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A case study exploring field-level risk assessments as a leading safety indicator

E.J. Haas,

Lead research behavioral scientist and research behavioral scientist, respectively, National Institute for Occupational Safety and Health, Pittsburgh, PA, USA

B.P. Connor,

Lead research behavioral scientist and research behavioral scientist, respectively, National Institute for Occupational Safety and Health, Pittsburgh, PA, USA

J. Vendetti, and

Manager, mining operations, Solvay Soda Ash & Derivatives North America, Green River, WY, USA

R. Heiser

CSP, Mine production superintendent, Solvay Chemicals Inc., Green River, WY, USA

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 individuals within the mining companies to work together to identify such indicators, executing risk assessments comes with challenges. Specifically, varying or inaccurate perceptions of risk, in addition to trust and buy-in of a risk management system, contribute to inconsistent levels of participation in risk programs. This paper focuses on one trona mine's experience in the development and implementation of a field-level risk assessment program to help its organization understand and manage risk to an acceptable level. Through a transformational process of ongoing leadership development, support and communication, Solvay Green River fostered a culture grounded in risk assessment, safety interactions and hazard correction. The application of consistent risk assessment tools was critical to create a participatory workforce that not only talks about safety but actively identifies factors that contribute to hazards and potential incidents. In this paper, reflecting on the mine's previous process of risk-assessment implementation provides examples of likely barriers that sites may encounter when trying to document and manage risks, as well as a variety of mini case examples that showcase how the organization worked through these barriers to facilitate the identification of leading indicators to ultimately reduce incidents.

Keywords

Risk assessment; Safety indicator; Field-level risk assessment

Disclaimer

The findings and conclusions in this paper are those of the authors and do not necessarily represent the views of NIOSH. Reference to specific brand names does not imply endorsement by NIOSH.

Introduction

Work-related health and safety incidents often account for lost days on the job, contributing to organizational/financial and personal/social burdens (Blumenstein et al., 2011; Pinto, Nunes and Ribeiro, 2011). Accompanying research demonstrates that risk and ambiguity around risk contribute to almost every decision that individuals make throughout the day (Golub, 1997; Suijs, 1999). In response, understanding individual attitudes toward risk has been linked to predicting health and safety behavior (Dohmen et al., 2011). 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 health and safety (Haslam et al., 2016). Additionally, research suggests that a current lack of knowledge, skills and motivation are primary barriers to worker participation in mitigating workplace risks (Dohmen et al., 2011; Golub, 1997; Haslam et al., 2016; Suijs, 1999). 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 one field-level risk assessment (FLRA) program, including a matrix that anyone can use to assess site-wide risks and common barriers to participating in such activities. We use a trona mine in Green River, WY, to illustrate that a variety of methods may be needed to successfully implement a proactive risk management program. By discussing the mine's tailored FLRA program, this paper contributes to the literature by providing (1) common barriers that may prevent proactive risk assessment programs in the workplace and (2) case examples in the areas of teamwork, front-line leadership development, and tangible and intangible communication efforts to foster a higher level of trust and empowerment among the workforce.

Risk assessment practices to reveal leading indicators

Risk assessment is a process used to gather knowledge and information around a specific health threat or safety hazard (Smith and Harrison, 2005). Based on the probability of a negative incident, risk assessment also includes determining whether or not the level of risk is acceptable (Lindhe et al., 2010; International Electrotechnical Commission, 1995; Pinto, Nunes and Ribeiro, 2011). Risk assessments can occur 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 (Boyle, 2012; Haas and Yorio, 2016; Hallenbeck, 1993; International Council on Mining & Metals (ICMM), 2012; World Health Organization (WHO), 2008). 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 (Van Ryzin, 1980). These methods focus on a specific part of an operation or task within a system, rather than the system as a whole (Lindhe et al., 2010). Conversely, a qualitative approach is useful for potential or recently identified risks to decide where more detailed assessments may be needed and prioritize actions (Boyle, 2012; ICMM, 2012; WHO, 2008).

