SME Annual Meeting
Feb. 19 - 22, 2017, Denver, CO

Preprint 17-001

A CASE STUDY EXPLORING FIELD LEVEL RISK ASSESSMENTS AS A LEADING SAFETY INDICATOR

E. J. Haas, Nat. Inst. for Occupational Safety and Health, Pittsburgh, PA
B. P. Connor, Nat. Inst. for Occupational Safety and Health, Pittsburgh, PA
J. Vendetti, Solvay, Green River, WY
R. Heiser, Solvay, Green River, WY

DISCLAIMER

The findings and conclusions in this paper are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health. Reference to specific brand names does not imply endorsement by the National Institute for Occupational Safety and Health.

ABSTRACT

Health and safety indicators help mine sites predict the likelihood of an event, advance initiatives to control risks, and track progress. Although useful to encourage organizations to work together, executing such risk assessments comes with challenges. This paper focuses on one trona mine's experience in the development and implementation of a field level risk assessment program to help its entire organization understand and manage risk to an acceptable level. Through a transformational process of ongoing support and communication, Solvay Green River fostered a culture of trust and safety grounded in risk assessment, safety interactions, and hazard correction. The application of consistent risk assessment (RA) tools was critical to create a participatory workforce that not only talks about safety, but actively identifies energies that contribute to hazards and potential incidents. In this paper, reflecting on the mine's process of RA implementation provides examples of likely barriers that sites may encounter when trying to document and manage risks. As discussed, consistent efforts to establish a participatory risk management program are worth the initial struggle to ultimately reduce incidents.

INTRODUCTION

Work-related health and safety (H&S) incidents often account for lost days on the job, contributing to organizational/financial and personal/social burdens [1-2]. Accompanying research demonstrates that risk and ambiguity around risk contribute to almost every decision that individuals make throughout the day [3-4]. In response, understanding individual attitudes toward risk has been unquestionably linked to predicting H&S behavior [5]. Although an obvious need exists to identify more comprehensive methods to assess and mitigate potential hazards, some argue that risk management is not given adequate attention in occupational H&S [6]. Additionally, research suggests that a current lack of knowledge, skills, and motivation are primary barriers to mitigating workplace risks [3-6]. Therefore, enhancing knowledge and awareness around risk-based decisions, including individuals' abilities to understand, measure, and assign levels of risk to determine an appropriate response, is increasingly important in hazardous environments to predict and prevent incidents.

This paper focuses on tailored approaches to field level risk assessment (FLRA), measurement, and common barriers to participating in such activities. The authors use a trona mine in Green River, Wyoming, as a case study to illustrate how the organization overcame widespread and site-specific challenges to implement a proactive risk management program. By discussing the mine's tailored FLRA program, this case study contributes to the literature by first, providing examples of critical components that need to be in place to ensure successful risk management and second, context for continuous quality improvement that can foster a higher level of trust and empowerment on site.

Risk Assessments as a Leading H&S Indicator

Risk assessment is a process used to gather knowledge and information around a specific health threat or safety hazard [7]. Based on the probability of a negative event occurring, RA also includes determining whether or not the level of risk is acceptable [2,8-9]. If initiated and completed consistently, such assessments allow root causes of accidents and even patterns [of risky behavior] to emerge [10]. These patterns function as proactive, or leading, indicators.

Leading indicators demonstrate pre-incident trends rather than direct measures of performance, such as lagging indicators do (e.g., incident rates). Generally, leading indicators are used to: (1) measure direct/indirect precursors to harm; (2) provide opportunities for preventative actions to be taken; (3) allow the discovery of proactive risk reduction strategies; (4) develop a database of such strategies; and (5) provide some type of warning before an undesired event occurs [1,11].

Some studies show that it can be more difficult to motivate or influence workers' safety measures through the use of lagging indicators, making the use of leading indicators appealing [12]. More recently, high-risk industries have allocated more resources toward preventative activities, not only to prevent injuries, but also to avoid the financial costs associated with incidents – which has produced encouraging results [13-15]. Therefore, establishing pragmatic RA methods, tools, and metrics that can be integrated into H&S management may assist the industry in including mineworkers in proactive identification and response to worksite risks.

Risk Assessment Methods, Metrics, and Matrices. Risk levels can be measured either quantitatively or qualitatively. Research values both types in high-risk occupations to ensure that all possible hazards and outcomes have been identified, considered, and reduced if needed [11,13,17-20]. Quantitative methods are commonly found where the site is trying to reduce a specific health or environmental exposure, such as respirable dust or another toxic substance [16]. These methods focus on a specific part of an operation or task within a system, rather than the system as a whole [8]. Conversely, a qualitative approach is useful for potential or recently identified risks to decide where more detailed assessments may be needed and prioritize actions [8,11, 17-18].

