1st Solicitation for Single Investigator Research Grants (AFC113)

ALPHA FOUNDATION FOR THE IMPROVEMENT OF MINE SAFETY AND HEALTH

Final Technical Report

1.0 Cover Page

Project Title: Implementation of Risk Management Programs: Identification of Best Practices to Reduce Injuries and Maximize Economic Benefits

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Principal Investigator: Jefferey L. Burgess, MD, MS, MPH

Contact Information: Email: jburgess@email.arizona.edu

Phone: 520-626-4918

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Acknowledgment/Disclosure

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2.0 Executive Summary:

Despite improvements in health and safety, mining remains a dangerous profession. Risk management (RM) is a cyclical process of identifying activities at high risk for injuries, redesigning procedures to reduce risks, implementing these changes and evaluating their effectiveness. Formal risk management is a legal requirement in many countries but in the United States (U.S.), safety and health regulations are generally compliance- rather than risk-based. In prior research, adoption of risk management 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 U.S. coal industry over the same time period (Poplin et al., 2008). However, there is currently insufficient information on how risk management can most optimally be utilized in U.S. mines, and an economic analysis of risk management programs is needed to evaluate return on investment (ROI) and guide mine adoption decisions.

Our study evaluated the effectiveness of risk management interventions in reducing injuries and economic costs in the partnering mining operations. We hypothesized that following introduction of formal risk management programs, injury rates would decrease in mines compared with the pre-intervention rates and compared to all other U.S. mines in the same sector. We also hypothesized that the individual RM interventions would have a positive economic return on investment (ROI).

Partner mines included a convenience sample of four U.S. sites with extensive risk management expertise, representing metal, non-metal (aggregate) and coal sectors. Site visits and face-to-face interviews were conducted, during which time interviewees described all interventions implemented and year of implementation since 1990. Publicly available injury data from MSHA's Accident, Injury and Illness files were analyzed to identify statistically significant changes (increases/decreases) in longitudinal injury rates. To assess the effect of risk management on injury rates for each of our partner mines, we compared their 25-year injury rates to mines of similar employee size (and also to total coal production, for coal mines only) using MSHA data. Partner mines estimated the costs of program implementation for interventions subjectively identified as the most impactful, and the cost of injury was estimated from the literature, enabling calculation of the ROI. RM intervention "best practices" were associated with a reduction in injury rates and positive ROI.

Reductions in injuries were observed following implementation of RM programs at our partner mines, and lost-time injury rates were generally lower at our partner mines than comparison mines. A total of seven best practices interventions were identified, with ROIs ranging from 183% to 104,061%.

In addition to these findings, our project website also has valuable information for small mines (http://mining.publichealth.arizona.edu/risk-management). Small mines, which often have the greatest need for improved SHMS and the most limited resources, need information on how best to implement formal risk management programs. We helped to address this need by providing detailed checklists on critical risks and controls, tailored to the needs of small mines, to assist them in making decisions on the most important and effective changes to make initially.

The results of the current study provide a business case to help convince management to implement risk management interventions and to choose among the most effective interventions. We expect the study results will be used throughout the mining industry to aid in the selection of

effective injury-prevention interventions with positive economic returns.

3.0 Problem Statement and Objective

Mining remains a dangerous profession, with over 370 fatalities reported since 2006 and 2.56 to 3.64 injuries/200,000 work hours annually (http://www.msha.gov/MSHAINFO/FactSheets/MSHAFCT10.HTM). Proactive risk management (RM) is a central component of safety and health management systems (SHMS) involving a cyclical process of identifying operations or activities at high risk for injuries, redesigning operating procedures to reduce risks, implementing these changes and evaluating their effectiveness. Internationally, formal risk management is a legal requirement in many countries. In the United States (U.S.), safety and health regulations are generally compliance rather than risk based. There are very few peer-reviewed published studies on the effectiveness of RM. We have previously shown that implementation of RM by legislative mandate in Australia was associated with a marked reduction in coal mining injuries (Poplin et al., 2008). In addition, within select U.S. mines, the National Institute for Occupational Safety and Health (NIOSH) found that use of Major Hazard Risk Assessment was associated with reduced injuries (Iannacchione et al., 2008). However, a major gap exists in regards to the determination of the effectiveness of specific RM interventions, particularly in U.S. mines. This information would help identify RM best practices for SHMS and also demonstrate methods for assessing safety and health program effectiveness.

The current study addressed the following Alpha Foundation Call for Concept Papers focus areas in the Safety and Health Management Systems (SHMS) and Injury and Illness Prevention Programs sections:

- *Risk management integration and decision-making, including a data collection protocol for evaluating a risk-based surveillance program that can be used to assess management practices.*
- *Mine audits and resulting empirical data to identify and define existing SHMS practices and measure correlations between accident rates and existing practices.*
- *Relevance to mining of best practices demonstrated to be effective in other settings.*
- *Research on the minimum set of key elements (e.g., management leadership, worker participation, hazard identification, hazard prevention and control, education and training, program evaluation and improvement, etc.) that are appropriate to the mining environment.*
- *Methods development for assessment of safety & health program effectiveness and validation of those methods through evaluation of programs already in operation in the mining sector.*

The objective of the study was to determine the effectiveness of RM interventions in reducing injuries and economic costs in the U.S. mining industry. The project specific aims were as follows: 1) Evaluate current risk management implementation in the U.S. mining industry; 2) Determine intervention ROI and risk management best practices; and 3) Share risk management tools through a dedicated website.