Although mine management can use risk assessments to inform procedural decisions and policy changes, they are more often used by workers to identify, assess and respond to worksite risks. A common risk assessment practice is to formulate a matrix that prompts workers to identify and consider the likelihood of a hazardous event and the severity of the outcome to yield a risk ranking (Pinto, Nunes and Ribeiro, 2011). After completing such a matrix and referring to the discretized scales, any organizational member should be able to determine and anticipate the risk of a hazard, action or situation, from low to high (Bartram, 2009; Hokstad et al., 2010; Rosén et al., 2006). The combination of these two "scores" is used to determine whether the risk is acceptable, and subsequently, to identify an appropriate response. For example, a list of hazards may be developed and evaluated for future interventions, depending upon the severity and probability of the hazards. Additionally, risk assessments often reveal a prioritization of identified risks that inform where risk-reduction actions are more critical (Lindhe et al., 2010), which may result in changes to a policy or protocol (Boyle, 2012).

If initiated and completed consistently, risk assessments allow root causes of accidents and patterns of risky behavior to emerge — in other words, leading indicators (Markowski, Mannan and Bigoszewska, 2009). Leading indicators demonstrate pre-incident trends rather than direct measures of performance, unlike lagging indicators such as incident rates, and as a result, are useful for worker knowledge and motivation (Juglaret et al., 2011). Recently, high-risk industries have allocated more resources to preventative activities — not only to prevent injuries but also to avoid the financial costs associated with incidents — which has produced encouraging results (Maniati, 2014; Robson et al., 2007). However, 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 (Apeland, Aven and Nilsen, 2002; Reason, 2013). In response, better foresight into the barriers of risk management is needed to (1) engage workers in risk identification and assessment, and (2) develop pragmatic solutions to prevent incidents.

Methods and materials

In December 2015, Haas and Connor, two U.S. National Institute for Occupational Safety and Health (NIOSH) researchers, traveled to Solvay Green River's mine in southwest Wyoming. This trona mine produces close to 3 Mt/a of soda ash using a combination of longwall and solution mining and borer miners (Fiscor, 2015). A health, safety and risk management framework had been introduced in phases during 2009 and 2010 to the mine's workforce of more than 450 to help reduce risks to an acceptable level, and NIOSH wanted to understand all aspects of this FLRA program and how it became integrated into everyday work processes. We collected an extensive amount of qualitative data, analyzed the material and triangulated the results to inform a case study in health and safety system implementation (Denzin and Lincoln, 2000; Pattson, 2002; Yin, 2014). 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 (Wrede, 2013).

Participants

We collected several qualitative data points, including all-day expert interviews and discussions with mine-site senior-level management such as the mine manager, health and safety manager, and mine foremen/supervisors, some of whom were hourly workers at the time of the risk assessment program implementation (Flick, 2009). Additionally, we heard presentations from the mine managers and site supervisors, received archived risk assessment documents and were able to engage in observations on the surface and in the underground mine operation during the visit, where several mineworkers engaged in conversations about the FLRA, hazard interactions, and general safety culture on site.

Retrospective data analysis of risk assessment in action

Typically, qualitative analysis and triangulation of case study data use constant comparison techniques, sometimes within a grounded theory framework (Corbin and Strauss, 2008; Glaser and Strauss, 1967). We employed the constant comparison method within a series of iterative coding steps. First, we typed the field notes and interview notes, and scanned the various risk assessment 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 (Boyatzis, 1998; Fram, 2013).

Throughout the paper, quotes and examples from employees who participated in the visit are shared to better demonstrate their process to establish the FLRA program. To address the reliability and validity of our interpretation of the data, the two primary, expert information providers during the field visit, Vendetti and Heiser, became coauthors and served as 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 (Kitchener, 2002).

Results

It is important to know that in 2009 Solvay experienced a sharp increase in incidents in its more-than-450-employee operation. Although no fatalities occurred, there were three major amputations and injury frequencies that were increasing steadily. The root causes of these incidents — torn ligaments/tendons/muscles requiring surgical repair or restricted duty; lacerations requiring sutures; and fractures (Mine Safety and Health Administration, 2017) — showed that inconsistent perceptions of risk and mitigation efforts were occurring on site among all types of work positions, from bolters to maintenance workers. These incidents caused frustration and disappointment among the workforce.

Intervention implementation, pre- and post-FLRA program

Faced with inconsistencies in worker knowledge of risks and varying levels of risk tolerance, management could have taken a punitive, “set an example” response, based on an accountability framework. Instead, they began a process in 2009 to bring new tools, methods and mindset to safety performance at the site. Specifically, based on previous research and experience, such as from 1998, they saw the advantages of creating a common, site-wide set of tools and metrics to guide workers in a consistent approach to risk assessment in the field.

