

Risk Management Interventions to Reduce Injuries and Maximize Economic Benefits in U.S. Mining

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Objective: Risk management (RM) is a cyclical process of identifying and ranking risks, implementing controls, and evaluating their effectiveness. This study aims to identify effective RM interventions in the U.S. mining industry. **Methods:** RM interventions were identified in four companies representing metal, aggregate, and coal mining sectors. Injury rates were determined using Mine Safety and Health Administration (MSHA) data and changes in injury rates identified through change point analysis. Program implementation costs and associated changes in injury costs were evaluated for select interventions. **Results:** Six of 20 RM interventions were associated with a decline in all injuries and one with a reduction in lost-time injuries, all with a positive return on investment. **Conclusion:** Reductions in injuries and associated costs were observed following implementation of a limited number of specific RM interventions.

Keywords: injury prevention, mining, risk management

BACKGROUND

Despite improvements in health and safety, mining remains a dangerous profession.¹ To further control hazards and reduce injuries, proactive risk management (RM) has been employed as a central component of mining safety and health management systems and is a legal requirement in many countries. RM, codified in the International Organization for Standardization (ISO) 31000 standard, involves a cyclical process of identifying activities posing a high risk of injuries, redesigning procedures to reduce risks, implementing these changes, and evaluating their effectiveness. Although the implementation of RM varies across industry, common components include a scoping phase where hazards are identified and described; a risk assessment phase where risks are ranked based on frequency and severity of potential adverse outcomes; a control phase where control interventions are identified and implemented;

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Learning Objectives

- Become familiar with efforts to improve health and safety in the mining industry, including previous research on the effectiveness of risk management (RM) interventions.
- Summarize the methods and findings of the new analysis of RM interventions and their effects on injury rates and related costs in the US mining industry.
- Discuss the types of effective RM interventions identified and the implications for injury prevention in the mining industry.

and a review phase where the effectiveness of the controls is evaluated and changes are made to address deficiencies.

In prior research, adoption of RM in the Australian coal industry from 1996 to 2003 was associated with a 78% reduction in the lost-time injury rate in Queensland and 52% in New South Wales, as compared with a 20% reduction in the United States (U.S.) coal industry over the same time period.² However, there is currently insufficient information on the effectiveness of individual RM interventions, particularly in U.S. mines where safety and health regulations are generally compliance- rather than risk-based. A risk analysis of 10 years of Mine Safety and Health Administration (MSHA) injury data (1995 to 2004) found that there remains a serious risk for nonfatal days lost (NFDL) injuries and a moderate risk of no days lost (NDL) injuries in the U.S. mining industry.¹ Komljenovic et al¹ concluded that systematic planning and execution of safety programs within a risk assessment and management system is needed to reduce the risk of injury in mining.

According to NIOSH, relatively few workplace health and safety interventions have been evaluated in terms of their effectiveness and potential economic benefits; therefore, “many interventions are undertaken based on faith and expert judgment without convincing evidence that these approaches are effective.”³ One common RM intervention, mandatory safety training, has been associated with a 41% reduction in the risk of permanently disabling injury among mineworkers in the stone, sand, and gravel industry; however, costs were not explicitly evaluated in this study.⁴ An analysis of an engineering control, roof screening, designed to prevent injuries from rock fall in coal mines, estimated that the intervention cost of \$240,000 would be recovered in as little as 3 years through the prevention of an average of 13 “struck by” workers’ compensation claims, based on the savings in workers’ compensation premiums and claims.^{5,6} Economic analyses of RM interventions are needed to evaluate economic investment and guide mine adoption decisions. The current study aims to provide information for decision makers to help ensure limited resources are utilized efficiently by evaluating the association of RM interventions in four U.S. mining companies with changes in injury rates and related economic costs to identify effective RM interventions for injury prevention.