4.0 Research Approach

Data acquisition

Partner mines included a convenience sample of four U.S. sites with extensive risk management expertise, representing metal, non-metal (aggregate) and coal sectors. Site visits and face-to-face interviews were conducted and included safety managers and frontline miners. Interviewees described all interventions implemented and year of implementation since 1990. At all mine sites, access to employees with a long employment history was provided. A census of interventions was collected, with interviewees identifying those perceived of greatest impact. Mine site observations of implemented interventions were conducted at each operation by University of Arizona researchers. Publicly available injury data from MSHA's Accident, Injury and Illness files were used, excluding any reported administrative injuries and reported incidents resulting in no injuries. Lost time injuries were defined as injuries resulting in at least one day of lost work.

Effect of RM on injury rates

MSHA quarterly employment data from 1990 through 2013 were downloaded, including number of hours worked per calendar quarter. Injury and employment datasets were merged for calculating 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 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 analysis was used to identify statistically significant changes (increases/decreases) in the longitudinal injury rates. Change point analyses is used to detect the time point in where there is a significant change in the statistical properties of an ordered sequence of observations, such as time series data (Killick and Eckley, 2014). Using the 'changepoint,' statistical package in R, we used the binary segmentation algorithm to detect the change points in our partner mine injury rate time series, which begins by applying a change point statistic to the entire data and splitting the data into two segments if there is a detected change point. The algorithm is repeated on the resulting two segments until no new change points are identified. To minimize the potential for over identifying the number of change points, a penalty value can be used to reduce the sensitivity of the change point algorithm. We plotted the number of change points identified by p-values ranging from 0.001 to 1 to identify penalty values that produced a stable number of change points and decided to use a penalty value of $p=0.10$. We then plotted the longitudinal injury rates of each partner mine operation and indicated when significant decreasing change points were detected for all injuries and for lost-time injuries only. Congruence of intervention implementation timelines obtained through the face-to-face interviews to longitudinal injury rates was then assessed. Interventions that were implemented within 0-1 year prior to the identified downward changepoint were attributed to that changepoint, which assumes that intervention effects would be positive (decreasing injury rates) and that effects of interventions would occur within a year of implementation.

Comparison to other U.S. mines

To assess the effect of risk management on injury rates for each of our partner mines, we compared their 25-year injury rate to mines of similar employee size (and also to total coal production, for coal mines only) using MSHA data. For each mine partner, analysis was restricted to miners (non-administrative employees) and injury rates were calculated using mine hours (i.e.

total annual hours minus administrative hours). Mines reporting zero or missing hours and/or employees were excluded, as they were indicative of non-operating/closed mines. Comparison mines were restricted to mine type(s), product type(s), MSHA jurisdictional district(s), and standard industrial code(s). Injury records were collapsed by year and mine, such that the unit of analysis became a "mine year." Annual injury rates for each mine operation were calculated as the sum of injuries by year divided by the total number of mine hours worked. To calculate the 25-year injury rates for each mine partner, the total number of injuries for all operations were summed and divided by the total number of mine hours between 1989 and 2013.

Differences in estimated mine year injury rates and lost time injury rates were estimated with propensity score matching, using the 'Treatment Effects' (teffects) package in Stata 14 (StataCorp, 2015). The average treatment effect was estimated, representing the average difference in "mine year" injury rate between partner mines and matched comparison mines, by mine hours, number of miners, production (coal mines only), number of years in operation, and year of operation using a logit propensity score matching method (Abadie, 2004; Abadie 2009; Austin, 2011). Three of the most similar external (non-partner) mine year were matched to each partner mine year and comparison mine year. Analysis was done with a log plus one transformation of rates, as well as untransformed rates.

Return on Investment and Best Practices

Partner mines estimated the costs of program implementation for identified interventions. 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 1,231/73,027 (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 (Gowrisankaran et al., 2015). The authors used a value of $6.5M to estimate the cost of a fatality, and the National Safety Council's 2014 estimate for the average cost of an injury requiring medical treatment, $30,000 (Gowrisankaran et al., 2015), was used to estimate the cost of less severe injuries. For the current study, we used the National Safety Council's 2015 average cost of a less severe injury resulting in days away from work with or without restricted duty, $42,000 (National Safety Council, 2015). Using the injury frequency figures presented in Gowrisankaran et al. (2015), the weighted average of the $6.5M cost of severe injury and the $42,000 estimated cost of a less severe injury is $150,861.

The cost of injuries pre- and post-intervention was then estimated by multiplying the annual average number of injuries by the number of years in each period and the weighted average cost of injury ($150,861). The costs of injury in the pre- and post-intervention periods were then discounted at rates of 3, 7 and 10% using the formula, discounted present value = future value / (1 + r)n where r=discount rate (3, 7 or-10%) and n = years of accrued benefit (Eq. (1)). The benefits of the RM programs were estimated using the difference between the discounted total pre- and post-intervention injury costs. ROI was then calculated as [(injury cost reduction – RM program costs)/RM program costs]*100 (Eq. (2)). RM intervention "best practices" were associated with a reduction in injury rates and positive ROI.

5.0 Summary of Accomplishments:

The partner mine operations were located in the West and Southwest U.S., as: Partner A (underground coal); Partner B (surface and underground metal); C (aggregate cement plant), and D (surface and underground coal). Risk management interventions included behavioral and educational programs focused on safety, policy, administrative, and/or engineering controls.

