Report and Recommendations for Strategic Research Areas
from the
Metal Mining Automation and Advanced Technologies Workgroup
under the
Mine Safety and Health Advisory Committee, NIOSH-CDC

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Executive Summary

The following recommendations for work at NIOSH in the area of Metal Mining and Advanced Technologies are described in the report herein:

- Track the degree of automation in various sectors of the industry, best practices, and determine measurable impacts on health and safety.
- Assess and define appropriate limits for human operators interfacing with machines, particularly in remote control – what are the maximum number of alarms/decisions the operator can reasonably make, how is alertness maintained, what are appropriate strategies to provide situational awareness, and distill data? What are strategies for addressing the change from normal operating conditions to emergency conditions in a control room?
- Determine the applications of virtual and augmented reality for training workers and testing autonomous systems.
- Identify and study the gaps in sensing and situational awareness, developing solutions that complement existing technology. This may include designs for providing situational awareness to operators, new sensing devices, such as wearable sensors for mine workers, continue to expand and build upon work in proximity detection, sensing of operator alertness and controls for maintaining alertness and engagement.
- Research the use of unmanned vehicles for collection of environmental data that could lead to improved health outcomes, collection of environmental data to provide improved safety (prevention of explosive or toxic atmospheres, inspection of hazardous areas), and collection of data during emergencies and catastrophic events.
- Identify measures of success for autonomous systems in terms of health and safety, and disseminate standards and tools for such measures. In other words, what is the equivalent to a lost time accident in an autonomous system? How is efficacy of such systems measured in terms of health and safety outcomes?
- Conduct a complete review of other industries undergoing similar transformative change with regard to autonomous systems, and identify partner offices in NIOSH, as well as partner agencies around the world for transfer of knowledge and best use of resources.
- Identify partner operations for holistic research that characterizes the best approach for mine site design or retrofit with regard to autonomy, and develop plans for long term projects.
- Design risk management approaches that are less linear than current approaches for use with complex autonomous systems.
- Study how the behavior of workers in mines changes as they interact with autonomous systems.

Introduction and Background

During the May 22nd, 2018 meeting of the Mine Safety and Health Advisory Committee to NIOSH-CDC a workgroup was formed and charged to investigate the following:

The Metal Mining Automation and Advanced Technologies (MMAAT) Workgroup reports to the Mine Safety and Health Research Advisory Committee (MSHRAC) regarding specific questions that impact potential health and safety issues related to the implementation of automation and other advanced technologies in U.S. metal mining. The workgroup is specifically tasked to draft a report for MSHRAC to review, deliberate and consider recommendations. Three questions have been developed to facilitate the workgroup's activities:

1. To what extent will automation and smart technologies be implemented in metal mining and in what timeframe?
2. What are the related emerging health & safety concerns?
3. What gaps exist in occupational health & safety research related to automation and smart technologies?

Research and data gathering included facilitating a mining stakeholder meeting, open to the public, to discuss potential health and safety issues related to the implementation of automation and other advanced technologies in U.S. metal mining.

The charge document may be found in Appendix A.

The workgroup held the first meeting on June 14, 2018. A public workshop was held on September 10-11, 2018 in Aurora, Colorado at the University of Colorado Anschutz Medical Campus. There were approximately 40 workshop attendees, and stakeholders from the metals mining community included operators, vendors and technical, consultants, and academics, as well as several representative from NIOSH. The workshop agenda is available in Appendix B. Additionally, public materials from the workshop, including working documents are available at: https://sites.google.com/vt.edu/mshrac-metals-tech/home.

The remaining sections of this report will address the workshop outcomes in terms of the questions posed in the charging document, and recommendations for strategic research areas for NIOSH based on stakeholder feedback.

Workshop Outcomes

The next three sections aim to collate the presentations and discussion from the workshop into guidance under the three charge questions referenced above.

Extent and timeframe for implementation of automation and smart technologies in metal mining

The consensus of workshop attendees was that automation and smart technologies will be implemented and integrated into existing operations cautiously. In particular, stakeholders cited the fairly low tolerance of the public and by extension, miners, for failure of automated systems. For example, three fatal accidents involving autonomous vehicles in the US (Stewart, 2018) since Tesla rolled out Autopilot on its vehicles in October 2015 (Ramsey, 2015) have received significant attention, although the average number of fatalities due to vehicle crashes in 2017 alone was 37,133 (National

Center for Statistics and Analysis, NHSTA, 2018). The industry is very clear that automated systems must be robust and that miners must trust the systems in order to achieve success.