This involvement trickled down to hourly workers in the form of a typical risk assessment matrix (Table 1) described earlier to identify, assess and evaluate risks. Management indicated that if everyone had tools, then “It doesn’t matter what you knew or what you didn’t, you had tools to assess and manage a situation.” They hypothesized that matrices populated by workers would reveal leading indicators to proactively identify and prevent incidents that had been occurring on site. Workers were expected to utilize this matrix daily to help identify and evaluate risks.

To complete the matrix, workers rate consequences of a risk using the scales/key depicted in Table 2. As shown in the color-coded matrix, multiplying the scores for these two areas yields a risk ranking of low, moderate, high or critical, thereby providing guidance on what energies or hazards to mitigate immediately. Although the matrix approach, specifically, may not be new to the industry, the implementation and evaluation of such efforts offer value in the form of heightened engagement, leadership and eventually behavior change.

Observing incidents post-implementation of the FLRA intervention during 2009 and front-line leadership efforts during 2010, much can be learned to understand where and how impact occurred on site. Figure 1 shows Green River’s 2009 spike in non-fatal days lost (NFDL) incidents with a consistent drop thereafter, providing cursory support of the program.

Seeing a drop in incidents provides initial support for the FLRA program that Solvay introduced. Knowing that many covariates may account for a drop in incidents, however, additional data were garnered from MSHA’s website to account for hours worked. Still, the incident rate declined consistently, as shown in Fig. 2.

From a quantitative tracking effort of these lagging indicators, it can be gleaned that the implemented program was successful. However, it is important to understand what, how and why incidents decreased over time to maintain consistency in implementation and evaluation efforts. In response, this paper focuses on the qualitative data that NIOSH collected in hopes of sharing how common barriers to risk assessment can be addressed to identify leading indicators on site.

Discussion

During the iterative analysis of the data, researchers sorted the initial and ongoing barriers to continuous risk assessment. The results provide insight into promising ways to measure and document as well as support and manage a risk-based program over several years. After common barriers to risk assessment implementation are discussed, mini case examples to illustrate how the organization improved and used their FLRA process to identify leading indicators follow. Ultimately, these barriers and organizational responses show that an FLRA program can help (1) measure direct/indirect precursors to harm and provide opportunities for preventative action, (2) allow the discovery of proactive leadership risk reduction strategies, and (3) provide warning before an undesired event occurs and develop a database of response strategies (Blumenstein et al., 2011; ICMM, 2012).

Barrier to risk assessment intervention: Varying levels of risk tolerance and documentation

An initial challenge, not uncommon in occupational health and safety, was the varying levels of risk tolerance possessed by the workforce. Research shows that individuals have varying levels of knowledge, awareness and tolerance in their abilities to recognize and perceive risks as unacceptable (Brun, 1992; Reason, 2013; Ruan, Liu and Carchon, 2003). Managers and workers reflected that assessments of a risk were quite broad, having an impact on the organization's ability to consistently identify and categorize hazards. One employee who was an hourly worker at the time of the FLRA implementation said, "It took time to establish a sensitivity to potential hazards." This is not particularly surprising; as individuals gain experience, they can become complacent with health and safety risks and, eventually, have a lower sense of perceived susceptibility and severity of a negative outcome (Zohar and Erev, 2006). As a result, abilities to consistently notice and believe that a hazard poses threat to their personal health and safety decreases. The health and safety manager said, "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 onsite, acknowledging that sources of risk are always changing in some regard and tend to be more complicated for some employees to see than others. In response, discussions about the importance of encouraging conscious efforts of risk management became ongoing to support a new level of awareness on site. Additionally, the value of documenting risk assessment efforts on an individual and group level became more apparent. One area emphasized was encouraging team communication around risk assessment if it was warranted. An example of this process and outcome is detailed below to help elucidate how Solvay overcame disparate perceptions of risk through teamwork.