Summary of Intervention Efforts used at the Study Mines

Table 1 contains the list of risk management interventions identified. Partner A focused on risk assessment activities starting with MSHA Stop-Look-Analyze-Manage (SLAM) training and safe work observations in 2002. Partner B reported an emphasis on informal risk assessment activities using a "five-point card" system. The five-point card system was used as a reminder for miners to initiate an informal risk assessment in five specific domains prior to beginning work. . Mine partner C reported impactful engineering interventions, including a modernization of the plant in 2001/2002 and warehouse modernization in 2007 that automated a large portion of bagging. Partner D reported two behavioral based programs; a "Behavioral Based Safety" program (2003), that focused on peer work observations and "Human Performance Improvement Program" (2010), focusing on error reduction (see Table 1: Risk management interventions implemented by partner mines (1990-2013), below).

Partner	Year	Intervention	Description	Type	Estimated implementation cost
A	2002	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	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	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/#)	Behavior	$1M
	2007	HSE Peer Audit		Safety Management	
		Zero Incident Process Training (hourly)		Training	
	2008	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 has been completed by every employee.	Training	$1M
	2010	Fatigue Management			
B	1999	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
		Five Point Card	Based on 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 & travelway to workplace 2. Are workplace & equipment in good working order? 3. Are employees working properly? 4. Do an act of safety 5. Can & will employees continue to work properly?	Behavior	$1.2M - $2.2M

			When used properly, the five-point card helps supervisors and workers identify and control hazards, and is a cornerstone of developing good safety habits.		
	2003	Field Level Risk Assessment			
		Team Risk Assessment			
C	2001	Plant Modernization: Bagging operation	An automated packer-palletizer system, the Ventomatic, was installed in 2001, which approximately doubled productivity from an average of 600-700 bags per hour to 1300-1400 bags per hour. This system reduced the need for manual packing and likely had an impact on back injuries from manual lifting and carrying bags.	Engineering control	
	2002	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	
	2004	Proactive Updating of SOPs	SOPs are updated on a regular basis	Safety Management	$2,000
	2005	Lift Assist Equipment			
		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	Job Safety Analysis			
	2007	Warehouse Modernization			
D	2003	Behavioral Based Safety	A behavioral based safety 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	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 (i.e. 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. Post job reviews are conducted to discuss the day's activities and lessons learned.	Behavior	$304,700 - $409,500

Effect of RM on injury rates

Table 2 summarizes the change points for each partner mine operation. For all injuries, partner 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 their “Surveyors of Safety” and “Five-Point Card” system. Partner C had a change point in 2005 coincident with their implementation of their proactive SOP updating and SLAM training. Partner D had a significant decreasing change point in 2003 coincident with their “Behavioral Based Safety” program (Figure 1A). For lost time injuries, there were many more identified change points, but only one intervention (SLAM Training and Safe Work Observations) in Partner A corresponded to the identified change points. No other intervention was found to correspond with change points for lost time injuries (Figure 1B).

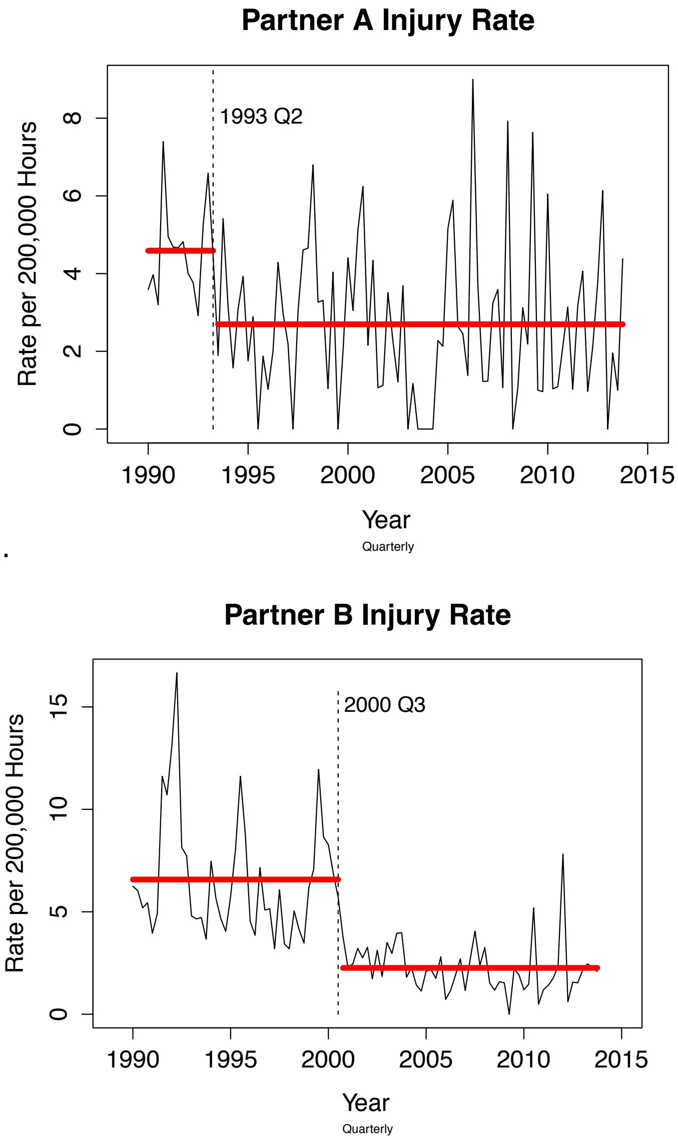
Table 2. Change points detected by partner mine and injury type, 1990-2013