Based on this feedback, it is difficult to establish a timeline, but it would be appropriate to assume that currents leading practice might be broadly implemented in large metals mines in the next 10-15 years. Leading practice includes:

- Fully automated haul truck fleets at surface operations
- Fully automated underground mining sections
- Remote control centers, and integrated automation of mining systems
- Implementation of ventilation-on-demand (VOD) in underground mines for efficient control of air quality (temperature, gases, particulate) and quantity.

Related Emerging Health and Safety Concerns

In particular, Robin Limerick-Burgess (2018) presented a suite of 18 questions that spurred discussion of emerging health and safety concerns, and nicely summarizes the discussion – they are:

1. How can we ensure decisions regarding automation implementation take human capabilities and limitations into account?
2. What lessons can be learned from the experiences in other industries of Human-Systems Integration during automation?
3. How can HSI methods be most effectively employed during the introduction of automation in the mining industry?
4. What design and evaluation strategies should be employed to ensure alarms and other interfaces are optimized?
5. How can isolation for maintenance be ensured and confirmed?
6. What strategies can be employed to introduce automated components into mining systems?
7. How can we create rewarding jobs for people to undertake within the increasingly automated system?
8. How do we select line managers and workforce for their roles within the more automated system?
9. How do we train (or retrain) line managers and workforce for their roles within the more automated system?
10. How can the competency of people working within the system be assessed and demonstrated?
11. What are the utility and limitations for virtual simulation in design processes and within training and competency assessment?
12. How can we unlock additional productivity gains through the optimal use of automation?
13. How do we ensure that unanticipated consequences of introducing automation and any consequential risks are identified and managed?
14. How can the wider societal impacts of increasing automation in the resources industry be managed most appropriately?
15. What verification processes can be developed to assure industry, regulators, unions, and the public, of the safety of systems including automated components?
16. What are the appropriate risk management frameworks and tools to guide the implementation of automation?

17. What is the role of standards and guidelines in facilitating the implementation of safe and effective automation?
18. What should the role of regulators be in facilitating the implementation of safe and effective automation?

Gaps in occupational health & safety research related to automation and smart technologies

1. Tracking the degree of automation in various sectors of the mining industry, along with best practices

Tracking trends and best practices related to safety and health in mining has long been a key strength and role of NIOSH in the national dialogue around mine safety and health, and detailing and communicating emerging automation in the various sectors, regions, and commodities of mining will provide a great service to the industry and allow for early identification of gains in health and safety as well as unintended consequences of automation and remediation of associated hazards.

Several researchers have examined the roles philosophical and ethical frameworks, as well as ethical design considerations that are necessary for widespread acceptance of self-driving cars (e.g., Charness et al., 2018; Karnouskos, 2018; Borenstein, et al., 2019). Similar investigation of acceptance in the domains of occupational safety and health, and specifically, mine workers, may prove important in successful and safe implementation of automation in the industry. The major issues around acceptance of the technology identified by workshop attendees were training, regulatory approval (US), interoperability, and reassignment of displaced workers.

2. Human-computer interface design to include leading practice, issues related cognitive overload, and feedback strategies

Sensors, boredom, reduction in actionable cues, loss of skill, loss of information, loss of situational awareness, new types of errors

There are many aspects that need to be studied about the increasing trend of expanded use of technology in mining and in any industry for that matter. To a large extent, the development of technology is being driven by the technology manufacturers. In many cases, technology is being designed and built without clear application, although the manufacturer will have a particular industry application in mind. This is a backwards design approach which can lead to a force-fit or a miss-fit. The mining industry must continually be in search of improvements in safety, efficiency, productivity, quality, and reliability. The answer often seems to be somewhere in the application of the next new technology; unfortunately, in some cases, the safety and health of the workers who will use this technology are not considered in the development or in the application. Or, if human use is considered, it is considered under the banner of "removing the operator from harm's way". This can result in the displacement of our human operators. Displacement does not necessarily mean they lose their jobs, but it can mean that they are assigned to another function for which they may not adequately trained or that may not have been fully developed. However, they are often still expected to remain engaged with the equipment and system that they once more actively operated. They are expected to apply their expertise to mitigate problems an automated system may encounter. At that point, it is often too late for a now, bored, distracted or dis-interested operator focused on other things, to respond; an operator who has experienced skill decay (loss of operator expertise), loss of situational awareness, lack of information, lack of practice, unfamiliarity with the feedback, or a loss of memory of what to do when called upon. This can and likely will lead to new types of errors, and in some cases, a loss of the system to damage, or even worse, injuries to employees. These safety and health impacts of the transition to more a technologically driven or more automatic world are not yet well enough understood and this is a significant general gap in industry safety and health research.