Case example: FLRA discussion and documentation in action—An example of the FLRA in action as a leading indicator was provided by the maintenance supervisor during the visit. This example included an installation of a horizontal support beam. Workers collectively 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 for consideration within the matrix as possible indicators 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 (Tables 1 and 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 risk assessment meeting.
- Inspect all personal protective equipment (PPE) fitting and harnesses.
- Understand structural removal sequence.
- Communicate between crane operator and riggers.
- Assure 100 percent of tie-off protocol is followed.
- Watch out for coworkers.
- Participate in housekeeping activities.

Upon determining and implementing controls, a final risk rank was rendered to make a decision for the job task: whether or not the headframe could be removed in one section. Ultimately, workers decided it could safely be done. 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 risk assessment was important and adhered to for this task.

In this sense, the FLRAs served as a communication platform to share a common language and ultimately, common proactive behavior. In general, vagueness of data on health and safety risks can prevent hazard recognition, impair decision-making, and disrupt risk-based decisions among workers (Ruan, Liu and Carchon, 2003). This example showed that the more workers understood what constitutes an acceptable level of risk, the greater sense of shared responsibility they had to prevent hazards and make protective decisions on the job (Reason, 1998) such as shutting down a procedure due to potential problems. Now, workers have the ability to implement their own check-and-balance system to determine if a response is needed and their decision is supported. Treating the FLRA as a check-and-balance system allowed workers to improve their own risk assessment knowledge, skills and motivation, a common barrier to hazard identification (Haslam et al., 2016). In theory, as FLRAs are increasingly used to predetermine possible incidents and response strategies are developed and referenced, the occurrence of lagging indicators should decrease, as has been the case at Solvay in recent years.

Barrier to risk assessment intervention: Resisting formal risk assessment methods

Worksites often face challenges of determining the best ways to measure and develop suitable tools to facilitate consistent risk measurement (Boyle, 2012; Haas and Yorio, 2016; Haas, Willmer and Cecala, 2016). For example, research shows that assessing site risks

using a series of checklists or general observations during site walkthroughs is more common (Navon and Kolten, 2006). Although practical, checklists and observations require little cognitive investment and have more often been insufficient in revealing potential safety problems (Jou et al., 2009). Due to familiarity with "the way things were," implementing the system of risk assessments at Solvay came with challenges. Workers experienced initial resistance to moving toward something more formal.

For example, at the outset, hourly workers said they felt, "I do this in my head all the time. I just don't write it down." Particularly, individuals who were hourly workers at the time of the FLRA program implementation felt that they already did some form of risk identification and that they did not need to go into more detail to assess the risk. 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 worker reflected on the previous mindset, he said, "It would be okay to be in the red, so long as you knew you were in the red." Because of the varying levels of initial acceptance, there were inconsistencies in the quality of the completed risk assessment matrices. Management noted, "Initially, people were doing them, but not to the quality they could have been." In response, Solvay management focused on strengthening their frontline leadership skills to help facilitate hourly buy-in, as described in the following case example.

Case example: Starting with frontline leadership to facilitate buy-in, "The Club"—To facilitate wider commitment and buy-in, senior-level management took additional steps with their frontline supervisors. To train frontline leaders on how to understand rather than punish worker actions, Solvay management started a working group in 2010 called "The Club." This group 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 risk assessment tools and their outcomes (Fiscor, 2015; Heiser and Vendetti, 2015).

After receiving this leadership training and engaging in discussions about FLRA, the execution of model leadership from The Club started. Specifically, the frontline foremen that the researchers talked with indicated that they were better able to communicate about and manage safety across the site. Prior to The Club and adapting to the FLRA, one of these supervisors reflected, "No one wanted to make a safety decision." Senior management acknowledged with their frontline leadership that the FLRA identifies steps that 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 with hourly workers if something happened or went wrong. They shared the importance of supportive language: "We say 'let's not do this again,' but they don't get in trouble."

To further illustrate the leadership style and communicative focus, one manager shared a conversation conducted with a worker after an incident. Rather than reprimanding the worker's error in judgement, the manager 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 the worker acknowledged he did not have the right tools but tried to improvise, the manager asked him what other risky choices he had made that turned out okay. This process engaged the worker, 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 safer practice in the future (Yorio and Willmer, 2015; Zohar and Luria, 2005). 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.