METHODS

Data Acquisition

Partner mines included a convenience sample of four U.S. sites with RM expertise, including two large (>500 employees)

metal, one large coal, and one medium (20 to 500 employees) aggregate operation. Site visits and face-to-face interviews with a variety of mine employees, including safety managers, operations managers, supervisors, and frontline mineworkers, were conducted at each mine site, including personnel with the longest possible tenure at the mine site in order to gain more complete information about older interventions. Interviews were conducted over 2 to 3-day site visits and were unscripted, but included a brief introduction to the purpose of the study and a request that mine employees describe their role in the organization and provide information on interventions at their mine site over the time period, 1988 to 2013. Mine employees were asked probing questions about the interventions they identified, including what successes and challenges they have observed and intervention costs. Mine employees also provided information regarding their health and safety practices and their knowledge of the RM interventions put in place by management. Although generally the same interview questions were posed to the interviewees at each site, conversations were organic in nature and qualitative information was collected accordingly. These data were supplemented with publicly available injury data from the MSHA Accident, Injury, and Illness files. Lost time injuries were defined as injuries resulting in at least one day of lost work, excluding any reported administrative injuries and reported incidents resulting in no injuries.

Effect of Risk Management Interventions on Injury Rates

MSHA quarterly employment data from 1990 through 2013 were downloaded, including the number of hours worked per calendar quarter. Injury and employment datasets were merged to calculate quarterly injury rates for each operation. Injury rates were calculated for each quarter by dividing the total number of injuries for the calendar quarter by the total number of hours worked in the same quarter. A standard incidence rate calculation was performed by multiplying injury rates by 200,000 to represent the equivalent of 100 employees working 40 hours per week and 50 weeks per year.

Change point analyses is used to detect time points of significant changes in the statistical properties of an ordered sequence of observations (ie, time series data).⁷ Change point analysis was used to identify statistically significant longitudinal changes (increases/decreases) using the binary segmentation algorithm (the most commonly used algorithm) to detect change points in partner mine injury rate time series using the “change-point” statistical package in R.⁷ A penalty value of $P = 0.10$ was applied to identify significant change points. Change point analysis was done for all injuries and separately for lost time injuries. Congruence of intervention implementation timelines obtained through the face-to-face interviews to longitudinal injury rates was then assessed.

Return on Investment

Each partner mine estimated the costs of program implementation for identified interventions using their own records or by completing an intervention cost estimate worksheet including direct (personnel, materials, and supplies) and indirect costs of interventions in their estimates (available on our website, <https://mining-publichealth.arizona.edu/risk-management/cost-intervention>). These estimates were inflation adjusted to 2015 dollars using the Bureau of Labor Statistics inflation calculator (<http://data.bls.gov/cgi-bin/cpicalc.pl>). The cost of injury was derived from previous research in coal mining, which found that severe injuries (fatalities and injuries resulting in permanent total or partial disability) represented 1231/73,027 (1.7%) of the total number of injuries with the remaining injuries being less severe, resulting in days away from work (with or without restricted duty) or medical treatment only.⁸ A value of \$6.5 M was used to estimate the cost of a fatality and the National Safety Council’s estimate for the average cost of an

injury requiring medical treatment, \$30,000 was used to estimate the cost of less severe injuries.⁹ For the current study, the cost of less severe injuries (resulting in days away from work with or without restricted duty) was estimated as \$42,000, using the 2015 National Safety Council figure for the cost of an injury requiring medical treatment.⁹ Using the injury frequency figures presented in Gowrisankaran et al.,⁸ the weighted average of the \$6.5 M cost of severe injury and the \$42,000 estimated cost of a less severe injury is \$150,861.

The costs of injury in pre- and postintervention periods were estimated by multiplying the annual average number of injuries by the weighted average cost of injury (\$150,861). The annual benefits of the RM programs were calculated as the difference between the annual pre- and postintervention injury costs. Benefits of injury prevention in years subsequent to the implementation of the injury prevention were discounted at a rate of 7% using the formula: discounted future value = future value / $(1 + r)^n$ (Eq. (1)), where r = discount rate (7%) and n = years since the intervention. A 7% discount rate was chosen as a conservative figure that is higher than real interest rates observed during this time period.

The total present discounted value of injury cost reduction from the intervention was then calculated as the sum of the discounted future values of the benefits. Our baseline present discounted value measures used a 5-year horizon (summing time periods from 0 to 4 years after the intervention). The use of a 5-year horizon reflects the investigators’ belief that the effect of intervention would not be shorter than 5 years and likely longer, given that interventions that were implemented more than 5 years ago were observed. Finally, ROI was calculated as: [(total present discounted value of injury cost reduction – inflation adjusted RM program costs)/inflation adjusted RM program costs]*100.