Regardless of the type of metric used, all RAs include systematic steps to identify hazards and estimate workers' risk levels [2]. A common practice is to formulate a matrix that prompts workers to consider the likelihood of a hazardous event and the severities of the outcome to yield a risk ranking [18]. When ranking risks, the probability and consequence of each identified hazard involved in an activity is assessed using discretized scales [e.g., 21-23]. The combination of these two 'scores' is used to determine whether the risk is acceptable, and subsequently, to identify an appropriate response. An example using qualitative measures is provided below, taken from Boyle [18, p. 46].

A viable metric for RA, completing this matrix would allow any organizational member to determine and anticipate the risk of a hazard, action, or situation from very low to very high. Upon completion of an RA associated with a proposed activity, a list of hazards may be identified and evaluated for future interventions. Additionally, RAs often

reveal a prioritization of identified risks that inform where risk-reduction actions are more critical [8], which may result in changes to a policy or protocol [18].

Table 1. Example Qualitative Risk Rating Matrix (see Boyle, 2012, page 46)

	Likelihood/Probability				
Severity/ Consequences	***Very Unlikely***	***Unlikely***	***Likely***	***Very Likely***	***Almost Certain***
No injury	Very Low	Low	Low	Medium	Medium
Minor injury	Low	Low	Medium	Medium	Medium
Serious injury	Low	Medium	Medium	Medium	High
Major injury	Medium	Medium	Medium	High	High
Disabling injury/ fatality	Medium	Medium	High	High	Very High

Barriers to Risk Assessment. Despite its advantages, industry faces several challenges in implementing effective RA programs. Although RA methods can be used as a management tool to inform procedural decisions and policy changes, they are more often used by workers to identify and assess worksite risks and motivate them to take action. Therefore, the skill with which the everyday workforce can perform RAs is of key importance. Yet research has pointed to workers' general confusion about the interpretation of hazards and assignment of probabilities as a hindrance to appropriate risk identification and response [24-25].

Generally, individuals have varying levels of knowledge, awareness, and tolerance in their abilities to recognize and perceive risks as unacceptable [25-27]. Individuals tend to become complacent with occupational H&S risks and, eventually, have a lower sense of perceived susceptibility and severity of a negative outcome [28]. As perceived susceptibility and severity decrease, so do individuals' abilities to consistently notice and believe that a hazard poses some level of risk to their personal H&S.

In addition, worksites face challenges of determining the best ways to measure and develop suitable tools to facilitate consistent risk measurement [13,18,29]. Although general risk management strategies are deemed an important element of overarching mine H&S management [30], previous research has found that many managers assess site risks using a series of checklists or general observations during site walkthroughs [12,31]. Checklists and observations are practical and can be useful; however, they have more often been insufficient in revealing potential safety problems and as a result, not a useful leading indicator [32].

In summary, the vagueness of data on H&S risks can prevent hazard recognition, impair decision-making, and disrupt risk-based decisions among workers [26]. As a result, more information about real-time RA in mining may support risk reduction practices. Specifically, better understanding and predicting of potential barriers is needed to engage workers in risk monitoring, in addition to determining pragmatic solutions. This case study begins to fill this gap in knowledge and implementation.

METHODS

In December, 2015, two National Institute for Occupational Safety and Health (NIOSH) researchers traveled to visit Solvay Green River's mine. Located in southwest Wyoming, this trona mine produces soda ash – close to 3 million tons per year [33]. Mine management explained that they use three methods to mine trona – longwall and solution mining and borer miners. This multifaceted approach could bring more uncertainty to the mining processes for the 450+ employees at the Green River operation, including disparate perceptions of risk.

Inconsistent RA may have been a contributing factor to the sharp increase in incidents – some resulting in amputations – which the site experienced around 2009. These incidents caused frustration and disappointment among management and workers. Although management could have taken a punitive, "set an example" response (based on an accountability framework), the management team instead began a process to bring new tools, methods, and mindset to safety performance at the site.