Changing system dynamics (physical, cyber, and human system design – mine system design)

Even as operators are kept engaged in the system, one of the fallouts from automated control systems is the abundance of information with which operators are bombarded every minute. Because of this new found ease with which information can be provided (sensors can be placed almost anywhere and computers are capable of processing and sending data wherever it is needed), there is a profusion of actionable information that is nearly impossible for a human operator to synthesize and make informed decisions with. In one hospital study, Haight, Wetz, Daves, and Olumese (2018) stated that cardiac unit monitoring technicians were expected to process twice the information that a human should be able to effectively process every minute with over 800,000 alarms in a month. Several phenomena are known to occur in this environment and one of the more dangerous is that operators become overwhelmed, under-rely on the system, and then respond errantly or not at all. Mine system design needs to incorporate a balanced function vs. human capability approach. This information overload and its impact on safety and health in the mining industry must be better understood through active research.

Communications and networking infrastructure

Engineers creating the technology focus on functionality; Engineers responsible for developing industrial, mining, defense, health care, and other systems and processes focus on design of the tasks and processes necessary to generate product output, and then the human factors engineers, psychologists and sociologists focus on the human operator, the community in which he or she lives, and society as a whole. They all have a job to do, but they all speak different languages.   They do not always speak with each other or, in some cases, do not even understand each other to the extent that will ensure optimum system integration or the best and safest performance of the overall system. If the technology developer does his or her job, the computer, robot, autonomous vehicle, or other component will function reliably and effectively. But if the human operator's behavior, motivation, interests, or capabilities are not considered, the operator could become overwhelmed, be less attentive, become bored or not know what to do if something goes wrong.   Unfortunately, systems are often built without consideration of the human's capabilities or limits and then, the now less-capable and less-attentive operator is left to save the system if an unanticipated scenario arises, and then it is often too late to save the system. The human operator cannot be an afterthought; he or she must be actively and meaningfully engaged through the entire operation to ensure proper operation of any system. This applies to the fully autonomous state as well. The engagement will be different, but no less important and critical to ensuring system performance. (Hancock, Billings, Oleson, Chen, de Visser and Parasuraman, 2011 and Miller and Parasuraman, 2007)

Research is needed to better understand what communication – content, media, and context - is necessary and how it needs to be delivered so all ***affected people*** have appropriate, adequate, accurate and thorough understanding and input to the functions, expectations, goals, and design of automated control systems and autonomous systems being developed in the mining world today. Multi-disciplinary teams must be assembled to engage in this critical communication research and it impact on safety and health.

The invention of new technology versus the automation of "old technology"

The question of developing new technology versus simply automating existing systems that were manually operated in the past presents some new and interesting problems. In actuality good design is less about implementing the use of new technology or redesigning old, it is most critical to understand an system and truly design the automation instead of just plugging in or force fitting a system without effective design in the automation domain or determination of the objective function or without considering human impact.

Critical controls, decision support, and decision making

There are many industries working to implement leading edge autonomous systems, as well as grappling with the questions posed here. Certainly, a thorough review of work in industries such as long-haul trucking, air traffic control, health care, and other process industries as if might apply to or transfer to mining is a critical first step. In addition, much of the focus on autonomous systems for mining emphasizes haulage, but all unit operations should be considered – rock fragmentation, for example.

In the process industries where explosions and fires are a real possibility with 24 hour/day operations and continuous processes that operate at high temperatures, high pressure and high flow rates the extensive use of automation is required. These control systems are fed data through hundreds and even thousands of sensors throughout plant operations. This information is processed and provided to the human operators in many forms. This feedback is provided, but when the system is in control, the operators does not necessarily have to synthesize the information as plant actions are effectively controlled by the automated system. However, when something goes wrong, for example, a temperature spikes, a leak occurs, or a reaction rate increases beyond control limits, the number of alarms can easily be overwhelming (as many as 300 alarms or more within 5 minutes). To help in the rapid decision-making and quick response actions needed, there are alarm prioritization systems that are used to only present the critical alarms that are necessary to bring a unit under control before containment of flammable or toxic material is lost. Operators are able to manage the 10 or 12 most critical alarms in 5-10 minutes; they are not able to handle 300. Industries utilizing such approaches include oil and gas, specialty chemicals, pharmaceutical, and paper manufacturing among others. The health care industry is also paying more attention to alarm overload in its telemetry covered units. They are evaluating patient conditions to determine when telemetry monitoring is necessary and they are evaluating rotation schedules to ensure no one monitoring technician stays at the monitoring screen for 12 hours. Air traffic controllers also use critical information prioritization systems and job rotation to address the potential information overload situations. There should be no reason why mining operations cannot take advantage of these systems and administrative controls such as creative job rotations.