RESULTS

The partner mine operations were located in the West and Southwest U.S., as Partner A (underground coal); Partner B (surface and underground metal); Partner C (aggregate cement plant); and Partner D (surface and underground coal). A total of 10 mine employees were interviewed at Partner A; 16 at Partner B; seven at Partner C; and, 16 at Partner D. RM interventions identified during these interviews included standard operating procedures (SOPs), behavioral and educational programs focused on safety, policy, administrative, and/or engineering controls.

Effect of Risk Management Interventions on Injury Rates

Table 1 contains the list of the 20 RM interventions identified by our partner mines. The names and dates of all the RM interventions implemented over the study period were provided by our partner mines, along with descriptions and implementation costs for the interventions they felt were effective based on their preferences and experiences. The intervention type categories developed organically over the course of our conversations with mine personnel; a total of five categories were used, including Administrative controls, Behavior, Engineering control, Safety management, and Training. There are several interventions that fall into more than one category. For example, the ZIP program implemented by Partner A was a training program for a behavioral intervention, and is therefore included in both categories.

Partner A focused on RM activities starting with MSHA’s Stop-Look-Analyze-Manage (SLAM) training and safe work observations (Intervention 1) in 2002. Partner B reported an emphasis on informal RM activities using a “five-point card” system (Intervention 9). The five-point card system was used as a reminder for miners to initiate an informal risk assessment in five specific domains before beginning work on a per task basis. Mine partner C reported impactful engineering interventions, including a

TABLE 1. Risk Management Interventions Implemented by Partner Mines (1990–2013)

Partner	Year	Intervention Number and Name	Description	Type	Estimated Implementation Cost
A	2002	1. SLAM Training and Safe Work Observations	Stop, Look, Assess, & Manage (SLAM) is a behavior-based safety program instituted at this site in 2002. This training is provided during new employee orientation, with continuous on-the-job training provided by shop supervisors. Similarly, safe work observations encourage peers, supervisors, and safety staff to intervene and remind people about activities that appear unsafe	Behavior	\$1M
	2004	2. Fatal Risk Control Protocols	The Fatal Risk Control Protocols (FRCP) were initiated by corporate and implemented at this site. The mine site created control documents and SOPs, incorporating MSHA requirements. Corporate created an audit and scoring system to help individual mine sites benchmark their progress. Each FRCP had a “champion” on site. The FRCP effort affected training and compliance efforts, and caused positive changes in the corporate reporting requirements.	Safety management	\$500,000
	2006	3. Zero Incident Process Training (managers)	This behavior-based training program was developed by Sentis. The ZIP program “helps drive toward zero-incident approaches to injury frequency rates, near misses, and more.” (http://www.sentis.net/solutions/safety/#)	Training/Behavior	\$1M*
	2007	4. HSE Peer Audit	A Health, Safety & Environment peer audit was held in 2007 to look into road safety issues at the mine site.	Safety management	No cost data available
		5. Zero Incident Process Training (hourly employees)	This behavior-based training program was developed by Sentis. The ZIP program “helps drive toward zero-incident approaches to injury frequency rates, near misses, and more.” (http://www.sentis.net/solutions/safety/#)	Training/Behavior	*All ZIP program costs (managers and hourly employees) included in the \$1M estimate above
	2008	6. Move Smart Program	This training and reinforcement program aims to “combat soft tissue and hand injuries, sprains, strains, cumulative trauma disorders, slips, trips, and falls” (http://www.movesmart.com/index.php?page=25&faq=13). The site initiated the training in 2008 and it has been completed by every employee.	Training	\$1M
	2010	7. Fatigue Management	In 2010, the mine site enhanced their existing fatigue management system by installing “Seeing Eye” machines in their haul trucks and utilizing a swipe card system to increase accountability of employees on site.	Safety management	No cost data available
B	1999	8. Surveyors of Safety	This employee-based safety program provided training for the work crew, and was fully customizable to their needs. The focus of the program was the reduction of all injuries.	Behavior	\$143,976–\$225,904
		9. Five-Point Card	On the basis of the Five-Point Safety System created by Neil George in 1942, the five-point card is used by the supervisor as he checks on work crews and by the workers themselves as they travel to their workplace and conduct their assigned work activities. Partner B initiated this program in 2000 with a second roll-out in 2002. The five steps are: 1. Check entrance and travelway to workplace 2. Are workplace and equipment in good working order? 3. Are employees working properly? 4. Do an act of safety 5. Can and will employees continue to work properly? When used properly, the five-point card helps supervisors and workers identify and control hazards, and is a cornerstone of developing good safety habits.	Behavior	\$1.2M–\$2.2M
	2003	10. Field Level Risk Assessment	A way to identify hazards and mitigate the risks associated with those hazards at the job site before beginning any task, by answering these five questions: 1. What am I doing? (what is the task) 2. What could go wrong? (what are the hazards) 3. How can it affect me or others? 4. How likely is it to happen? 5. What can I do about it? These are done for each new task or when something changes in the task at hand	Safety management/ Behavior	Approximately \$4,500.00 on mine site; however, this was an initiative that started at the corporate level and these costs have not been estimated.