Importantly, this communication and documentation among The Club allowed insight into how employees think, serving as a leading indicator for health and safety management. The stack of FLRAs that were pulled out — completed between 2009 and 2015 — were filled out with greater detail as the years progressed. It was apparent that the hourly workforce continually adapted, resulting in an improved sense of organizational motivation, culture and trust. Management indicated to NIOSH that workers now have an increased sense of empowerment to identify and mitigate risks. Contrary to how workers used to document their risk assessments, a management member 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."

Barrier to risk assessment intervention: Communicate and show tangible support for risk assessment methods—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 (Rundmo, 2000; Zohar and Luria, 2005). Therefore, promoting these organizational factors was needed to encourage workers to identify hazards and prevent incidents (Pinto et al., 2011). 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 hourly and salary workers about site conditions and practices (Fiscor, 2015; Heiser and Vendetti, 2015; Neal and Griffin, 2006; Reason, 1998; Rundmo, 2000; Wold and Laumann, 2015; Zohar and Luria, 2005). 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.

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. Despite perhaps not wanting to hear feedback against a policy in place or attitude of risk acceptance, all levels of management wanted to communicate their understanding for changing risks and hazards, and the need to sometimes adapt policies in place based on changing energies in the environment, as revealed by the FLRAs that the workers were taking time to complete. The following case example showcases the value of ongoing communication to maintain a risk assessment program and buy-in from workers.

Case example: Illustrating flexibility with site procedures—During the visit, managers and workers both discussed the conscious efforts made during group meetings and

one-on-one interactions to improve their organizational leadership and communication, noting the difficulty of incorporating the FLRA as a complement to existing rules and regulations on site: “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 encourage worker accountability, the managers wanted to show their commitment to the FLRA process and that they could be flexible in changing a rule or policy if the risk assessment showed a need. As an example, they showed NIOSH a “general isolation” procedure about lock-out/tag-out that was distributed at their preshift safety meeting that morning. They handed out a piece of paper saying that, “While a visual disconnect secured with individual locks is always the preferred method of isolation, there are specific isolation procedures for tasks unique to underground operations.” The handout went on to state: “In rare circumstances, when a visual disconnect with lock is not used and circumstances other than those specifically identified are encountered, a formal documented risk assessment will be performed. All potential energies will be identified and understood, every practical barrier at the appropriate level will be identified and implemented, and the foreman in charge of the task will approve with his/her signature prior to performing the work. All personnel involved in the job or task must review and understand the energies and barriers implemented prior to any work being performed…”

This example shows the site’s commitment to risk assessment while also showing that, if leading indicators are identified, a policy can be changed to avoid a potential incident. Noting that they would change a procedure if workers identified something, the document illustrated management’s confidence and value in the FLRA process. Workers indicated that these behaviors are a support mechanism for them and their hazard identification efforts. Along the same lines, the managers we talked with noted the importance of not just training to procedure but also to emphasize: “High-level policies complement but don’t drive safety.” This example showcases their leadership and communicative commitment.

The lock-out/tag-out example is just one safety share that occurred at a preshift meeting. These shares “might be no more than five minutes, they might go a half-hour, but they’re allowed to take as long as they need,” one manager said. This continued commitment to foster the use of leading indicators to support a health and safety 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 health and safety as well as afforded workers an opportunity to engage in improving the policies and rules on site. This continued consistency in communication helped to create a sense of ownership 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.”

Limitations and conclusions

The purpose of this paper was to illustrate an example in which everyone could participate to identify leading safety indicators. In everyone’s judgment, it took about four to five years until Solvay actually saw the change in action, meaning that the process was sustained by

workers and they were using the risk assessment terminology in their everyday discussions. In addition to providing how leading indicators can be developed or look “in action,” this paper advanced the discussion to provide insight into common barriers to risk assessment, and potential responses to these barriers. As Figs. 1 and 2 show, incidents had been down at Solvay since the implementation of the FLRA program and enhanced leadership training of frontline supervisors, showing the impact of the FLRAs as a strong leading indicator for health and safety. Additionally, hourly workers discussed how much better the culture is on site now than it was several years ago, noting their appreciation for having a common language on site to communicate about risks. It is rare that both sides — hourly and salary — see benefits in a written tool from an operational and behavioral standpoint. The cooperation on site speaks to the positive attributes discussed within this case study and mini examples provided that cannot be shown in a graph.