The main purpose of NIOSH's visit was to discuss and understand the health, safety, and risk management frameworks that these leaders brought into everyday work processes, and specifically the field level risk assessment (FLRA) program they adapted and successfully implemented at Green River (see [35] for an additional discussion of an FLRA process). NIOSH researchers wanted to gain insight into how everyone at Solvay eventually started to work together to manage and mitigate risks to an acceptable level. Because researchers collected an extensive amount of data during the field visit, they were able to analyze the material as a "case study" [36-38] in H&S system implementation. The combination of expert interviews, existing documentary materials, and observation of onsite activities provided a holistic view of both post-hoc and current data points, allowing for various contexts to be compared and contrasted to determine consistency and saturation of the data [39].

Participants

The management team initially engaged organizational leaders and this involvement eventually trickled down to workers. These discussions resulted in a reenergized focus on three main areas: risk assessment, safety interactions, and hazard identification and correction [34]. These were the main areas explored during NIOSH's visit. Researchers collected several data points including all-day expert interviews and discussions [40] with mine site senior-level management including the mine manager, H&S manager, and mine foremen/supervisors. Additionally, researchers heard presentations from the mine managers and site supervisors, received example RA documents, and were able to engage in observations on the surface and in the underground mine operation during the visit, where several mineworkers engaged the researchers in conversations about the FLRAs, hazard interactions, and general safety culture on-site.

Data Analysis of Risk Assessment in Action

Typically, analysis of case study data uses constant comparison techniques, sometimes within a grounded theory framework [41-42]. NIOSH researchers employed the constant comparison method within a series of iterative coding steps. First, researchers typed the field notes, interview notes, and scanned the various RA example documents received during the visit. Each piece of data was coded for keywords and themes through an initial, focused, and then constant comparison approach [43-44].

Throughout the paper, quotes and examples from members of mine management who participated in the visit are shared to better demonstrate their process to establish the FLRA program. To address reliability and validity of the researchers' interpretation of the data, the two primary, expert information providers during the field visit, Joe Vendetti and Rowdy Heiser, served as coauthors and member checkers of the data to ensure all information was described in a way that is accurate and appropriate for research translation to other mine sites [45].

RESULTS

During the iterative analysis of the data, researchers sorted the initial and ongoing barriers to continuous RA to provide insight into promising ways to measure, document, and manage a risk-based program. Researchers noticed several broad themes that were critical to establishing a risk program that could help proactively measure and manage individual and organizational H&S practices. The clarity and detail discussed around the social, cultural, and cognitive barriers involved in successful implementation prompted the reporting of this information. The primary barriers identified during the visit revolved around getting everyone to a similar level of knowledge and motivation to establish reliability in risk identification, assessment, and response.

Defining Barriers and Solutions to Increase Worker H&S Knowledge and Proactivity

A common theme discussed was the varying levels of risk tolerance possessed by the workforce. Each individual's initial perception and then assessment of a risk was quite broad, impacting their abilities to identify a hazard and respond consistently to minimize a risk. Throughout the visit, everyone communicated the time it took to establish a sensitivity to potential hazards. As expressed by management:

> "It took a long time to get through to people that this isn't the same as what they do every day. To really assess a risk you have to mentally stop what you're doing and consider something."

Eventually, management developed an understanding that risk tolerance differed individually and generationally on-site, acknowledging that sources of risk are always changing in some regard and tend to be more complicated for some employees to see than others. Discussions about the importance of encouraging conscious efforts of risk management became ongoing to support a new level of awareness on-site. As a result, the value of documenting RA efforts became even more apparent.

Lack of Consistency in RA Documentation Faced with inconsistencies in worker knowledge of risks and varying levels of risk tolerance, management saw the advantages of creating a common, site-wide set of RA tools and metrics to guide workers in a consistent approach to RA in the field. Management indicated, if they had tools then, *"It didn't matter what you knew [or what] you didn't, you had tools to assess and manage a situation."* They determined that such tools populated by workers would provide management leading indicators to proactively identify and prevent incidents.

Solvay management chose to employ a matrix to identify, assess, and evaluate risks on-site similar to what was described earlier (Table 2). Solvay mineworkers were expected to utilize this matrix daily to help identify and evaluate risks needing immediate attention.

Table 2. Risk assessment matrix used by Solvay (Heiser and Vendetti, 2015).

	Consequence				
Probability	**1**	**2**	**3**	**4**	**5**
1	1	2	3	4	5
2	2	4	6	8	10
3	3	6	9	12	15
4	4	8	12	16	20
5	5	10	15	20	25

When completing the above matrix, workers rate consequences of a risk using the scales/key depicted below.

Table 3. Evaluation Matrix Key (Heiser and Vendetti, 2015).