(Continued on next page)

TABLE 1. (Continued)

Partner	Year	Intervention Number and Name	Description	Type	Estimated Implementation Cost
C		11. Team Risk Assessment	The same as a Field Level Risk assessment, this is completed with two or more people at the job site, which allows for more than one set of eyes to see the hazards associated with the task.	Safety management/ Behavior	Minimal
	2001	12. Plant Modernization	New single kiln process built, replacing the three existing kiln processes. Total plant capacity is increased while drastically reducing plant emissions, power consumption, and exposure points.	Engineering control	\$125M
	2002	13. Control Center built	Circa 2002, the mine built a brand new control center where all mission critical equipment, operations, and activities were monitored. The system allows controllers to see all areas of the mining operations and monitor key safety and productivity metrics throughout the plant.	Engineering control	\$200,000
	2004	14. Proactive Updating of SOPs	SOPs are updated on a regular basis	Safety Management	\$2,000
	2005	15. Lift Assist Equipment	Purchased drum carts and lifts, pallet jacks and lift gates for pickup trucks, which directly affected 15–20% of the workforce at the time of implementation.	Engineering control	Approx. \$50,000
		16. SLAM Training	SLAM RISKS is an informal pre-task risk assessment exercise developed by MSHA to increase situational awareness of miners and to control and/or mitigate hazards before beginning work.	Behavior	\$15,000
	2006	17. Job Safety Analysis	JSA's introduced to the workforce and required for critical tasks	Safety management/ Administrative control	No cost data available
	2007	18. Warehouse Modernization	New warehouse built and modernized shelving/storage plan implemented	Engineering control	\$1.2M
D	2003	19. Behavioral-Based Safety	A program that involved structured observations of employee body use, behaviors, ergonomics and positioning while performing work tasks. Observations are voluntary and miners would have to ask permission to observe fellow miners. Observations would be recorded on an observation form and submitted to the BBS administrator. The observed employee would receive immediate feedback. No names are used and no blame is assigned to any faulty behaviors observed (“No Name No Blame” rule). The miners reported that immediate feedback on safe work behaviors was key to its success. The miners would discuss the outcome of the safety checklist and identify areas of improvement. Checklists were submitted to a central safety office for review.	Behavior	\$531,308–693,440
	2010	20. Human Performance Improvement Program	Human Performance Improvement is characterized as a human error reduction program, involving a suite of tools to reduce the generation of situations where human errors are likely (ie, error-likely situations). The tools include pre-job briefings where a team based informal risk assessment is conducted; potential hazards and are identified, reported and mitigated. When incidents do occur, incident investigations are conducted to identify the systematic flaw which allowed the event to occur. Employees are also encouraged and advised to stop all work processes whenever an unsafe situation may arise. Postjob reviews are conducted to discuss the day's activities and lessons learned.	Behavior	\$304,700–\$409,500

TABLE 2. Change Points Detected by Partner Mine and Injury Type, 1990–2013

Injury Type	Partner	Change Point (s)	Change Direction	Prechange Rate*	Postchange Rate*	Difference	Corresponding Intervention
All injuries	A	1990 Q2	↑	4.589	2.695	–1.893	N/A
	B	2000 Q3	↑	6.576	2.261	–4.314	Intervention 8, 9
	C	1999 Q4	↓	9.908	20.887	10.979	N/A
		2005 Q4	↑	20.887	8.780	–12.107	Intervention 14, 15, and 16
	D	1992 Q3	↓	5.056	20.853	15.798	N/A
		1993 Q1	↑	20.853	5.137	–15.716	N/A
		2003 Q2	↑	5.137	2.653	–2.485	Intervention 19

*Rate per 200,000 work hours.