Although the results of this study are only part of a small case study and cannot be generalized across the industry, data support the argument that poor leadership and an overall lack of trust on site can inhibit workers’ willingness to participate in risk measurement, documentation and decision-making. Obviously, the researchers could not talk with every worker and manager present on site, so not all opinions are reflected in this paper. However, the consistency in messages from both levels of the organization showed saturation of insights that reflect the impact of the FLRAs. It is acknowledged that 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 practices that are needed to foster such proactive behavior, the results provide several potential areas of improvement for the industry in terms of formal risk assessment over a period of time.

In lieu of these limitations, mine operators should consider this information when interpreting the results in terms of (1) how to establish formal risk assessment on site, especially when trying to identify and mitigate hazards, (2) what the current mindset of frontline leadership may be and how they could support (or hinder) such an risk assessment program and (3) methods to consistently support a participatory risk assessment program. Gaining an in-depth view of Solvay’s own health and safety journey provides expectations and a possible roadmap for encouraging worker participation in risk management at other mine sites to proactively prevent health and safety incidents.

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References

Apeland S, Aven T, Nilsen T. Quantifying uncertainty under a predictive epistemic approach to risk analysis. Reliability Engineering and System Safety. 2002; 75:93–102. https://doi.org/10.1016/s0951-8320(01)00122-3.

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

Blumenstein, D., Ferriter, R., Powers, J., Reiher, M. Accidents – The Total Cost: A Guide for Estimating The Total Cost of Accidents. Western Mining Safety and Health Training and Translation Center, Colorado School of Mines, Mine Safety and Health Program technical staff. 2011. http://inside.mines.edu/UserFiles/File/MSHP/GuideforEstimatingtheTotalCostofAccidentspercent20FINAL(8-10-11).pdf

Boyatzis, RE. Transforming Qualitative Information: Thematic Analysis and Code Development. Sage; Thousand Oaks, CA: 1998.

Boyle, T. Health And Safety: Risk Management. Routledge; New York, NY: 2012.

Brun W. Cognitive components in risk perception: Natural versus manmade risks. Journal of Behavioral Decision Making. 1992; 5:117–132. https://doi.org/10.1002/bdm.3960050204.

Corbin, J., Strauss, A. Basics of Qualitative Research. 3. Sage; Thousand Oaks, CA: 2008.

Denzin, NK., Lincoln, YS. The discipline and practice of qualitative research. In: Denzin, NK., Lincoln, YS., editors. Handbook of Qualitative Research. 2. Sage; Thousand Oaks, CA: 2000. p. 1-28.

Dohmen T, Falk A, Huffman D, Sunde U, Schupp J, Wagner GG. Individual risk attitudes: measurement, determinants, and behavioral consequences. Journal of the European Economic Association. 2011; 9(3):522–550. https://doi.org/10.1111/j.1542-4774.2011.01015.x.

Fiscor S. Solvay implements field level risk assessment program. Engineering and Mining Journal. 2015; 216(9):38–42.

Flick, U. An Introduction to Qualitative Research. Sage; Thousand Oaks, CA: 2009.

Fram SM. The constant comparative method outside of grounded theory. The Qualitative Report. 2013; 18(1):1–25.

Glaser, B., Strauss, A. The Discovery of Grounded Theory. Adeline; Chicago, IL: 1967.

Golub, A. Decision Analysis: An Integrated Approach. Wiley; New York, NY: 1997.

Haas EJ, Yorio P. Exploring the state of health and safety management system performance measurement in mining organizations. Safety Science. 2016; 83:48–58. https://doi.org/10.1016/j.ssci.2015.11.009. [PubMed: 26823642]

Haas EJ, Willmer DR, Cecala AB. Formative research to reduce mine worker respirable silica dust exposure: a feasibility study to integrate technology into behavioral interventions. Pilot and Feasibility Studies. 2016; 2(6) https://doi.org/10.1186/s40814-016-0047-1.

Hallenbeck, WH. Quantitative Risk Assessment for Environmental and Occupational Health. 2. Lewis Publishers; Boca Raton, NY: 1993.

Haslam C, O'Hara J, Kazi A, Twumasi R, Haslam R. Proactive occupational safety and health management: Promoting good health and good business. Safety Science. 2016; 81:99–108. https://doi.org/10.1016/j.ssci.2015.06.010.

Heiser, R., Vendetti, JA. Field Level Risk Assessment - A Safety Culture. Longwall USA Exhibition and Convention; June 16, 2016; Pittsburgh, PA. 2015.