Other research gap areas

Learning Curve Impact

A major area of concern for the mining industry is related to the learning curve impact that the industry will see as its employees and contractors are forced to take on new and different roles. As their traditional roles and functions are taken over by the autonomous systems, experienced people will quite suddenly become inexperienced as they take on new jobs and are expected to perform new tasks. Often, these tasks will require higher order thinking and will require new and more advanced training and education. These mid- and long-service employees will become inexperienced in a new role and in integrating with the autonomous systems. This will undoubtedly have health and safety impacts. These impacts will need to be identified, located, quantified and better understood in the mining industry. (Sauer, Hockey and Wastell, 2000; Sauer and Chavaillaz, 2017)

System Performance Effectiveness and Risk Reduction Research

A widespread assumption is being made that when we get the fallible, unreliable human out of the machine and out of harm's way, system performance and safety will improve. However, the intelligence and decision making capabilities and process speed of the human brain may be underestimated in the this assumption. As new technology is introduced and used, system performance effectiveness research will need to be conducted to quantify system performance improvements and actual risk reduction and to measure them against system performance during pre-technology use.

Human error research

The behavior of humans in partially- and fully autonomous environments has not been adequately explored. Will humans step in when they shouldn't? Will the human operator fail to step in when he or she should? The fully autonomous world is well into the future and it is not yet established whether the mining industry or any industry, for that matter, can actually be made fully autonomous. No matter what the next generation mining industry looks like, the transition will involve humans making errors and an understanding of the types, the numbers, occurrence rates, and the locations should be well understood and predicted if possible. Much research will need to be conducted in a virtual environment (equipment, mine, etc.) to explore this phenomenon to the level that it is currently studied in the aviation industry (Haight and Kecojevic, 2005).

Autonomous systems as a preventive intervention

Since autonomous systems are often presented as a means of removing people from harm's way, it makes sense to consider autonomous systems and their potential to be used as prevention interventions. When automated systems can be used to accomplish physically challenging work, work in adverse environments (close quarters or high traffic, wet, cold, slippery, etc.), work in dangerous environments (such as rescue in a flammable environment), risk of injury is reduced. This protective phenomenon is widely accepted anecdotally, but research is needed to quantify the risk reducing benefit such that these protective systems can actually be designed to achieve a specific risk reduction levels.

3. Unmanned vehicles for the improvement of health and safety

While unmanned vehicles play an extensive role in automated mining systems this primarily refers to the use of vehicles explicitly for improvement of health and safety. For examples vehicles that are used to inspect structures, enter hazardous areas for purposes of exploration and information gathering. Both ground vehicles and drones are included. Examples included drones that can be used to inspect large mills in mineral processing plants, so that personnel are not exposed to the risk of entrapment in enclosed spaces, hazardous atmospheres, potential failure of lock out/tag out systems. Another example was a small rubber-tired vehicle used to examine recently opened stopes, and abandoned areas about to undergo rehabilitation. Discussion during the workshop also included the notion that these vehicles may be unrecoverable and are actually designed to be sacrificed once information is gathered, either because recovery is too hazardous or too expensive.

4. Characterization of the efficacy of automated systems in terms of health and safety

Characterization of the efficacy of automated systems centered around some standard guidance for identifying, logging and characterizing near-miss accidents in automated systems, so that systems may be comparably and objectively evaluated. Attendees at the workshop specifically indicated that there were needs for measurable performance metrics that are consistent and standardization of these metrics across the industry (nationally and globally). Also, they indicated that there must be standard recognizable units for these metrics. For example, the question was raised, how do we describe vehicle interaction and incidents - is the measure something like, incidents/mile?

The role of adaptive automation

The adaptive automation concept, benefits and pitfalls have not been adequately explored. Adaptive automation is the descriptive name given to systems where the human operator shares functions with the automated system. Each maintains their own role as long as they are able to effectively manage. When either becomes overwhelmed or the system experiences an upset, the other takes over functions while the compromised component regains stability. It is an effective way that designers and users can be sure that the user is going to stay engaged with the autonomous operation of the system. This will become more and more important as the human function is transferred to the automated control system. Specific research into shared function, resource allocation is still needed, particularly in mining. (Endsley and Kaber, 1999)

Ventilation-on-demand systems may be one of the best current examples of adaptive automation in the mining industry. These systems control quantity and quality of air based on environmental changes (humidity, pressure, temperature, gas inflow), location of equipment (associated changes in temperature, fumes, and expectation of human operators), and mining operations (currently active levels, real-time location of personnel). The systems may operate in near-autonomous mode under normal conditions with full operator oversight, but shift to partial or full operator control as unusual conditions develop.