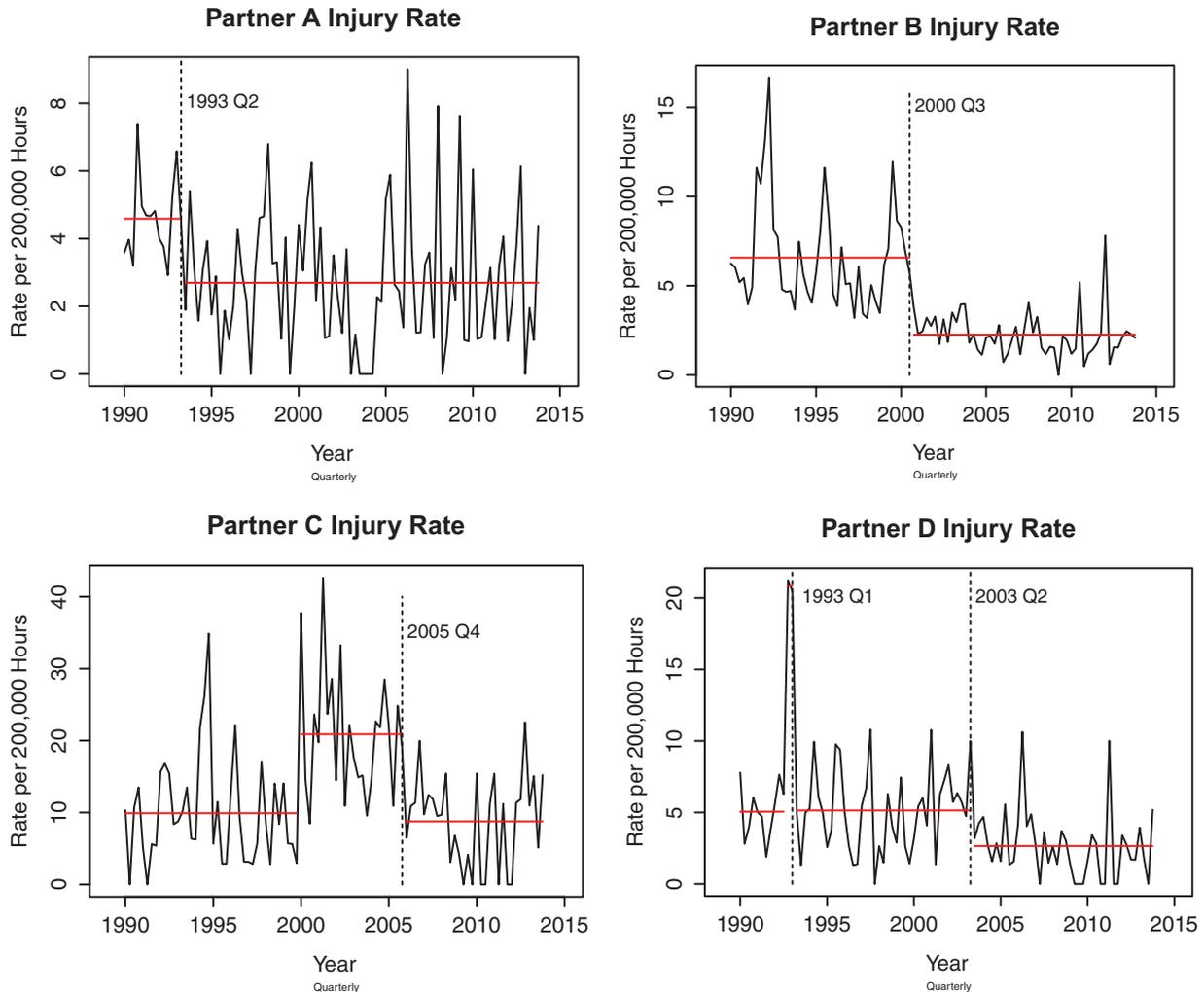


FIGURE 1. Change points for all injury rates for each mine partner operation. Dashed lines indicate decreasing change point.

modernization of the plant in 2001/2002 (Interventions 12 and 13), lift assist equipment (Intervention 15), and warehouse modernization (Intervention 18) in 2007, which automated a large portion of the bagging operation. Partner D reported two interventions; the “Behavioral Based Safety” program (Intervention 19; 2003), which focused on peer work observations and a “Human Performance Improvement Program” (Intervention 20; 2010), which focused on error reduction.