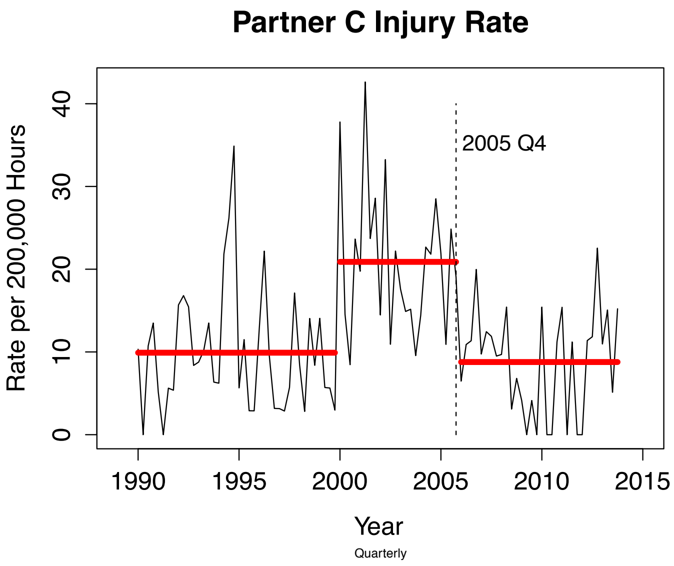
Injury Type	**Partner**	**Change Point(s)**	**Pre Change Injury Count**	**Post Change Injury Count**	**Pre Change Rate* , mean (var)**	**Post Change Rate*, mean (var)**	**Difference**	**Corresponding Intervention**
All Injuries	A	1993 Q2	82	220	4.589 (1.51)	2.695 (4.08)	-1.893	N/A
	B	2000 Q3	901	279	6.576 (8.87)	2.261 (1.62)	-4.314	Surveyors of Safety/ Five Point Card
	C	1999 Q4	127	176	9.908 (54.32)	20.887 (76.32)	10.979	N/A
		2005 Q4	176	71	20.887 (76.32)	8.78 (39.82)	-12.107	Proactive Updating of SOPs/ SLAM Training
	D	1992 Q3	57	35	5.056 (3.49)	20.853 (0.3)	15.798	N/A
		1993 Q1	35	153	20.853 (0.3)	5.137 (8.22)	-15.716	N/A
		2003 Q2	153	72	5.137 (8.22)	2.653 (5.63)	-2.485	Behavioral Based Safety
Lost Time Injuries	A	2001 Q1	47	0	0.918 (0.83)	0 (0)	-0.918	N/A
		2002 Q1	0	1	0 (0)	0.377 (0.43)	0.377	N/A

		2002 Q4	1	0	0.377 (0.43)	0 (0)	-0.377	SLAM Training/ Safe Work Observations
		2004 Q2	0	2	0 (0)	1.101 (0.0027)	1.101	N/A
		2004 Q4	2	56	1.101 (0.0027)	1.632 (2.42)	0.53	N/A
	B	1992 Q4	137	80	4.139 (2.38)	1.911 (1.14)	-2.228	N/A
		1995 Q4	80	108	1.911 (1.14)	0.649 (0.23)	-1.261	N/A
		2010 Q2	108	8	0.649 (0.23)	1.545 (4.75)	0.896	N/A
		2011 Q1	8	8	1.545 (4.75)	0.469 (0.18)	-1.076	N/A
	C	1995 Q1	49	0	2.296 (9.19)	0 (0)	-2.296	N/A
		2001 Q1	0	48	0 (0)	3.051 (11.71)	3.051	N/A
	D	1990 Q4	0	3	0 (0)	0.964 (0.001)	0.964	N/A
		1991 Q3	3	17	0.964 (0.001)	3.247 (12.86)	2.282	N/A
		1993 Q1	17	3	3.247 (12.86)	1.277 (0.001)	-1.97	N/A
		1993 Q4	3	24	1.277 (0.001)	0.407 (0.58)	-0.87	N/A

* Rate per 200,000 work hours

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




Partner C Injury Rate
Rate per 200,000 Hours
0
10
20
30
40
2005 Q4
1990
1995
2000
2005
2010
2015
Year
Quarterly