These systems may have measurable impacts on health and safety. They can allow for reduction of DPM and dust in locations where mine workers are active; they can also more closely monitor and control environments, particularly environments that are potentially explosive, and very high risk. Additionally, their ability to improve cost and efficiency by directing ventilation resources only where necessary make them attractive, easy to justify in terms of return on investment and are ripe for uptake in large underground mines.

5. Technology transfer and leading practice from automated transportation and mining systems especially for small operators

When the workgroup was charged there was some discussion as to why the metals mining industry was the focus, and the consensus was that: i) metals mining tends to move very large tonnages at a single operation and that, as a result, they would tend to be the first to approve capital resources toward large automation projects; ii) the metal/non-metal mining legislation in the US is less prescriptive, and in particular, does not have the permissibility requirements that can slow the introduction of new underground automation technologies, and; iii) leading practice in mining automation worldwide appears to be in the metals mining sector.

In particular, as many of the automation practices discussed here come to fruition, it is critical to record and publish best practices, and identify practices that are easily scalable and transferable, so that smaller operators and other sectors can realize the health and safety benefits of mining automation.

6. Mine design for safe automation (greenfield and brownfield)

Large metal mines tend to have long operating lives, and represent enormous investments. The opportunities to design a mine for automation in the next ten year are limited, but they do exist – one of the largest and most complex projects often cited during the workshop is the Resolution Copper Project near Superior, Arizona. This project represents an unparalleled case study in the design of a mine for automation, and, hopefully, NIOSH will be able to collect data and work closely with this operation.

More often, however, the US industry will be faced with retrofitting equipment and sites for automation. Disseminating the lessons learned at these sites will represent a substantial contribution to the health and safety of mine workers and has the potential to improve and speed the development of safe autonomous mining technology.

7. Risk Management

Risk management is the identification of hazards, the definition of potential consequences and the development and incorporation of controls to prevent or mitigate loss of control associated with a hazard. Much of the development of autonomous systems has been predicated on their use as preventative controls in the improvement of health and safety. However, these same controls may also introduce a new, and perhaps unpredicted hazard or even change the behavior of a worker.

Existing risk management and assessment tools tend to be fairly linear, relying on a single loss of control not applicable to more complex automated. A critical review of current systems for risk management, along with gaps associated with complex systems is needed. Their most comprehensive use is likely in Australian mining operations – several of which also have a high degree of automation.

8. Sensing and Situational Awareness

Sensing and situational awareness is one of the principle components of autonomous and semi-autonomous systems. In the autonomous sense, there must be inputs to the systems describing the environment, location, presence of obstacles (human or otherwise), status of the machine, status of the entire system, etc.

In the semi-autonomous system, where human interaction is a primary component of the system is to provide situational awareness operator, via multiple techniques, including visual, auditory, haptic, etc. IN addition to providing situational awareness, systems may also need to measure operator awareness or status.

In a sense, situational awareness presents a paradox in terms of automation. Automation actually increases the need to situational awareness. They system needs inputs and the operator must be aware of the environment, moving equipment, other people, but also the automation system itself – its operation and potential decisions.

Conclusions

Given the information presented above, and the particular strengths and position of the Office of Mine Safety and Health Research at NIOSH the work group suggests the following gaps may be priorities for NIOSH that could substantially impact the safety and health and U.S. mine workers. This list is not exhaustive and the work group intends that the information provided herein be used as a springboard toward advancing the broad aims of the organization in the area of automation.