Table 2 summarizes the change points for each partner mine operation for all injuries. Partners A, B, and C had one significant decreasing change point each while partner D had two. For all mine partners, the decreasing change points occurred before 2005. For Partner A, there were no corresponding interventions implemented during or before the identified change point in 1990. For Partner B, there was a significant decreasing change in injury rates around 2000, corresponding to the implementation of Interventions 8 and 9. Partner C had a change point in 2005 coincident with their implementation of Interventions 14, 15, and 16. Partner D had a significant decreasing change point in 2003 coincident with Intervention 19 (Fig. 1). For lost time injuries, there were more identified change points, but only Partner A’s Intervention 1 in 2002 Q4 corresponded an identified change point (pre-change rate = 0.377; postchange rate = 0.000; difference = -0.377) (Fig. 2).

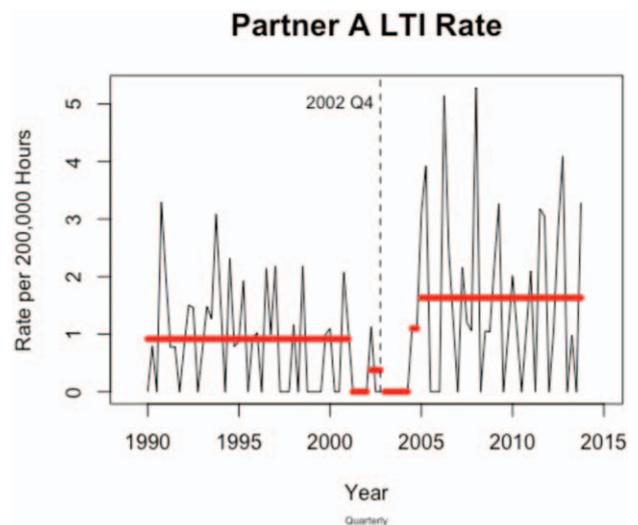


FIGURE 2. Change points for lost-time injury rate for Partner A. Dashed lines indicate decreasing change point.

TABLE 3. ROI Results

		Partner A	Partner B	Partner C	Partner D
	Intervention and Year Implemented	Intervention 1 (2002)	Intervention 8 (1999) and 9 (2000)	Intervention 14 (2004), 15, and 16 (2005)	Intervention 19 (2003)
a	Estimated cost of implementation	\$1M (2002) \$1,317,493 (2015)	\$225,904 and \$2.2M Total = \$2.4M (2000) \$3,196,112 (2015)	\$2,000, \$50,000 and \$15,000 Total = \$67,000 (2005) \$81,311 (2015)	\$693,440 (2003) \$893,244 (2015)
b	Pre-intervention annual average injury frequency (mean, sd)	25.3 (5.5)	18.9 (2.6)	17.9 (2.1)	14.7 (1.9)
c	Annual cost of injury – preintervention (b*\$150,861)	\$3,816,783	\$2,851,273	\$2,700,412	\$2,217,657
d	Pre-intervention years	12 (1990–2001)	9 (1990–1998)	14 (1990–2003)	13 (1990–2002)
e	Postintervention annual average injury frequency (mean, sd)	6.3 (1.0)	8.9 (1.8)	6.7 (1.3)	9.6 (1.3)
f	Annual cost of injury – post intervention (e*\$150,861)	\$950,424	\$1,342,663	\$1,010,769	\$1,448,266
h	Annual injury cost savings (c-f)	\$2,866,359	\$1,508,610	\$1,689,643	\$769,391
i	5 years				
	Undiscounted benefits (h*5 years)	\$14,331,795	\$7,543,050	\$8,448,215	\$3,846,955
	Discounted benefits	\$12,575,322	\$6,618,591	\$7,412,821	\$3,375,481
	ROI	854%	107%	9,017%	278%
j	2 years				
	Undiscounted benefits (h*2 years)	\$5,732,718	\$3,017,220	\$3,379,286	\$1,538,782
	Discounted benefits	\$5,545,199	\$2,918,526	\$3,268,749	\$1,488,448
	ROI	321%	–9%	3,920%	67%
k	1 year				
	Undiscounted benefits (h*1 year)	\$2,866,359	\$1,508,610	\$1,689,643	\$769,391
	Discounted benefits	–	–	–	–
	ROI	118%	–53%	1,978%	–14%

Notes: (1) Results of the change point analysis revealed reductions in the rate of all injuries that corresponded with the implementation of a health and safety program at partners B, C, and D; Partner A experienced a reduction in the lost-time injury rate only.