Probability	Consequence
1. RARE, practically impossible	1. Could cause 1st aid injury/minor damage
2. UNLIKELY, not likely to occur	2. Could cause minor injuries (recordable)
3. MODERATE, possibility to occur	3. Could cause moderate damage (LTA)
4. LIKELY, to happen at some point	4. Could cause permanent disability or fatality
5. ALMOST CERTAIN, to happen	5. Could cause multiple fatalities

Assessment

15 – 25: CRITICAL
9 – 12: HIGH
5 – 8: MODERATE
1 – 4: LOW

As shown in the color-coded matrix, multiplying the scores for these two areas yields a risk ranking of low, moderate, high, or critical – providing guidance on what energies or hazards to mitigate immediately. These leading efforts helped prioritize responses to site-wide risks such as triggering a near-miss report or changing a protocol.

The obvious parallels between Solvay's matrix and the earlier example from Boyle testify to how tools can be adapted for specific probability and consequence ratings – whether a more numeric or word-based system for risk categorization is chosen.

INITIAL RESISTANCE TO A FORMAL RISK METRIC

Implementing the system of RAs at Solvay did not come without challenges. Although workers began using these tools, gaps in their understanding remained. For example, at the outset, hourly workers often said, *"I do this in my head all the time. I just don't write it down."* Just as some workers did not see a difference with what they did implicitly, and so discounted the value of conducting an FLRA, others did not think they needed to take action based on their matrix risk ranking. As one manager reported, he encountered the idea that, *"It's okay to be in the red, so long as you know you're in the red."*

Reflecting on the inconsistent implementation management noted, *"Back then, initially, people were doing them, but not to the quality they could have been."* However, progressing through a continual change process to improve organizational motivation, culture, and trust, management eventually convinced workers that documenting and recording risk with this tool would be valuable both to keep them safe and to share with less experienced miners as a training tool. As one supervisor described the progression from initial resistance and misunderstanding to understanding and fluent use of the tool,

> "It's like peeling an onion – another layer and another layer. At the start, they have to understand the matrix, how it applies to what they are doing. Then, the energies – people don't even see the energies. Then, the barriers – some didn't see distance as a barrier, for example."

By spending time building workers' understanding of the relationship between their work tasks and the tool and its metrics, management increased workers' knowledge about how to assess and respond to site-wide risks. They reflected that these communication efforts started to change awareness and attitude, increasing knowledge and proactive behavior:

> "We talked a lot about energies – we found that we can talk about things that make sense to the guys – the energies and identifying barriers and controls in place whether they are engineering controls or the actions of people to reduce energies. It started to make sense."

The continued support for and communication about this approach ultimately created a sense of ownership over the process among workers, which led them to recognize the need for a minute-to-minute thought process that helped them foresee consequences, probabilities, and deliberate different response options. As one manager said, *"You can have a defined plan but an actual risk assessment shows the dynamics of a situation and allows different plans to emerge."* Management indicated to NIOSH that workers now have an increased sense of knowledge, motivation, and empowerment to identify and mitigate risks. Contrary to how workers used to document their RAs, management said:

> "You pull one out today, and even if it isn't perfect, the fundamentals are all there, even if it isn't exactly how we would do it. And more likely than not, you'd pull out one and find it to be terrific."

Importantly, this documentation also allows insight into how employees think, serving as a leading indicator for H&S management on-site, as illustrated in the example below.

FLRA Example in Action. One example of FLRA in action was provided by the maintenance supervisor during an installation of a horizontal support beam. Workers completed an FLRA to determine if they could simply remove the gantry system without compromising the integrity of the headframe. As part of their FLRA process, workers were expected to identify energies/hazards that could exist during this job task. Hazards that they recorded for this process included:

- Working from heights/falling
- Striking against/Being struck by objects
- Pinch points

- Traction and balance
- Hand placement
- Caught in/on/between objects

An initial risk rank was provided for each of the identified hazards, based on the matrix presented in Table 2. Based on the initial risk rank, workers decided which controls to implement to minimize the risk to an acceptable level. Examples of controls implemented included:

- Review the critical lift plan
- Conduct a pre-job safety and RA meeting
- Inspect all PPE fitting and harnesses
- Understand structural removal sequence
- Communication between crane operator and riggers
- Assure 100% of tie-off protocol is followed
- Watch out for coworkers
- Participate in housekeeping activities

Upon determining and implementing controls, a final risk rank was assessed and provided to come up with a decision for the job task – whether or not the headframe could be removed in one section. Ultimately, workers decided it could safely be removed in one section. However, management emphasized the importance of staying true to their FLRA. They said that 50 percent of their hoisting capabilities are based on wind and that if the wind is too high, they shut down the task – which happened one day during this process. So, although an FLRA was completed and provided a documented measurement and direction about what decisions to carry out, the idea of staying true to a minute-by-minute RA was important and adhered to for this task.