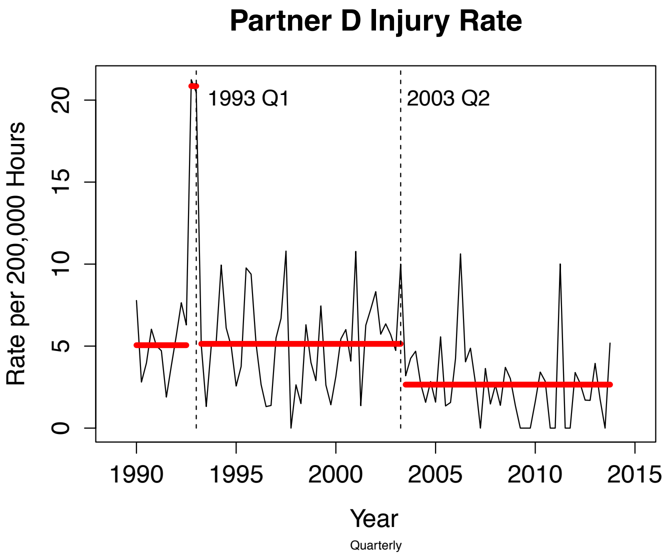
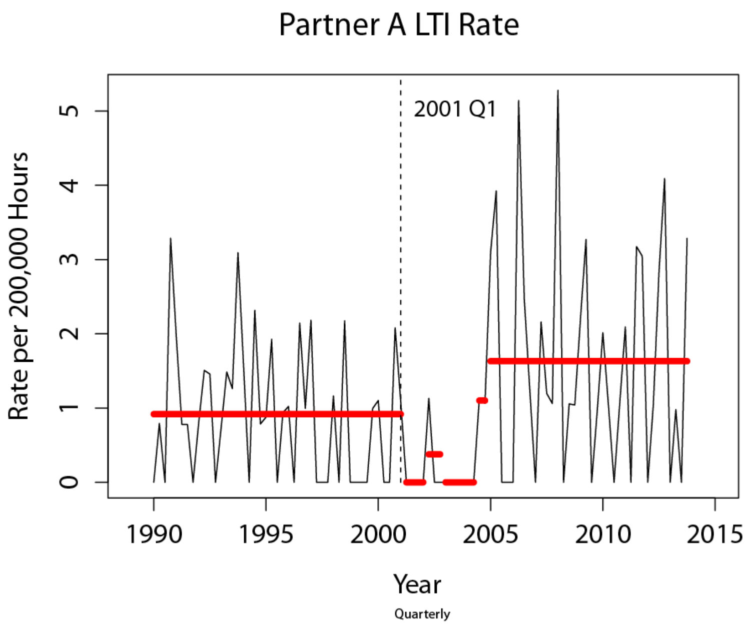
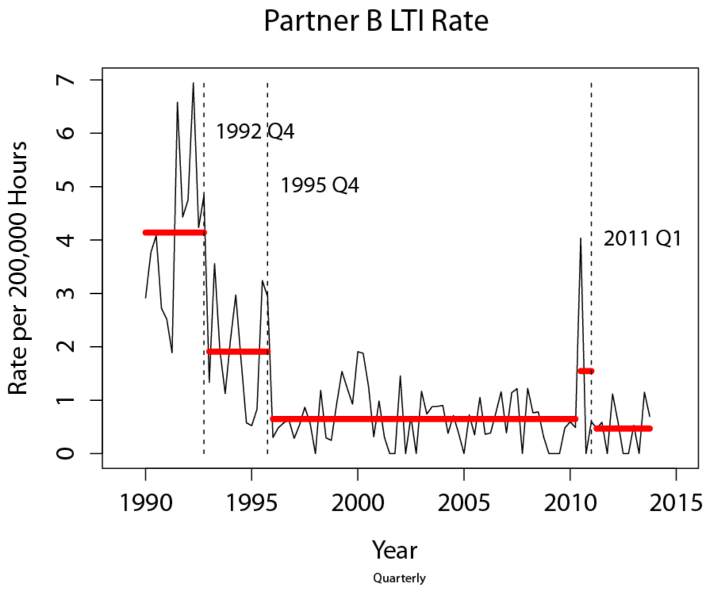
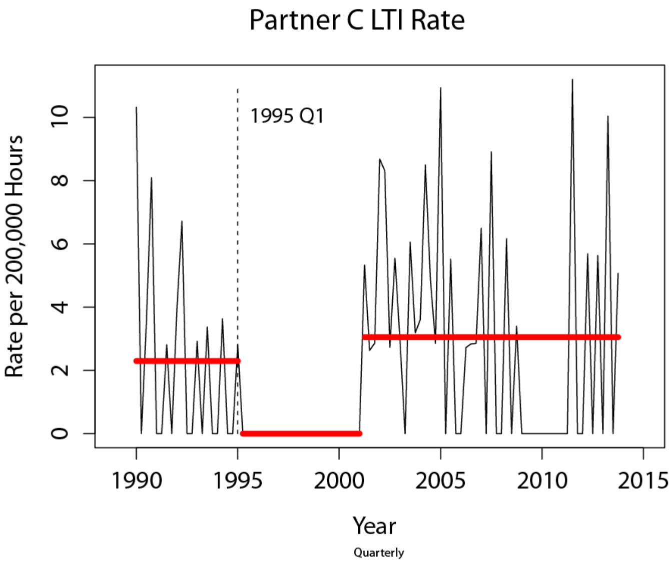
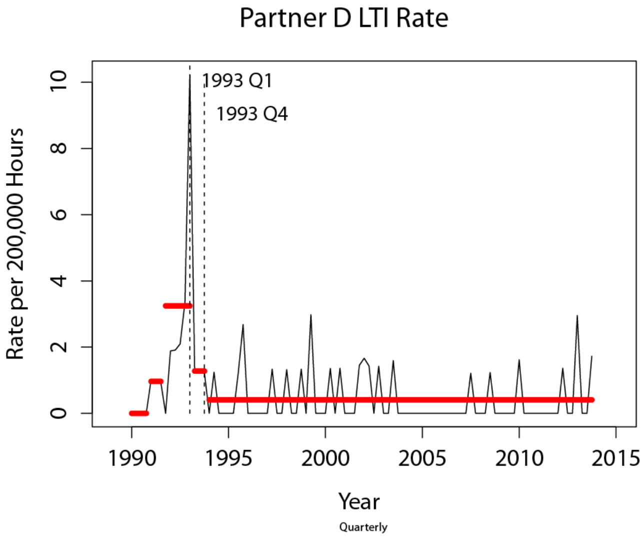

Partner D Injury Rate
Rate per 200,000 Hours
0
5
10
15
20
1993 Q1
2003 Q2
1990
1995
2000
2005
2010
2015
Year
Quarterly

Figure 1B. Change points for lost time injury rates for each mine partner operation. Dashed lines indicate decreasing change point.









