information gathered will be used in publications and dissertation research. A minimum of 50 subjects consisting of underground coal miners is required for a meaningful analysis.

II. Procedures

Should you agree to participate, you will be asked to complete two surveys, one prior to training with the atmospheric monitoring interface, and one post this training. You will be given time to interact with the interface, possibly with a group and ask questions at any time. It is estimated that this will take no longer than an hour to complete. Written notes may be anonymously taken of group discussions if topics are not covered in the survey.

This research will take place at your place of work as to interfere with your daily tasks as little as possible.

III. Risks

No risks are predicted for this project.

IV. Benefits

Although this research provides no direct benefits to you, it will help the researchers better understand atmospheric monitoring attitudes and procedures in the mine to assist in developing better communication of such information for improved safety and health.

No promise or guarantee of benefits has been made to encourage you to participate.

V. Extent of Anonymity and Confidentiality

No identifying information is collected in this study and survey.

The Virginia Tech (VT) Institutional Review Board (IRB) may view the study's data for auditing purposes. The IRB is responsible for the oversight of the protection of human subjects involved in research.

Note: in some situations, it may be necessary for an investigator to break confidentiality.

If a researcher has reason to suspect that a child is abused or neglected, or that a person poses a threat of harm to others or him/herself, the researcher is required by Virginia State law to notify the appropriate authorities. If applicable to this study, the conditions under which the investigator must break confidentiality must be described.

VI. Compensation

You will receive no compensation for participating in this project

VII. Freedom to Withdraw

Your participation in this project is entirely voluntary. You are free to withdraw from this study at any time without penalty. You are also free to refuse to answer any question at your discretion without penalty.

VIII. Questions or Concerns

Should you have any questions about this study, you may contact one of the research investigators whose contact information is included at the beginning of this document.

Should you have any questions or concerns about the study's conduct or your rights as a research subject, or need to report a research-related injury or event, you may contact the VT IRB Chair, Dr. David M. Moore at moored@vt.edu or (540) 231-4991.

IX. Subject's Consent

I have read the Consent Form and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent:

____ Date__________

Subject signature

Subject printed name

Data Collection Instruments

Form Approved
OMB No. xxxx-xxxx
Exp. Date xx/xx/201x

Atmospheric Monitoring Interface: Pre-Interaction Questionnaire

1. Age_______

2. How many years of experience do you have? (years)

As a miner? ______

At your current mine? ______

In your current job? ______

3. What is your current main job classification?

Inby Machine operator
Inby laborer
Outby laborer (Utility)
Underground Supervisor Face
Underground Supervisor Outby
Fireboss
Mechanic/Electrician
Motorman/Supply
Engineer
Management
Regulatory Agency/Government
Safety
Other: ______________________________

4. Highest level of education

Some High School
High School
Some College
Associates degree
Bachelors degree
Post Bachelors

5. On a normal day do you carry a multigas detector?

☐ No ☐ Yes

6. The safety culture at your operations is?

☐ Weak ☐ Neutral ☐ Strong

7. Gender: ☐ Male ☐ Female

8. Are you a..?

Union Worker
Non Union Worker
Management
Contractor
Regulatory/Government

9. What underground mine certifications do you have? (check all that apply)

Underground Miner
Machine Operator
Fireboss
Assistant Mine Foreman
Mine Foreman
Underground Gas Check
None
Other: ________________________________

10. What job classification(s) have you performed? (check all that apply)

Inby Machine operator
Inby laborer
Outby laborer (Utility)
Underground Supervisor Face
Underground Supervisor Outby
Fireboss
Mechanic/Electrician
Motorman/Supply
Engineer
Management
Regulatory Agency/Government
Safety
Other: ______________________________

On average, how often do you…	Never	Monthly	Weekly	Few times a week	Daily
11. Play video games? (e.g., computer, Xbox, Playstation)					
12. Spend time on the computer? (eg, work, internet, games)					
13. Spend time on your tablet or smartphone?					