In this sense, the FLRAs serve as a communication platform to share a common language and ultimately, common proactive behavior. This example shows that the more workers understand what constitutes an acceptable level of risk, the greater sense of shared responsibility they have to prevent hazards and make protective decisions on the job [46]. In theory, as FLRAs are increasingly used to pre-determine possible incidents, the occurrence of lagging indicators should decrease, which has been the case at Solvay in recent years.

Having shown the case for using FLRAs as a metric, or leading indicator of H&S, we turn now to a discussion of what organizational components need attention and support to encourage successful implementation of such a system. As demonstrated, Solvay management pointed to the importance of trust and leadership within the organization's safety culture in enabling workers to feel comfortable not only participating in RA activities, but in making last-minute change to procedures when RAs warranted them.

DISCUSSION

Establishing an Organizational Culture of Safety to Instill Trust in the Risk Assessment Process

Although it is readily visible that Solvay established a well-functioning system of documenting FLRAs and using them to inform decision-making, it is important to stress the less visible, but equally important leadership efforts of Solvay during this process. As the study shows, designing a coherent system of RA tools and metrics and educating workers on how to use them does not, by itself, result in a successful RA process. Rather, for an RA system to function successfully, the safety culture in place must support workers' decision-making and behavior.

A lack of management commitment, poor communication, and poor worker involvement have all been identified as features of a safety climate that inhibit workers' willingness to proactively identify risks [47-48]. Therefore, promoting these organizational factors is needed to encourage workers to identify hazards and prevent incidents [2]. Solvay management was aware that their success depended on winning across-the-board buy-in by nurturing a culture of trust and support, and took various actions to help facilitate its creation. In their discussion of those actions and lessons learned, two themes emerged that would be particularly valuable for those attempting to implement an RA system.

Gaining Trust by Consistent Focus on 'Why', not 'Who'. When first rolling out their FLRA process, Solvay management knew that if they were going to transform safety practices at the mine, there had to be open communication between workers and management about worksite conditions and practices [33-34,46-50]. But, creating a process of open sharing meant that, especially at the outset, management was likely to hear things that they didn't necessarily want to hear. They discussed preparing themselves to be "exposed" to such information and commit as a group to react in a way that would maintain buy-in, use, and behavior. Winning buy-in for this approach took time; however, Solvay discussed the importance of focusing on the 'why' and not 'who' to improve their organizational leadership and communication:

> "Accountability vs. punitive punishment was a difficult barrier to overcome. As a management team we had to collectively commit to understanding the facts of why an event occurred and not focus on who was at fault. In addition, we needed to continually stress the importance of utilizing the risk assessment tool and if something were to occur to evaluate the level of controls implemented during a reassessment of the task."

To gain not only a wider commitment to consistently apply the RA tools and methods, but also to establish the mindset that looked to understand rather than punish, Solvay management started a working group called "The Club" in 2010 that consisted of supervisory personnel within various levels of the organization. The purpose of The Club was to develop leaders and a different sort of accountability with respect to safety. One of its first actions was to, as a group, agree on qualities of a safety leader. From there, they eventually executed a quality leadership program that embraced the use of the tools and their outcomes [33-34].

Early adopters of RA had become accustomed to filling out and reporting risks, but there were still people who had reservations. When The Club started, the front-line foremen were better able to communicate about and manage safety across the site. Prior to The Club and adapting to the FLRA, management reflected, *"People would just stop. No one wanted to make a safety decision. Now, workers have the ability to implement their own check and balance system to determine if a response is needed."* The check and balance system allowed workers to improve their own RA knowledge, skills, and motivation – a common barrier to risk identification [6].

To further illustrate this leadership style and communicative focus, management shared a conversation they had with a worker after he had an incident. Rather than reprimanding his error in judgement, they asked:

> "What was going through your mind before, during this task? I just want to understand you, your choices, your thought process, so we can prevent someone else from doing the same thing, making those same choices."

After saying he knew he did not have the right tools but tried to improvise, they asked him what other risky choices he had made that turned out okay. This process engaged the employee and he "really opened up" about his perceptions and behaviors on-site. This incident is an example of site leaders establishing accountability for action but ensuring that adequate resources and site support were available to facilitate a safer practice in the future [30,47].