- Track the degree of automation in various sectors of the industry, best practices, and determine measurable impacts on health and safety.
- Assess and define appropriate limits for human operators interfacing with machines, particularly in remote control – what are the maximum number of alarms/decisions the operator can reasonably make, how is alertness maintained, what are appropriate strategies to provide situational awareness, and distill data? What are strategies for addressing the change from normal operating conditions to emergency conditions in a control room?
- Identify and study the gaps in sensing and situational awareness, developing solutions that complement existing technology. This may include designs for providing situational awareness to operators, new sensing devices, such as wearable sensors for mine workers, continue to expand and build upon work in proximity detection, sensing of operator alertness and controls for maintaining alertness and engagement.
- Research the use of unmanned vehicles for collection of environmental data that could lead to improved health outcomes, collection of environmental data to provide improved safety (prevention of explosive or toxic atmospheres, inspection of hazardous areas), and collection of data during emergencies and catastrophic events.
- Identify measures of success for autonomous systems in terms of health and safety, and disseminate standards and tools for such measures. In other words, what is the equivalent to a lost time accident in an autonomous system? How is efficacy of such systems measured in terms of health and safety outcomes?
- Conduct a complete review of other industries undergoing similar transformative change with regard to autonomous systems, and identify partner offices in NIOSH, as well as partner agencies around the world for transfer of knowledge and best use of resources.
- Identify partner operations for holistic research that characterizes the best approach for mine site design or retrofit with regard to autonomy, and develop plans for long term projects.
- Design risk management approaches that are less linear than current approaches for use with complex autonomous systems.
- Study how the behavior of workers in mines changes as they interact with autonomous systems.

Finally, NIOSH OMSHR has a history and reputation for developing productive relationships in all sectors of the industry – it is critical that this continues. The Office should consider which equipment manufacturers, operators and researchers are key to providing sites for work, providing case studies, sharing facilities and data, and work to maintain these relationships. The importance of support for the NIOSH OMSHR research personnel to also stay abreast of the leading edge internationally should also not be underestimated.

References

Borenstein, J., Herkert, J.R. & Miller, K.W. (2019). Self-driving cars and engineering ethics: The need for a system level analysis. *Science and Engineering Ethics*, 25: 383. https://doi.org/10.1007/s11948-017-0006-0

Burgess-Limerick, Robin (2018.) 14 [sic] Mining Automation Research Questions in Managing Autonomy Risks. A presentation in the NIOSH-MSHRAC Emerging Technologies in Metals Mining Workshop. September 10-11, 2018, University of Colorado Anschutz Medical Campus, Aurora, CO.

Charness, N., Yoon, J. S., Souders, D., Stothart, C., & Yehnert, C. (2018). Predictors of Attitudes Toward Autonomous Vehicles: The Roles of Age, Gender, Prior Knowledge, and Personality. Frontiers in psychology, 9, 2589. doi:10.3389/fpsyg.2018.02589

Endsley, M.R., Kaber, D., 1999. Level of automation effects on performance, situation awareness and workload in a dynamic control task. Ergonomics 42, 462e492.

Endsley, M.R., Kiris, E.O., 1995. The out of the loop performance and level of control in automation. J. Hum. Factors Ergonomics Soc. 37, 381e394.

Haight, J. M. and Kecojevic, V. (2005), Automation vs. Human intervention: What is the best fit for the best performance?. Proc. Safety Prog., 24: 45–51. doi:10.1002/prs.10050

Haight, J.M., Do Automated Control Systems Reduce Human Error and Incidents? Professional Safety - The Journal of the American Society of Safety Engineers, Vol. 52, No. 5, May 2007, pp. 20 -27

Haight, J.M. and Caringi, R.G., Automation vs. Human Intervention What is the best mix for optimum system performance? A Case Study, International Journal of Risk Assessment and Management, Vol. 7, No. 5, May 2007, pp 708-721

Haight, J.M., Cole, D.G., Sejdic, E., The Optimized Design and Use of Automated Control Systems – State of the Literature and Proposed Research, Proceedings of the 9th International Topical Meeting on Nuclear Plant Instrumentation, Control, and Human Machine Interface Technologies, American Nuclear Society, 25 February, 2015

Hancock, P. A., Billings, D. R., Oleson, K. E., Chen, J. Y. C., de Visser, E., & Parasuraman, R. (2011). A meta-analysis of factors impacting trust in human-robot interaction. Human Factors, 53, 517–527.

Kaber, D.B., Wright, M.C. Prinzel, L.J. III, Clamann, M.P., Adaptive Automation of Human-Machine System Information-Processing Functions, International Journal of Cognitive Ergonomics, 2005, 5(1), 37-57

Karnouskos, S. (2018). Self-driving car acceptance and the role of ethics. IEEE Transactions on Engineering Management. 1-14. doi:10.1109/TEM.2018.2877307.

Miller C.A., and Parasuraman, R., Designing for Flexible Interactions Between Humans and Automation: Delegation Interfaces for Supervisory Control (2007) Human Factors, 49(1), 57-73.