Atmospheric Monitoring Interface: Pre-Interaction Questionnaire

14. Do you regularly (minimum weekly) look at the mine log (books)? ☐ No ☐ Yes

15. Would continuous monitoring of additional gasses (other than CO) be helpful to you? (eg Methane, Oxygen..) ☐ No ☐ Yes
If NO, Skip #16

16. And if continuous monitoring would be helpful to you, what areas should be monitored? (check all that apply)
- Face
- Belt
- Outby
- Bleeder
- Other:________________________________

17. Are you responsible for taking gas readings and logging them into the book or for callout?
☐ No ☐ Yes

18. What types of Atmospheric Monitoring system(s) (ATMs) are at your mine? (check all that apply)
- Belt CO system
- Additional gas monitoring system
- I don't know
- Other:________________________________

19. Is this atmospheric monitoring systems current information available in common areas and easily accessible?
☐ No ☐ Yes

20. Why or why not is atmospheric monitoring beneficial to you? ____
____
____
____
____

Atmospheric Monitoring Interface: Post-Interface Questionnaire

1. Working with this Atmospheric Monitoring Interface, how easy was it to

	Very Hard	Hard	Neutral	Easy	Very Easy
a) Identify the active working section?					
b) Identify the sensors in the active working section?					
c) Find the sensor locations throughout the mine?					
d) Access the data from the sensors?					
e) Understand the data from the sensors?					
f) Move to different sensors throughout the mine?					
g) Identify changes in gases at sensor locations?					
h) Change gas chart data to different time frames? (e.g.,24 hr, 1 week, etc.)					
i)					
j)					

2. Rate how you feel about

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
a) Miners can make better decisions by having additional atmospheric monitoring data available.					
b) Providing this information will lead to improved interactions with regulatory agencies?					
c) Providing this information will lead to increased or unfair oversight from regulatory agencies?					
d) The safety and health of the miner and operation will be increased by having atmospheric monitoring system data available.					
e) It will be easy to interpret this information and make it useful for the miner?					
f) Presenting this information on a handheld device for use underground at my operation(s) would be useful.					

Atmospheric Monitoring Interface: Post-Interface Questionnaire

3. Do you think that the following people would use the interface or ATM information on a regular basis at work?

	Yes	No
a) You		
b) Miners		
c) Supervisors		
d) Engineers		
e) Management		
f) Regulatory		

4. Additional monitoring will be useful for (check all that apply):

- ☐ Section Returns
- ☐ Outby Section Returns
- ☐ Emergency situations
- ☐ All Returns
- ☐ Main Returns
- ☐ Intakes
- ☐ Belts
- ☐ Gob Areas
- ☐ Areas examined weekly
- ☐ Seal Lines
- ☐ Shaft Bottoms
- ☐ Slope or haulage shaft

5. What types of atmospheric monitoring would be beneficial for underground coal mining operations in your experience? (check all that apply)

- ☐ Oxygen
- ☐ Carbon Monoxide (CO)
- ☐ Carbon Dioxide (C02)
- ☐ Hydrogen
- ☐ Smoke
- ☐ Methane
- ☐ Fan Amps
- ☐ Barometric Pressure
- ☐ Weather
- ☐ Temperature
- ☐ Humidity
- ☐ Air Pressure
- ☐ Belt Amps
- ☐ Other ___________________________

6. Do you identify any other opportunities for improvement in current atmospheric monitoring systems?

____

____

____

____

____

APPENDIX B

Pre-Interaction Questionnaire - Access Database Information				
Question #	Question	Access Label	Value/ Numeric/ Text	List
1	Age	Age	Value	
2	How many years of experience do you have as a miner? (Years)	MinerExp	Value	
	How many years of experience do you have at your current mine?	CurrentExp	Value	
	How many years of experience do you have in your current job?	CurJobExp	Value	
3	What is your current main job classification	CurrentMainJob	List (check one)	Inby Machine operator
				Inby laborer
				Outby laborer (Utility)
				Underground Supervisor Face
				Underground Supervisor Outby
				Fireboss
				Mechanic/Electrician
				Motorman/Supply
				Engineer
				Management
				Regulatory Agency/Government
				Safety
				Other