Hokstad, P., Røstum, J., Sklet, S., Rosén, L., Lindhe, A., Pettersson, T., Sturm, S., Beuken, R., Kirchner, D., Niewersch, C. Deliverable No. D 4.2.4. Techneau; 2010. Methods for Analysing Risks of Drinking Water Systems from Source to Tap.

International Council on Mining & Metals. Overview of Leading Indicators For Occupational Health And Safety In Mining. 2012 Nov. https://www.icmm.com/en-gb/publications/health-and-safety/overview-of-leading-indicators-for-occupational-health-and-safety-in-mining

International Electrotechnical Commission. IEC 300-3-9. Geneva: 1995. Dependability Management – Risk Analysis of Technological Systems.

Jou Y, Lin C, Yenn T, Yang C, Yang L, Tsai R. The implementation of a human factors engineering checklist for human–system interfaces upgrade in nuclear power plants. Safety Science. 2009; 47:1016–1025. https://doi.org/10.1016/j.ssci.2008.11.004.

Juglaret, F., Rallo, JM., Textoris, R., Guarnieri, F., Garbolino, E. New balanced scorecard leading indicators to monitor performance variability in OHS management systems. In: Hollnagel, E.Rigaud, E., Besnard, D., editors. Proceedings of the fourth Resilience Engineering Symposium; June 8–10, 2011; Sophia-Antipolis, France, Presses des Mines, Paris. 2011. p. 121-127.https://doi.org/10.4000/books.pressesmines.1015

Kitchener M. Mobilizing the logic of managerialism in professional fields: The case of academic health centre mergers. Organization Studies. 2002; 23(3):391–420. https://doi.org/10.1177/0170840602233004.

Lindhe, A., Sturm, S., Røstum, J., Kožíšek, F., Gari, DW., Beuken, R., Swartz, C. Deliverable No. D4.1.5g. Techneau; 2010. Risk Assessment Case Studies: Summary Report. https://www.techneau.org/fileadmin/files/Publications/Publications/Deliverables/D4.1.5g.pdf

Markowski A, Mannan S, Bigoszewska A. Fuzzy logic for process safety analysis. Journal of Loss Prevention in the Process Industries. 2009; 22:695–702. https://doi.org/10.1016/j.jlp.2008.11.011.

Maniati, M. The Business Benefits of Health and Safety: A Literature Review. British Safety Council; 2014. https://www.britsafe.org/media/1569/the-business-benefits-health-and-safety-literature-review.pdf

Mine Safety and Health Administration (MSHA). Data & Reports. U.S. Department of Labor; 2017. https://www.msha.gov/data-reports

Navon R, Kolton O. Model for automated monitoring of fall hazards in building construction. Journal of Construction Engineering and Management. 2006; 132(7):733–740. https://doi.org/10.1061/(asce)0733-9364(2006)132:7(733).

Neal A, Griffin MA. 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. 2006; 91(4):946–953. https://doi.org/10.1037/0021-9010.91.4.946. [PubMed: 16834517]

Pattson, MQ. Qualitative Research and Evaluation Methods. 3. Sage; Thousand Oaks, CA: 2002.

Pinto A, Nunes IL, Ribeiro RA. Occupational risk assessment in construction industry – Overview and reflection. Safety Science. 2011; 49:616–624. https://doi.org/10.1016/j.ssci.2011.01.003.

Reason J. Achieving a safe culture: Theory and practice. Work & Stress. 1998; 12(3):293–306. https://doi.org/10.1080/02678379808256868.

Reason, J. A Life in Error: From Little Slips to Big Disasters. Ashgate Publishing; Burlington, VT: 2013.

Robson LS, Clarke JA, Cullen K, Bielecky A, Severin C, Bigelow PL, Mahood Q. The effectiveness of occupational health and safety management system interventions: a systematic review. Safety Science. 2007; 45(3):329–353. https://doi.org/10.1016/j.ssci.2006.07.003.

Rosén L, Hokstad P, Lindhe A, Sklet S, Røstum J. Generic Framework and Methods for Integrated. Water Science and Technology. 2006; 43:31–38.

Ruan D, Liu J, Carchon R. Linguistic assessment approach for managing nuclear safeguards indicators information. Logistics Information Management. 2003; 16(6):401–419. https://doi.org/10.1108/09576050310503385.