Miller, C.A., and Parasuraman, R., Designing for Flexible Interaction Between Humans and Automation: Delegation Interfaces for Supervisory Control, Human Factors: The Journal of the Human Factors and Ergonomics Society, 2007, 49(1), 57-75

Miller, C.A., Funk, H., Wu, P., Goldman, R., Meisner, J., Chapman, M., The PlaybookTM Approach to Adaptive Automation, MFWGMC-HFES 2005

National Center for Statistics and Analysis. (2018, October). 2017 fatal motor vehicle crashes: Overview. (Traffic Safety Facts Research Note. Report No. DOT HS 812 603). Washington, DC: National Highway Traffic Safety Administration.

Ramsey, M. (2015, October 25) Driver videos push Tesla's 'Autopilot' to its limits. Wall Street Journal. https://www.wsj.com/articles/driver-videos-push-teslas-autopilot-to-its-limits-1445765404

Sauer, J., Chavaillaz, A., The use of adaptable automation: Effects of extended skill lay-off and changes in system reliability, In Applied Ergonomics, Volume 58, 2017, Pages 471-481, ISSN 0003-6870

Sauer, J., Hockey, G.R.J., Wastell, D., Effects of training on short- and long-term skill retention in a complex multiple-task environment Ergon., 43 (12) (2000), pp. 2043-2064, 10.1080/00140130010000893

Stewart, J. (2018, March 30) Tesla's autopilot was involved in another deadly car crash. Wired. https://www.wired.com/story/tesla-autopilot-self-driving-crash-california/

Appendix A

Charge Document

Metal Mining Automation and Advanced Technologies Workgroup of the Mine Safety and Health Research Advisory Committee

Metal Mining Automation and Advanced Technologies Workgroup of the Mine Safety and Health Research Advisory Committee

PURPOSE

This document defines the activities, membership, and administrative requirements associated with the establishment of the Metal Mining Automation and Advanced Technologies (MMAAT) Workgroup under the Mine Safety and Health Research Advisory Committee (MSHRAC), National Institute for Occupational Safety and Health (NIOSH), Centers for Disease Control and Prevention (CDC). The workgroup is being established to research and discuss potential health and safety issues related to the implementation of automation and other advanced technologies in the United States (U.S.) metal mining industry.

BACKGROUND

The mining industry is undergoing significant changes as mining companies are looking to gain a competitive advantage by adopting smart technologies to decrease costs, increase efficiency, and improve safety. Smart technologies include technologies associated with automation and robotics, wireless communications, smart sensors, wearable platforms, augmentation of reality, interconnectivity of devices, and data analytics. In the U.S., the adoption of smart technologies is now growing, particularly in metal mining. The introduction of these technologies into mining will potentially affect worker health & safety.

DESCRIPTION OF ACTIVITIES

The Metal Mining Automation and Advanced Technologies (MMAAT) Workgroup will report to the MSHRAC regarding specific questions that impact potential health and safety issues related to the implementation of automation and other advanced technologies in U.S. metal mining. The workgroup is specifically tasked to draft a report for MSHRAC to review, deliberate and consider recommendations. Three questions have been developed to facilitate the workgroup's activities:

1. To what extent will automation and smart technologies be implemented in metal mining and in what timeframe?
2. What are the related emerging health & safety concerns?
3. What gaps exist in occupational health & safety research related to automation and smart technologies?

Research and data gathering will include facilitating a mining stakeholder meeting, open to the public, to discuss potential health and safety issues related to the implementation of automation and other advanced technologies in U.S. metal mining.

WORKGROUP MEMBERSHIP

The Workgroup will consist of a Designated Federal Officer (DFO), either the MSHRAC DFO or another CDC employee, and at a minimum, two Special Government Employee (SGE) volunteers from the MSHRAC. One of the MSHRAC SGEs will serve as Workgroup Chair.

The workgroup may also consist of 1-2 ad hoc Consultants or other subject-matter experts with specific knowledge and experience related to automation and smart technologies. Ad hoc consultants only participate in the workgroup activities on an intermittent basis and are not permanent members. Candidates would most likely be from academia. In addition, Federal officials representing the Mine Safety and Health Administration; National Science Foundation; or National Institutes of Health as ex officio members of MSHRAC may also be members of the workgroup.

DELIVERABLE

The output of the Workgroup will be a summary report based on research activities and information gathered during the open stakeholder meeting. The report should specifically address the three questions above. The report will be presented at a future MSHRAC meeting for discussion and potential recommendations to NIOSH to proactively address worker health and safety issues related to the implementation of automation and smart technologies in metal mining. The draft report may include draft action steps/strategies for MSHRAC to consider.