Comparison to U.S. mines

Between 245 and 807 mines were available for matching after applying our defined restriction criteria. On average, the comparison set had fewer annual miners employed and mine hours reported than partner mines.

Table 3A. Summary of Partner Mines and Their Comparison Set. United States, 1989-2013.

	Comparison	**Luminant**	**Comparison**	**BHP**
N Mines	484	9	245	4
Annual Miners Employed, mead (sd)	99.82 (154.46)	235.8 (150.49)	149.44 (167.35)	282.03 (122.87)
Annual Mine Hours (thousands), mean (sd)*	207.95 (325.48)	498.24 (312.48)	310.71 (352.18)	595.77 (260.45)
Annual Production (millions), mean (sd)**	3.93 (10.55)	3.95 (2.24)	5.24 (11.34)	5.19 (2.93)
Total Injuries	11029	1729	18947	782
Total Lost Time Injuries	5052	264	8680	265
Injury Rate, rate (95% CI)†	3.45 (0.03,105.02)	4.06 (0.1,41.58)	4.79 (0.03,137.65)	3.75 (0.13,27.96)
LTI Rate, rate (95% CI)†	1.58 (0.02,71.08)	0.62 (0.04,16.25)	2.19 (0.02,93.17)	1.27 (0.08,16.28)

* Hours worked excluding administrative hours

** Only coal production data available (tons)

† Rates per 200,000 Mine Hours for all injuries between 1989 - 2013

Table 3B. Summary of Partner Mines and Their Comparison Set. United States, 1989-2013.

	Comparison	**Barrick**	**Comparison**	**SRMG°**
N Mines	807	3	263	1
Annual Miners Employed, mead (sd)	61.19 (131.88)	562.54 (461.99)	21.34 (33.08)	113.52 (18.22)
Annual Mine Hours (thousands), mean (sd)*	124.52 (283.22)	1188.56 (988.26)	41.69 (66.62)	243.22 (49.34)
Total Injuries	16363	1805	5517	392
Total Lost Time Injuries	5436	482	1628	73
Injury Rate, rate (95% CI)†	6.75 (0.05,127.92)	4.98 (0.12,42.49)	9.36 (0.13,74.28)	12.89 (0.65,19.8)
LTI Rate, rate (95% CI)†	2.24 (0.03,73.73)	1.33 (0.06,21.95)	2.76 (0.07,40.35)	2.4 (0.28,8.54)

* Hours worked excluding administrative hours

** Only coal production data available (tons)

† Rates per 200,000 Mine Hours for all injuries between 1989 - 2013

Comparing Injury Rates

All partner mines had 25-year injury rates lower than comparison sets, but none were statistically significantly lower. Twenty-five year injury rates varied across each partner and the comparison mines, with partner D having a 25-year injury rate of 3.95 injuries per 200,000 hours that was not significantly different from their comparison set (Difference in Injury Rates = -1.96, P=0.22). In this context, a P value is the probability of observing an injury rate difference as extreme or more extreme than observed. Typically, a 5% probability is a cut off to indicate that a measure of effect (in this case a difference in injury rates) is statistically significant. Because this P value is 0.22, would indicate observing a difference of -1.96 in mean injury rates would not be uncommon and could be attributed to random chance. Partner A had an injury rate of 3.75 per 200,000 hours and was lower than its matched comparison (Difference in Injury Rates = -1.88, P=0.25); however, not significantly so. Partner A had lower injury rates before 2000; however, rates have increased above its comparison set since 2001. Partner B had a 25-year injury rate of 4.98 injuries per 200,000 hours, which was lower than the comparison set. Partner C had 12.89 injuries per 200,000 hours, and mine year rates, which were higher than their matched comparisons (Difference in Injury Rates = 1.50, P=0.53), but the difference was not significant.

Table 4a. Propensity Score Matching Results. Coefficients Are Differences In **Rates** Per 200,000 Mine Hours. United States, 1989-2013. Propensity score matching with 3 nearest neighbors.

	All Injury Rate					**Lost Time Injury Rate**				
Mine Partner	**Coef**	**SE**	**P**	**95% CI**		**Coef**	**SE**	**P**	**95% CI**	
Partner A	-1.884	1.638	0.25	-5.09	1.33	-0.977	1.259	0.438	-3.44	1.49
Partner B	36.665	48.673	0.451	-58.73	132.06	-1.547	9.907	0.876	-20.97	17.87
Partner C	1.496	2.397	0.533	-3.20	6.19	-0.957	0.561	0.088	-2.06	0.14
Partner D	-1.960	1.612	0.224	-5.12	1.20	-2.377	0.416	<0.001	-3.19	-1.56

Table 4b. Propensity Score Matching Results. Coefficients Are Differences In **Log Rates** Per 200,000 Mine Hours. United States, 1989-2013. Propensity score matching with 3 nearest neighbors.