4	Highest level of education	Education	List (check one)	Some High School
				High School
				Some college
				Associates degree
				Bachelors degree
				Post Bachelors
5	On a normal day do you carry a multigas detector?	Detector	True/False	
6	The Safety culture at your operation is?	SafetyCulture	Weak/Neutral/Strong	1=Weak, 2=Neutral, 3=Strong
7	Gender	Gender	Male/Female	Check box
8	Area you a…?	Classification	List (check one)	Union Worker
				Non Union Worker
				Management
				Contractor
				Regulatory/Government
9	What underground mine certifications do you have? (Check all that apply)	Cert1	True/False	Undergrounds Miner
		Cert2	True/False	Machine Operator
		Cert3	True/False	Fireboss
		Cert4	True/False	Assistant Mine Foreman
		Cert5	True/False	Mine Foreman
		Cert6	True/False	Underground Gas Check
		Cert7	True/False	None
		Cert8	True/False	Other
10	What job classification(s) have you preformed? (check all that apply)	AllJobClass	List (check all)	Inby Machine operator
				Inby laborer
				Outby laborer (Utility)

				Underground Supervisor Face
				Underground Supervisor Outby
				Fireboss
				Mechanic/Electrician
				Motorman/Supply
				Engineer
				Management
				Regulatory Agency/Government
				Safety
				Other
11	On average how often do you play video games? (eg, computer, Xbox, Playstation)	VideoGameTime	Never, Monthly, Weekly, Few times a week, Daily	Never=1, Monthly=2, Weekly=3, Few times a week=4, Daily=5
12	On average how often do you spend time on the computer? (eg, work, internet, games)	ComputerTime	Never, Monthly, Weekly, Few times a week, Daily	Never=1, Monthly=2, Weekly=3, Few times a week=4, Daily=5
13	On average how often do you spend time on your tablet or smartphone?	TabletPhoneTime	Never, Monthly, Weekly, Few times a week, Daily	Never=1, Monthly=2, Weekly=3, Few times a week=4, Daily=5
14	Do you regularly (minimum weekly) look at the mine log (books)?	LogBook	Yes/No	True/False
15	Would continuous monitoring of additional gases (other than CO) be helpful to you? (eg, Methane, Oxygen..)	ATMHelpful	Yes/No	True/False
16	And if continuous monitoring would be helpful to you, what areas whould be	ATMMonitoring	List (check all)	Face

	monitored? (check all that apply)			
				Belt
				Outby
				Bleeder
				Other
17	Are you responsible for taking gas readings and logging them into the book or for callout?	ATMResponsability	Yes/No	True/False
18	What types of Atmospheric Monitoring system(s) (ATMs) are at your mine? (check all that apply)	ATMKnowledge	List (check all)	Belt CO system
				Additional gas monitoring system
				I don't know
				Other
19	Is this atmospheric monitoring system current information available in common areas and easily accessible?	ATMCommon	Yes/No	True/False
20	Why or why not is atmospheric monitoring beneficial to you?	ATMBeneficialComments	Open Text	

Post-Interface Questionnaire - Access Database Information				
Question #	Question	Access Label	Value/ Numeric/ Text	List
1	Working with this Atmospheric Monitoring Interface, how easy was it to			
1a	Identify the active working section?	Section	Very Hard, Hard, Neutral, Easy, Very Easy	Very Hard=1, Hard=2, Neutral=3, Easy=4, Very Easy=5
1b	Identify the sensors in the active working section?	Sensors	Very Hard, Hard, Neutral, Easy, Very Easy	Very Hard=1, Hard=2, Neutral=3, Easy=4, Very Easy=5
1c	Find the sensor locations throughout the mine?	SensorLoc	Very Hard, Hard, Neutral, Easy, Very Easy	Very Hard=1, Hard=2, Neutral=3, Easy=4, Very Easy=5
1d	Access the data from the sensors?	SensorData	Very Hard, Hard, Neutral, Easy, Very Easy	Very Hard=1, Hard=2, Neutral=3, Easy=4, Very Easy=5
1e	Understand the data from the sensors?	Data	Very Hard, Hard, Neutral, Easy, Very Easy	Very Hard=1, Hard=2, Neutral=3, Easy=4, Very Easy=5
1f	Move to different sensors throughout the mine?	SensorMove	Very Hard, Hard, Neutral, Easy, Very Easy	Very Hard=1, Hard=2, Neutral=3, Easy=4, Very Easy=5
1g	Identify changes in gases at sensor locations?	GasChg	Very Hard, Hard, Neutral, Easy, Very Easy	Very Hard=1, Hard=2, Neutral=3, Easy=4, Very Easy=5
1h	Change gas chart data to different time frame? (eg, 24hr, 1 week, etc)	ChartTime	Very Hard, Hard, Neutral, Easy, Very Easy	Very Hard=1, Hard=2, Neutral=3, Easy=4, Very Easy=5