(2) Program implementation cost estimates were provided by the partner mines who were coached by the study team members to fully consider costs including indirect costs; the values they provided were used in the calculations without revision.

Return on Investment

Partner mines estimated the costs of implementation for seven programs. Inflation-adjusted, estimated implementation costs ranged from a low of \$81,311 for Partner C’s Interventions 14, 15 and 16, to a high of \$3.2M for Partner B’s Interventions 8 and 9 (Table 3). Partner D had the lowest average annual number of injuries (14.7) with an annual cost of injury in the pre-intervention period of \$2.2M. Partner A experienced an average of 25.3 injuries per year in the pre-intervention period with an annual pre-intervention injury cost of \$3.8M (Table 3). In the postintervention period, the average number of injuries ranged from 6.3 at Partner A to 9.6 at Partner D. Annual postintervention injury costs ranged from a low of \$950,424 at Partner A to a high of \$1.4M at Partner D. Five-year undiscounted injury cost savings ranged from \$7.7M at Partner D to \$28.7M at Partner A. Discounted cost savings are presented in Table 3. Discounting reduced the 5-year injury cost savings to a range of \$3.4M at Partner D to \$12.6M at Partner A. The ROI was calculated on the basis of the 7% discounted injury cost savings and ranged between 107% for Interventions 8 and 9 programs at Partner B and 9017% for Interventions 14, 15, and 16 at Partner C, over 5 years. Intervention 19, implemented by Partner D, had a 5-year ROI of 278%.

DISCUSSION

The current study evaluated RM interventions at four U.S. mine sites, and identified seven interventions temporally associated with a reduction in injury rates and a positive ROI. Of the seven interventions, six were behavioral-based safety interventions, rather than engineering or administrative controls. The MSHA SLAM program was implemented by two of our partner mines. The SLAM program is a method of training basic risk assessment techniques to front-line workers and mine managers.¹⁰ Similarly, the safe work observations intervention implemented by Partner A encourages peers, supervisors, and safety staff to intervene and remind people about “stop work” empowerment if activities appear unsafe. Partner B’s Five-Point Card program is used by supervisors to check work crews, and by the workers themselves before, and during, assigned work activities. When used properly, Partner B employees believe the five-point card helps supervisors and workers identify and control hazards, and has been a cornerstone of developing good safety habits within their organization. Partner D’s Behavior-Based Safety program involves structured observations of employee body use, behaviors, ergonomics, and positioning while performing work tasks. The miners at Partner D reported that immediate feedback on safe work behaviors is key to this program’s success.

Behavior-based safety interventions that improve safety climate and reduce negative attitudes, job dissatisfaction, and risk-taking behaviors may be key to achieving further reductions in injury rates, beyond what has already been achieved with engineering and administrative controls.^{11–13}

One important consideration when interpreting the results of the current study is the range of time periods for the postimplementation injury prevention and accrual of economic benefits for the RM interventions. Our partner mines indicated that they believed the benefits of their safety programs continued on to the present. However, to be conservative, a more limited set of time periods was explored, ranging from 1 to 5 years. Results of this analysis showed that the ROI was positive in all time periods greater than 2 years. Similarly, the cost of injury could have been estimated in several different ways. A weighted average of the cost of fatality or serious injury (\$6.5 M) and less severe injury (\$42,000) was selected based on the frequency of each reported by Gowrisankaran et al.⁸ Alternatively, other estimates of injury costs reported in the literature could have been used in this analysis. For example, Gallagher et al.¹⁴ found that the average cost of a workers' compensation claim for injury at eight mines ranged from \$5,600 to \$24,600 (May 2008 dollars) over time periods ranging from 6 to 14 years. These estimates, however, do not include uninsured losses suffered by the employee or employer or societal costs. Research in industry has shown indirect or uninsured costs to be up to four times the firm's direct cost of injury^{15,16} and up to 3.5 times the medical costs of injury¹⁷ meaning the claims cost likely underestimates the true cost of injury. The National Safety Council estimates the costs of medically consulted injuries to be \$42,000 and occupational fatalities to be \$1,450,000.⁹ Using these figures to calculate a new weighted average, using the frequency estimations found in Gowrisankaran et al.⁸ yields a much lower estimated cost of injury, \$65,734. In a sensitivity analysis, this lower cost of injury yielded 5-year 7% discounted cost savings ranging from \$1.5 M at Partner D to \$5.5 M at Partner A. Further, using the lower cost of injury, three of four partner mines had positive 5-year ROIs ranging from 65% to 3872%; Partner B's intervention ROI was -10% using the lower cost of injury. Therefore, while the cost of injury is an important assumption, it does not appear to be driving the estimation of ROI in this study.