	All Injury Rate					**Lost Time Injury Rate**				
Mine Partner	**Coef**	**SE**	**P**	**95% CI**		**Coef**	**SE**	**P**	**95% CI**	
Partner A	0.148	0.265	0.575	-0.37	0.67	-0.098	0.273	0.72	-0.63	0.44
Partner B	2.134	0.656	0.001	0.85	3.42	0.592	0.726	0.415	-0.83	2.01
Partner C	1.276	0.198	<0.001	0.89	1.66	0.396	0.242	0.101	-0.08	0.87
Partner D	0.374	0.224	0.095	-0.07	0.81	-0.419	0.047	<0.001	-0.51	-0.33

Comparing Lost Time Injury Rates

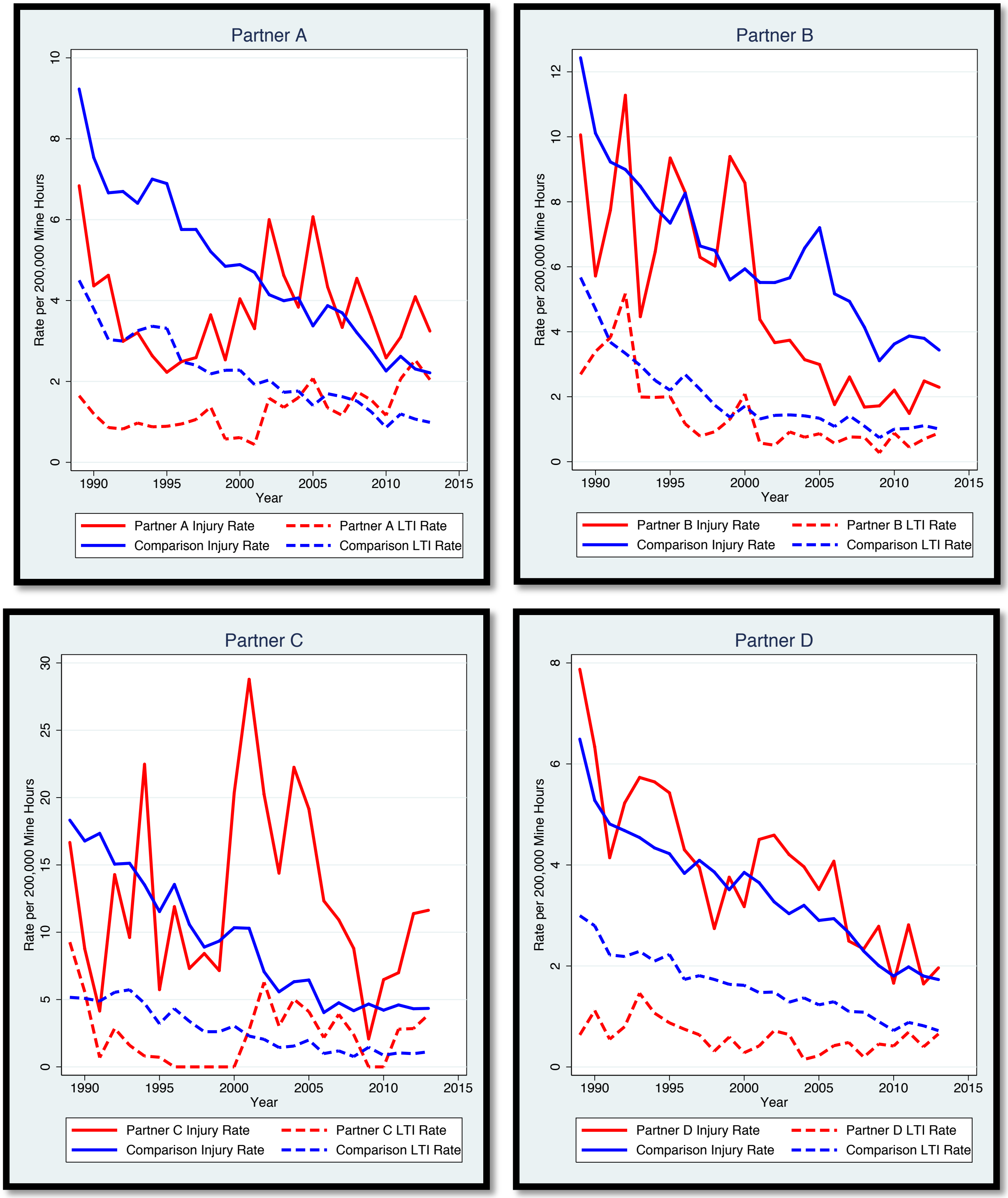
Our mine partner's lost time injury rates were generally lower than their respective comparison sets. Partner D had the lowest 25-year lost time injury rate of 0.62 injuries per 200,000; with their mine year injury rates significantly lower than the comparison set (Difference in Injury Rates = -2.38, P <0.001). From Figure 2, Partner D's lost time injury rate was lower than its comparison set since 1989. The other partners had lower lost time injury rates than their respective comparison set, but none were statistically significant.

Partner A had the second lowest 25-year lost time injury rate of 1.27 per 200,000 hours and mine year rates were lower than its comparison set (Difference in Injury Rates = -0.98, P = 0.44), but not statistically significant. BHP's lost time injury rate were lowest between 1989 through 2002, and has since have been in line with or exceeded the lost time injury rates of its comparison set (Figure 2). Both Partner B and Partner C had slightly lower 25-year lost time injury rates than their comparison sets, however their mine year lost time rates were not significantly different.

Analyzing Log Rates

The results the propensity score matching results using log (plus 1) of mine year rates yielded similar results (Table 4b).