2	Rate how you feel about			
2a	Miners can make better decisions by having additional atmospheric monitoring data available.	Decisions	Strongly Disagree, Disagree, Neutral, Agree, Strongly Agree	Strongly Disagree=1, Disagree=2, Neutral=3, Agree=4, Strongly Agree=5
2b	Providing this information will lead to improved interactions with regulatory agencies?	ImpReg	Strongly Disagree, Disagree, Neutral, Agree, Strongly Agree	Strongly Disagree=1, Disagree=2, Neutral=3, Agree=4, Strongly Agree=5
2c	Providing this informaiton will lead to increased or unfair oversight from regulatory agencies?	UnfairOver	Strongly Disagree, Disagree, Neutral, Agree, Strongly Agree	Strongly Disagree=1, Disagree=2, Neutral=3, Agree=4, Strongly Agree=5
2d	The safety and health of the miner and operation will be increased by having atmospheric monitoring system data available.	SHIncrease	Strongly Disagree, Disagree, Neutral, Agree, Strongly Agree	Strongly Disagree=1, Disagree=2, Neutral=3, Agree=4, Strongly Agree=5
2e	It will be easy to interpret this information and make it useful for the miner?	EasyInter	Strongly Disagree, Disagree, Neutral, Agree, Strongly Agree	Strongly Disagree=1, Disagree=2, Neutral=3, Agree=4, Strongly Agree=5
2f	Presenting this information on a handheld device for use underground at my operation(s) would be useful.	Presenting	Strongly Disagree, Disagree, Neutral, Agree, Strongly Agree	Strongly Disagree=1, Disagree=2, Neutral=3, Agree=4, Strongly Agree=5
3	Do you think that the following people would use the interface or ATM information on a regular basis at work?			
a	You	UseYou	True/False	

b	Miners	UseMiner	True/ False	
c	Supervisors	UseSuper	True/ False	
d	Engineers	UseEngr	True/ False	
e	Management	UseMgmt	True/ False	
f	Regulatory	UseReg	True/ False	
4	Additional monitoring will be useful for (check all that apply):			
	Section Returns	Add1	True/ False	
	Outby Section Returns	Add2	True/ False	
	Emergency situations	Add3	True/ False	
	All Returns	Add4	True/ False	
	Main Returns	Add5	True/ False	
	Intakes	Add6	True/ False	
	Belts	Add7	True/ False	
	Gob areas	Add8	True/ False	
	Areas examined weekly	Add9	True/ False	
	Seal Lines	Add10	True/ False	
	Shaft Bottoms	Add11	True/ False	
	Slope or haulage shaft	Add12	True/ False	
5	What types of atmospheric monitoring would be beneficial for underground coal mining operations in your experience? (check all that apply)			
	Oxygen	ATM1	True/ False	
	Carbon Monoxide (CO)	ATM2	True/ False	
	Carbon Dioxide(CO2)	ATM3	True/ False	
	Hydrogen	ATM4	True/ False	
	Smoke	ATM5	True/ False	
	Methane	ATM6	True/ False	
	Fan Amps	ATM7	True/ False	
	Barometric Pressure	ATM8	True/ False	
	Weather	ATM9	True/ False	
	Temperature	ATM10	True/ False	
	Humidity	ATM11	True/ False	
	Air Pressure	ATM12	True/ False	
	Belt Amps	ATM13	True/ False	
	Other	ATM14	True/ False	
6	Do you identify any other opportunities for improvement in current atmospheric monitoring systems?	Improvement	Text Field	