The change point analyses allow evaluation of the most likely time period at which an intervention resulted in an impact, thus allowing for the possibility that interventions had a delayed impact. These analyses do not directly allow consideration of the possibility that interventions would "bend the curve" of injuries, but presenting the raw data in the graph allows readers to visually consider this possibility. Some identified change points may therefore not necessarily be indicative of an effective RM program, and may be due to unrelated causes (eg, change in injury reporting) or secular trends. For instance, Partner C saw a significant increase in all injuries beginning in 2000 (between 2000 and 2005) and a subsequent reduction to pre-2000 levels after 2005. Although this coincided with the implementation of SLAM training and proactive SOP updates at the mine, this could also have been caused by a regression to the mean or residual/lagging effects from previously implemented interventions. However, our mine partners provided a census of safety interventions they implemented, and it is reasonable to assume that all interventions are accounted for and interventions effects occur within several years.

Given the large number of interventions and the lack of complete data particularly for older interventions with which the mine personnel were not fully familiar, full descriptions and implementation costs for all the interventions were not available. Another important limitation of the current study is that potential confounding factors cannot be accounted for within our partner mines or the comparison mines, including organizational and personnel changes,

policy or enforcement changes, technological or equipment improvements, or broader economic influences. Further, the potential benefits of concurrent RM interventions cannot be separated with the current study design. These limitations highlight the need for prospective studies in this subject area that rely on leading indicators such as peer observations of safety performance. Future research in this area may also benefit from greater structure in the data acquisition process, which could be accomplished by using structured, scripted interviews. Unfortunately, this was not possible in the current study, as we conducted unstructured interviews in a variety of settings (individual and group meetings, conversations during facility tours, etc). Our partner mines were unable to provide us a full accounting of safety-related expenditures, including technology and equipment improvements, worker training, consultant fees, etc. Ideally, the direct and indirect costs of the overall safety and health programs would have been included in the ROI calculations and validated using financial records from the mining operation; this should be a consideration in future studies. Assessment of potential changes in productivity associated with the RM interventions, inclusion of which might affect total ROI, was not included in the current study. Finally, we were unable to describe specifically which risks and/or hazards the interventions were aimed to reduce. For some interventions, the likely presumed intent is clear (eg, lift assist equipment, fatigue management), but for other interventions, the intent is less focused and therefore not obvious. When asked, our mine partners told us repeatedly that interventions were intended to reduce all hazards and prevent injuries of all type. It may be possible in future research, especially prospective studies, to better describe the intention behind each intervention.

The identification of best practices in this study may be helpful to other mining sites and adoption of these interventions and/or RM programs may lead to decreases in injury and positive economic returns. However, results of the current study may not be generalizable to all U.S. mines. Three of the four partner mines were owned by large, multinational companies. Research has shown that larger mines are safer than smaller mines, and that mining corporations with diverse mine operations have lower injury rates than more narrowly focused corporations.¹⁸

CONCLUSION

Twenty RM interventions were identified, including behavioral and educational interventions focused on general safety, policy and administrative interventions, and engineering controls, at U.S. mining companies representing the coal, metal/nonmetal, and aggregate sectors. Of these interventions, seven were associated temporally with a reduction in injury rate and a positive ROI. Future research in this area should work with partners to implement specific RM practices in order to isolate the effect of different practices using a prospective study design. The methods used in the current study, including the estimation of ROI, may be useful to safety professionals seeking to estimate the economic returns of specific safety interventions. The identification of effective interventions may lead to broader adoption of interventions associated with a reduction in injuries and a positive economic return on investment.

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