Figure 2. Rates of all injury and lost-time injury at partner mines, 1989-2013



Return on Investment

Partner mines estimated the costs of program implementation for a total of seven programs. Estimated implementation costs ranged from a low of $17,000 for Partner C's proactive updating of SOPs and SLAM program to a high of $2.4M for Partner B's Surveyors of Safety and Five Point Card programs (Table 5). Partner D had the lowest average annual number of injuries (14.7) with a total cost of injury in the pre-intervention period of $28M. Partner A experienced an average of 25.3 injuries per year in the pre-intervention period with a total pre-intervention injury cost of $45M (Table 5). In the post-intervention period, the average number of injuries ranged from 6.3, at Partner A to 9.6, at Partner D. Post-intervention injury costs ranged from a low of $10M at Partner C to a high of $20M at Partner B. Total undiscounted injury cost savings ranged from $5.5M at Partner B to $34M at Partner A. Discounted cost savings are presented in Table 5. Discounting reduced the injury cost savings for all except Partner B, due to the long time period (15 years) and the significant reduction of injury in the post intervention period. The ROI was calculated based on the 7% discounted injury cost savings and ranged between 183% for the Surveyors of Safety and Five Point card programs at Partner B and 104,061% at Partner C. Best practices interventions were associated with a reduction in injury rate and a positive ROI and include SLAM training, Safe Work Observations, Surveyors of Safety, updating SOPs, the Five Point Card, and Behavioral Based Safety.

Table 5. ROI results

		Mine partner			
		A	B	C	D
	Intervention and year implemented	SLAM Training and Safe Work Observations (2002)	Surveyors of Safety (1999) and Five Point Card (2000)	Proactive Updating of SOPs (2004) and SLAM Training (2005)	Behavioral Based Safety (2003)
a	Estimated cost of implementation	$1M	$225,904 and $2.2M Total = $2.4M	$2,000 and $15,000 Total = $17,000	$693,440
b	Annual average injury frequency (mean, sd) (pre-intervention)	25.3 (5.5)	18.9 (2.6)	17.9 (2.1)	14.7 (1.9)
c	Total annual cost of injury – pre intervention (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	Total cost of injury – pre intervention (c*d)	$45,801,400	$25,661,456	$37,805,767	$28,829,537
f	Annual average injury frequency (mean, sd) (post-intervention)	6.3 (1.0)	8.9 (1.8)	6.7 (1.3)	9.6 (1.3)
g	Total annual cost of injury – post intervention (f*$150,861)	$950,424	$1,342,663	$1,010,769	$1,448,266
h	Years of accrued benefit	12 (2002-2013)	15 (1999-2013)	10 (2004-2013)	11 (2003-2013)
i	Total cost of injury – post intervention (g*h)	$11,405,088	$20,139,944	$10,107,690	$15,930,926
j	Total (undiscounted) injury cost savings [(i-e)*(-1)]	$34,396,308	$5,521,513	$27,698,080	$12,898,616
k	Discounted injury cost savings (3%)	$29,387,701	$6,356,850	$22,538,448	$10,489,955
l	Discounted injury cost savings (7%)	$24,360,252	$6,792,196	$17,673,350	$8,211,531
m	Discounted injury cost savings (10%)	$21,483,536	$6,828,963	$15,050,590	$6,980,855
n	ROI [(m-a)/a*100]	2,336%	183%	104,061%	1,084%

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) Return on Investment calculated using the 7% discounted post-intervention cost savings.

6.0 Dissemination Efforts and Highlights

The study team has submitted the results to the journal, Mining Engineering. In addition, research team members have submitted two abstracts to present the study findings are national meetings: the Society for Mining Engineering meeting in Phoenix, Arizona (February 21-23, 2016) and the American Industrial Hygiene Association meeting in Baltimore, Maryland (May 21-26, 2016). Finally, we are continuing to improve and update our project website, which is the main dissemination vehicle for the project results. The project website will be available for posting to the Alpha Foundation website following publication of the manuscript.

7.0 Conclusions and Impact Assessment

We identified 14 risk management interventions, 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 and are therefore identified as best practices. Based on the findings of this study, all mines should consider adopting risk management interventions.

8.0 Recommendations for Future Work

The current research was conducted using a retrospective approach for a number of reasons, chief among them being able to evaluate the effects of multiple risk management interventions and allowing for an adequate time interval following the interventions to measure potential changes in injury rates. However, the retrospective approach has inherent limitations, including but not limited to frequent inability of the companies to measure the costs of program implementation beyond the very recent past and the lack of additional outcome data that would help to determine how well the programs were implemented. The short time interval of the Alpha funding prevented us from using the preferred prospective study design. In separate research with prospective RM implementation in the fire service, over a five year period we were able to more accurately measure program implementation costs, changes in injuries and add a process evaluation to help us understand what worked well and what did not. Our publications in this area provide extensive detail on how proactive RM should be implemented (Poplin et al., 2015), and they follow the process previously used in the Australian coal industry which we found to be associated with significant declines in injuries (Poplin et al., 2008). Future research in mining RM program implementation should build on the results of our current Alpha-funded research to prospectively evaluate new RM interventions with mining partners, using a process similar to that which we used with our firefighter partners. Such research this area should work with mining partners to proactively implement specific risk management practices over a minimum four year period. Given the results of the current study, behavioral based interventions would appear to be a better fit for the US mining industry at present, although the RM process allows for interventions to be tailored to the unique needs of each company.

9.0 References

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Disclaimer

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