MEETINGS, ADMINISTRATION, and TIMELINES

1. Administrative Oversight: The workgroup DFO will work with the workgroup chair, and the MSHRAC DFO to arrange meetings, document meeting proceedings, and report to the parent advisory committees on workgroup findings.
2. Meeting frequency: The workgroup will meet as often as needed to prepare for and organize the stakeholder meeting, and then after the stakeholder meeting as many times as necessary to address specified issues and to draft the summary report.
3. Meeting structure. Two MSHRAC SGEs and the workgroup DFO must be present at each workgroup meeting for a quorum. Meetings will occur in person or as teleconferences. An agenda and "read-ahead" material will be circulated 1-2 weeks prior to each meeting.
4. Conflicts of Interests: Non-SGE workgroup members will complete the form Conflict of Interest and Confidentiality Information for Workgroup Members (CDC Form 0.1473) to disclose interests (e.g., employment, special interests, grants, or contracts) that a reasonable person could view as conflicts or potential conflicts of interest with their committee workgroup participation. Members will also disclose any potential conflicts of interest before any meeting. If a workgroup member indicates a potential or actual conflict of interest, the DFO will advise the member to recuse from participating in workgroup discussions that implicate such a conflict of interest concern.
5. Timelines: The workgroup will be established at the May 22-23, 2018 MSHRAC meeting and should hold its first meeting within 30 days. The workgroup should plan to hold the

stakeholder meeting as soon as reasonable after its first meeting. The workgroup will provide its summary report to MSHRAC no later than December 28, 2018.

6. Subject content: Findings and opinions of the workgroup members will be discussed at workgroup meetings. A summary of the workgroup's findings will be presented to MSHRAC for consideration for action (discussion, deliberation and decision).
7. Workgroup Meeting Summaries: Summary documents will be created for all workgroup meetings. Workgroup documents provided to MSHRAC for consideration and deliberation in a public meeting will become part of MSHRAC's official record.
8. CDC Staff involvement: The workgroup may seek input from NIOSH subject-matter experts for consultation or informational presentations that contribute to the workgroup's tasks. Participation by and contributions of NIOSH staff must be transparent and evident, to avoid the risk of, or the appearance of, undue influence that would compromise independence. The parent committee and workgroup DFOs will ensure that the workgroup work products are appropriate and not influenced by NIOSH, CDC or by any special interest.

RECORDKEEPING and REPORTING

1. The workgroup chair will present meeting summaries to MSHRAC for consideration and for determining recommendations. Approved recommendations will be included in the MSHRAC annual report.

Appendix B

Workshop Agenda

Emerging Technologies in Metals Mining: Health and Safety Implications

Emerging Technologies in Metals Mining: Health and Safety Implications

Krugman Conference Space, University of Colorado Anschutz medical Campus
Aurora, Colorado
Workshop Agenda

Monday September 10, 2018

8:00 am – 8:15 am	**Welcome and Charge** Kray Luxbacher, Virginia Tech Josh Scott, Colorado School of Public Health
8:15 am – 9:00 am	**Case Study I – State of Art Autonomous Haulage in Australia** Robin Burgess-Limerick, University of Queensland
9:00 am – 9:45 am	**Case Study II – Autonomy and Sensing Underground** Jacob Rukavina and Mark Harris, Rio Tinto
9:45 am – 10:00 am	*BREAK*
10:00 am – 10:45 am	**Case Study III – Autonomous and Semi-Autonomous Systems for Surface Mining** Ron Crawford, Komatsu Bill Nassauer, Modular Mining Systems
10:45 am – 11:30 am	**Case Study Panel Discussion**
11:30 am – 12:30 pm	*LUNCH*
12:30 pm – 1:45 pm	**Human Factors Session** Joel Haight, University of Pittsburgh Discussion
1:45 pm – 2:45 pm	**Sensor Technology Session** Rob Bush, Howden Simsmart Moe Momayez, University of Arizona Discussion
2:45 pm – 3:00 pm	*BREAK*
4:00 pm – 5:00 pm	**Health and Safety Issues and Gaps Discussion** Moderated by Jeff Burgess, University of Arizona

Tuesday, September 11, 2018

8:00 am – 9:20 am	**Risk Management and Assessment** Rob McLain, Freeport McMoRan Robin Burgess-Limerick, University of Queensland Discussion
9:15 am to 10:15 am	**Data Analytics** Pratt Rogers, University of Utah Craig Ross, Hexagon Mining Discussion
10:15 am – 10:30 am	*BREAK*
10:30 am – 11:30 am	**Health and Safety Issues and Gaps Discussion** Moderated by Jeff Burgess, University of Arizona Kyle Zimmer, International Union of Operating Engineers
11:30 am – 11:45 am	**Closing Remarks and Adjourn** *Kray Luxbacher, Virginia Tech*