Eventually there was buy-in and trust from each manager and front-line supervisor. The lessons they learned from each other were ultimately helpful when rolling out the RA system to the whole site noting, "If we could demonstrate trust and collaboration as a site management team then we knew we could gain trust and support from our workforce."

Buy-in Takes a Long Time and Requires Sustained Efforts. In discussions with NIOSH, management frequently emphasized the time and effort it took to establish a sense of site-wide trust. In their judgment, it took about 4-5 years until they actually saw the change in action – meaning that the process was sustained by everyone (i.e. employees were not only doing RAs but using the terminology in their discussions). Management noted, it was important to not just train to procedure, but get into the hearts and minds of each worker in their emphasis of, "*High-level policies complement but don't drive safety."*

For the RA tools to drive safety, workers had to understand how they were relevant to their job tasks, but then use them to support safe behavior. Management acknowledged that the FLRA identifies steps which anyone might miss because they are interlocked components of a system. Because of the complex risks present on-site, they discussed the importance of sitting down and reviewing if something happened or went wrong. They shared, *"We say 'let's not do this again,' but they don't get in trouble. Really, reviewing the FLRAs has big impact on trust and use of the process."* In other words, management used these conversations not only to educate the workers about hazards involved in complex systems, but also to enact their positive safety culture.

Solvay management emphasized *"Even today, we try to not miss an opportunity to do an RA. Then a lot of our safety shares can tie in what we're doing right."* Likewise, the site has been placing more emphasis on the "safety shares" at the start of their pre-shift meetings. They indicated that these shares *"might be no more than 5 minutes, they might go a half-hour, but they're allowed to take as long as they need."* This continued commitment to foster the use of leading indicators to support a H&S management program has shown that the metrics used to assess risks are only as good as the response to those metrics to support and encourage H&S.

Limitations and Conclusions

To date, incidents are down at Solvay, showing the impact of the FLRAs as a strong leading indicator. Management commented anecdotally that more of the workforce is taking RA, as a framework, into their personal lives and applying it to their home context, demonstrating the usefulness of leading indicators as a successful measure for health and safety.

The purpose of this case study with Solvay was to illustrate an example and use of a leading safety indicator in which everyone can participate. In addition to providing how leading indicators look "in action," this paper advanced the discussion to provide insight into common barriers to RA, and potential responses to these barriers. Some of this information may already be known and utilized by mine site leadership. However, because the focus of the study was not only on the development and use of specific risk measurement tools, but the organizational culture that is needed to foster such proactive behavior, the results provide several potential areas of improvement for the industry in terms of formal RA over a period of time. Mine operators should consider this information when interpreting the results in terms of (1) where to initially focus to establish formal RA on site, especially when developing and implementing leading indicators; (2) what the current safety culture may be at the site which could support such an RA system; and (3) the time it may take to establish a participatory RA program.

Although the results of this study are only part of a small case study and cannot be generalized across the industry, data supports the argument that poor leadership, poor safety culture, and an overall lack of trust on-site can inhibit workers' willingness to participate in risk measurement, documentation, and decision-making. Specifically, gaining an in-depth view of Solvay's own H&S journey provides expectations and a possible roadmap for encouraging worker participation in risk management at other mine sites to proactively prevent H&S incidents.

ACKNOWLEDGMENTS

The authors wish to thank the Solvay Green River operation for its participation and cooperation in this case study and for openly sharing their experiences.