Rundmo T. Safety climate, attitudes and risk perception in Norsk Hydro. Safety Science. 2000; 34(1):47–59. https://doi.org/10.1016/s0925-7535(00)00006-0.

Smith SP, Harrison MD. Measuring reuse in hazard analysis. Reliability Engineering & System Safety. 2005; 89(1):93–104. https://doi.org/10.1016/j.ress.2004.08.010.

Suijs, J. Cooperative Decision-Making Under Risk. Kluwer Academic Publishers, Springer Science +Business Media New York; NY: 1999.

Van Ryzin J. Quantitative risk assessment. Journal of Occupational and Environmental Medicine. 1980; 22(5):321–326. https://doi.org/10.1097/00043764-198005000-00004.

Wold T, Laumann K. Safety management systems as communication in an oil and gas producing company. Safety Science. 2015; 72:23–30. https://doi.org/10.1016/j.ssci.2014.08.004.

World Health Organization. Recommendations. 3. Vol. 1. World Health Organization; Geneva: 2008. Guidelines for Drinking-Water Quality [Electronic Resource]: Incorporating First and Second Addenda.

Wrede, S. How country matters: Studying health policy in a comparative perspective. In: Bourgeault, I.Dingwall, R., de Vries, R., editors. The SAGE Handbook of Qualitative Methods in Health Research. Sage; Thousand Oaks, CA: 2013.

Yin, RK. Case Study Research: Design and Methods. 5. Sage; Thousand Oaks, CA: 2014.

Yorio, PaL, Willmer, DR. Explorations in Pursuit of Risk-Based Health and Safety Management Systems. SME Annual Conference & Expo; Feb. 15–18, 2015; Denver, CO: Society for Mining, Metallurgy & Exploration; 2015.

Zohar D, Erev I. On the difficulty of promoting workers' safety behaviour: Overcoming the underweighting of routine risks. International Journal of Risk Assessment and Management. 2006; 7(2):122–136. https://doi.org/10.1504/ijram.2007.011726.

Zohar D, Luria G. A multilevel model of safety climate: cross-level relationships between organization and group-level climates. Journal of Applied Psychology. 2005; 90(4):616–628. https://doi.org/10.1037/0021-9010.90.4.616. [PubMed: 16060782]

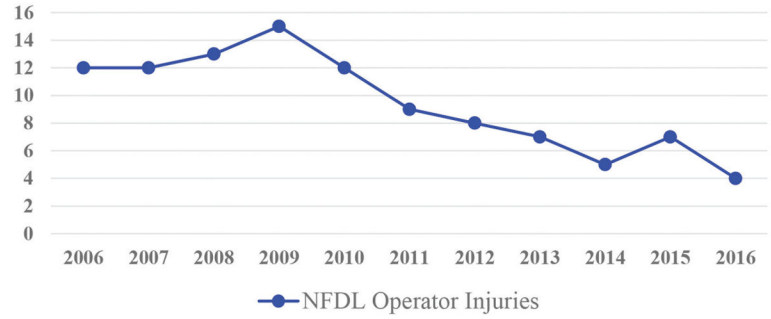

Figure 1.
Solvay non-fatal days lost operator injuries, 2006–2016 (MSHA, 2017).

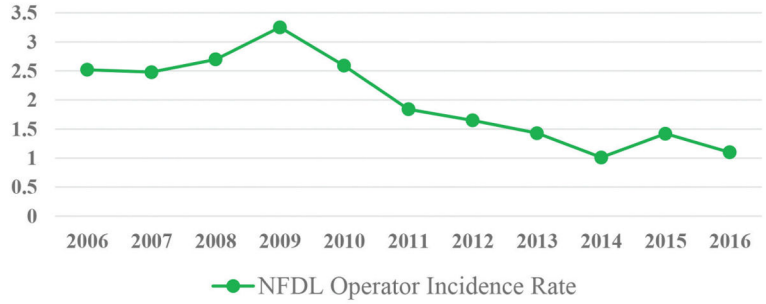

Figure 2.
Non-fatal days lost operator injury incidence rate (injuries by hours worked), 2006–2016 (MSHA, 2017).

Table 1

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

Probability	Consequence				
	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

Table 2

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: LO W	