REFERENCES

1. Blumenstein, D., Ferriter, R., Powers, J., and Reiher, M. (2011). *Accidents – the total cost: A guide for estimating the total cost of accidents.* By Mine Safety and Health Program Technical Staff, Western Mining Safety and Health Training and Translation Center, Colorado School of Mines. Available at: http://inside.mines.edu/UserFiles/File/MSHP/GuideforEstimatingtheTotalCostofAccidents%20FINAL(8-10-11).pdf.
2. Pinto, A., Nunes, I.L., and Ribeiro, R.A. (2011). Occupational risk assessment in construction industry – Overview and reflection. *Safety Science,* 49, pp. 616-624.
3. Golub, A. (1997). *Decision analysis: An integrated approach.* New York, NY: Wiley.
4. Suijs, J. (1999). *Cooperative decision-making under risk.* Springer Science+Business Media New York, NY: Kluwer Academic Publishers.
5. Dohmen, T., Falk, A., Huffman, D., Sunde, U., Schupp, J., and Wagner, G.G. (2011). Individual risk attitudes: measurement, determinants, and behavioral consequences. *Journal of the European Economic Association*, 9(3), pp. 522-550.
6. Haslam, C., O'Hara, J., Kazi, A., Twumasi, R., and Haslam, R. (2016). Proactive occupational safety and health management: Promoting good health and good business. *Safety Science*, 81, pp. 99-108.
7. Smith, S.P. and Harrison, M.D. (2005) Measuring reuse in hazard analysis. *Reliability Engineering & System Safety*, 89(1), p. 93-104.
8. Lindhe, A., Sturm, S., Røstum, J., Kožíšek, F., Gari, D.W., Beuken, R. and Swartz, C. (2010). *Risk assessment case studies: Summary report*. Deliverable no. D4.1.5g, TECHNEAU. Retrieved from https://www.techneau.org/fileadmin/files/Publications/Publications/Deliverables/D4.1.5g.pdf.
9. International Electrotechnical Commission [IEC]. (1995). *Dependability management – Risk analysis of technological systems* (IEC 300-3-9). IEC, Geneva.
10. Markowski, A., Mannan, S., and Bigoszewska, A. (2009). Fuzzy logic for process safety analysis. *Journal of Loss Prevention in the Process Industries,* 22, pp. 695-702.
11. International Council on Mining & Metals [ICMM] (2012). *Overview of leading indicators for occupational health and safety in mining.* November, 2012. Retrieved from: http://www.icmm.com/leading-indicators.
12. Juglaret, F., Rallo, J.M., Textoris, R., Guarnieri, F., and Garbolino, E. (2011). New balanced scorecard leading indicators to monitor performance variability in OHS management systems. In: Hollnagel, E., Rigaud, E., Besnard, D. (Eds.), Proceedings of the fourth Resilience Engineering Symposium, 8–10 June, Sophia-Antipolis, France, Presses des Mines, Paris, pp. 121-127.
13. Haas, E.J. and Yorio, P. (2016) Exploring the state of health and safety management system performance measurement in mining organizations. *Safety Science,* 83, pp. 48-58.
14. Maniati, M. (2014). *The business benefits of health and safety: A literature review.* Prepared on behalf of the British Safety Council. Retrieved at https://www.britsafe.org/sites/default/files/editor/C058_The_business_benefits_of_occupational_H%26S_update_v12.pdf.
15. Robson, L.S., Clarke, J.A., Cullen, K., Bielecky, A., Severin, C., Bigelow, P.L., and Mahood, Q. (2007). The effectiveness of occupational health and safety management system interventions: a systematic review. *Safety Science,* 45(3), 329-353.
16. Van Ryzin, J. (1980). Quantitative risk assessment. *Journal of Occupational and Environmental Medicine*, 22(5), 321-326.
17. World Health Organization [WHO] (2008). Guidelines for drinking-water quality [electronic resource]: Incorporating first and second addenda, Vol. 1, Recommendations, 3rd ed., World Health Organization, Geneva.
18. Boyle, T. (2012). *Health and safety: Risk management*. New York, NY: Routledge.

19. Hallenbeck, W.H. (1993). Quantitative risk assessment for environmental and occupational health, 2nd ed., Boca Raton, NY: Lewis Publishers.

20. CORESafety, nd. CORESafety framework. Handbook retrieved from http://www.coresafety.org/coresafety-framework/handbook/.

21. Rosén, L., Hokstad, P., Lindhe, A., Sklet, S., and Røstum, J. (2006). Generic Framework and Methods for Integrated. *Water Science and Technology*, 43, 31-38.

22. Hokstad, P., Røstum, J., Sklet, S., Rosén, L., Lindhe, A., Pettersson, T., Sturm, S., Beuken, R., Kirchner, D. and Niewersch C. (2010). Methods for analysing risks of drinking water systems from source to tap, Deliverable no. D 4.2.4, TECHNEAU.

23. Bartram, J. (2009). Water safety plan manual: step-by-step risk management for drinking-water suppliers. World Health Organization, Geneva.

24. Apeland, S., Aven, T., and Nilsen, T. (2002). Quantifying uncertainty under a predictive epistemic approach to risk analysis. *Reliability Engineering and System Safety*, 75, pp. 93-102.

25. Reason, J. (2013). *A life in error: From little slips to big disasters*. Burlington, VT: Ashgate Publishing.

26. Ruan, D., Liu, J., and Carchon, R. (2003). Linguistic assessment approach for managing nuclear safeguards indicators information. *Logistics Information Management*, 16(6), 401-419.

27. Brun, W. (1992) Cognitive components in risk perception: Natural versus manmade risks. *Journal of Behavioral Decision Making*, 5, pp. 117-132.

28. Zohar, D., and Erev, I. (2006). On the difficulty of promoting workers' safety behaviour: overcoming the underweighting of routine risks. International *Journal of Risk Assessment and Management,* 7(2), pp. 122-136.

29. Haas, E.J., Willmer, D.R., and Cecala, A.B. (2016). Formative research to reduce mine worker respirable silica dust exposure: a feasibility study to integrate technology into behavioral interventions. *Pilot and Feasibility Studies,* 2(6), 11 p. DOI 10.1186/s40814-016-0047-1.

30. Yorio, P.L. and Willmer, D.R. (2015). Explorations in pursuit of a risk-based health and safety management systems. In: Society for Mining, Metallurgy, and Exploration Annual Meeting, Feb. 15–18, 2015, Denver, CO.

31. Navon, R. and Kolton, O. (2006). Model for automated monitoring of fall hazards in building construction. *Journal of Construction Engineering and Management,* 132(7), pp. 733-740.

32. Jou, Y., Lin, C., Yenn, T., Yang, C., Yang, L., and Tsai, R. (2009). The implementation of a human factors engineering checklist for human–system interfaces upgrade in nuclear power plants. *Safety Science*, 47, 1016-1025.

33. Fiscor, S. (2015). Solvay implements field level risk assessment program. *Engineering and Mining Journal*, 216(9), 38-42.

34. Heiser, R. and Vendetti, J.A (2015). *Field level risk assessment - A safety culture*. Presented at Longwall USA Exhibition and Convention, June 16, 2016. Pittsburgh, PA.

35. Hudson, E. and Smith, D. (1998). *Worker's guide to field level risk assessment.* Free use document for the Construction Owners Association of Alberta. Retrieved at http://www.coaa.ab.ca/Portals/10/documents/WorkersModule.pdf.

36. Yin, R.K. (2014). Case study research: Design and methods, 5th ed. In United States: Library of Congress Cataloguing-in-Publication Data.

37. Denzin, N.K., and Lincoln, Y.S. (2000). The discipline and practice of qualitative research. In NK Denzin and YS Lincoln, Handbook of qualitative research, 2nd ed (pp. 1-28). Thousand Oaks, CA: Sage.

38. Pattson, M.Q. (2002). *Qualitative research and evaluation methods,* 3rd. ed. Thousand Oaks, CA: Sage.

39. Wrede, S. (2013). How country matters: Studying health policy in a comparative perspective. In I Bourgeault, R Dingwall, and R de Vries, *The SAGE handbook of qualitative methods in health research*. Thousand Oaks, CA: Sage.

40. Flick, U. (2009). *An introduction to qualitative research.* Thousand Oaks, CA: Sage.

41. Glaser, B., and Strauss, A. (1967). *The discovery of grounded theory.* Chicago, IL: Adeline.

42. Corbin, J., and Strauss, A. (2008). Basics of qualitative research, 3rd ed. Thousand Oaks, CA: Sage.

43. Boyatzis, R.E. (1998). *Transforming qualitative information: Thematic analysis and code development*. Thousand Oaks, CA: Sage.

44. Fram, S.M. (2013). The constant comparative method outside of grounded theory. *The Qualitative Report,* 18(1), pp. 1-25.

45. Kitchener, M. (2002). Mobilizing the logic of managerialism in professional fields: The case of academic health centre mergers. *Organization Studies*, 23(3), pp. 391-420.

46. Reason, J. (1998) Achieving a safe culture: Theory and practice. *Work & Stress,* 12(3), pp. 293-306.

47. Zohar, D., and Luria, G. (2005). A multilevel model of safety climate: cross-level relationships between organization and group-level climates. *Journal of Applied Psychology,* 90(4), pp. 616-628.

48. Rundmo, T. (2000). Safety climate, attitudes and risk perception in Norsk Hydro. *Safety Science,* 34(1), pp. 47-59.

49. Wold, T., and Laumann, K. (2015). Safety management systems as communication in an oil and gas producing company. *Safety Science,* 72, pp. 23-30.

50. Neal, A. and Griffin, M.A. (2006). A study of the lagged relationships among safety climate, safety motivation, safety behavior, and accidents at the individual and group levels. *Journal of Applied Psychology,* 91(4), pp. 946-953.