Risk assessment for haul truck-related fatalities in mining

Z.A. MD-NOR, V. KECOJEVIC, D. KOMLJENOVIC AND W. GROVES

Z.A. Md-Nor, V. Kecojevic, member SME, and **W. Groves,** member SME, are graduate student, associate professor and associate professor, respectively, with The Pennsylvania State University, University Park, PA; **D. Komljenovic** is adjunct professor with the Department of Industrial Engineering, University of Quebec, Trois-Rivières, Canada, and is reliability engineer and safety advisor with Hydro-Québec, Becancour, PQ, Canada. Paper number TP-07-033. Original manuscript submitted September 2007 and accepted for publication January 2008. Discussion of this peer-reviewed and approved paper is invited and must be submitted to SME Publications Dept. prior to June 30, 2008.

Introduction

Historically, mining has been one of the most hazardous work environments around the world. Due to their severity and frequency, mining fatalities, injuries and illnesses are among the costliest. For example, Leigh et al. (2004) reported that U.S. lignite and bituminous coal mining ranks second in the nation for the average cost per worker for fatal and all nonfatal injuries and illnesses. Although progress has been made during the last century (the number of U.S. mining fatalities, fatality incidence rates and injuries have decreased), the number and severity of mining incidents and injuries remains unacceptably high. Increased demand for coal and minerals and the current demographics of the mining workforce may make future reductions in incidents and injuries more difficult.

Kowalski-Trakofler et al. (2005) reported that a large portion of the mining workforce will retire during the next five years. Given the current growth in many sectors of the mining industry and attrition by retiring workers, the number of workers with little experience will increase. In addition, Fotta and Bockosh (2000) indicated that the health and safety of aging workers will be of increasing concern to all segments of mining. This scenario reinforces the need to develop effective intervention strategies to further reduce injuries and fatalities in mining industry.

The National Mining Association created an independent commission in January 2006 to examine the conditions under which new and existing technologies and training procedures can improve safety in underground coal mines. The commission released its report in December 2006 (Grayson et al., 2006). This report calls for a new paradigm for ensuring safety in U.S. underground coal mines that focuses on systematic and comprehensive risk management as the foundation from which all life-safety efforts emanate. The commission recommended that a comprehensive approach, founded on the establishment of a culture of prevention, be used to focus employees on the prevention of all incidents and injuries. Further, the commission recommended that every mine should employ a sound risk-analysis process, should conduct a risk analysis and should develop a risk-management plan to address the significant hazards identified by the analysis.

Simple regulatory compliance alone may not be sufficient to mitigate significant risks. Because not all mines have a familiarity with risk management, it was recommended that the National Institute for Occupational Safety and Health (NIOSH) develop a series of case studies that mines could use as templates, and it was further recommended that workshops and seminars be developed to disseminate this approach throughout the industry. Although the focus of the commission was to achieve zero fatalities and zero serious injuries in the U.S. underground coal mining industry, this approach and goals should also be applicable to the U.S. mining industry as a whole.

Risk management is a known loss-control methodology that has been applied by many industries, including the chemical, oil and natural gas, nuclear, military, aviation, environment and aerospace. These industries consider risk management as an integrated part of their daily business. A number of "generic" risk-assessment and management standards and guidelines are available (CAN/CSA, 2002; MIL-STD, 2000; AS/NZS, 2004; DIN-EN, 1997). However, specific applications usually require extensive modification of generic plans to address industry-specific needs and industry-related regulatory requirements. For

Abstract

Risk management is an established loss-control methodology that has been applied successfully in many industries. Recently, interest in this structured approach has grown in the mining industry. The main objective of this research was to develop a risk-assessment process, which is a part of risk management, that can be used by the U.S. mining industry to more thoroughly characterize risks associated with haul truck-related fatalities. The assessment is based on historical data obtained from the U.S. Mine Safety and Health Administration (MSHA) investigation reports, which includes 113 fatal incidents that occurred from 1995 through 2006. The risk-assessment process used in this research involves the following basic steps: identification of the risks, risk analysis and risk evaluation. The preliminary hazard assessment (PHA) method is used in identifying and quantifying risks. Risk levels are then developed using a pre-established risk matrix that ranks them according to probability and severity. The resulting assigned risk value can then be used to prioritize control strategies. This paper is a part of a detailed study on risk assessment for equipment-related fatalities in mining sponsored by the Western U.S. Mining Safety and Health Training and Translation Center.

FIGURE 1

Risk assessment matrix.

PROBABILITY			
Almost certain	VH	VH	H
Very likely	VH	H	M
Likely	H	M	M
Possible	M	M	L
	High	Medium	Low
	SEVERITY		

Risk: VH –VeryHigh H – High M – Medium L- Low

this reason, industries possessing a complex range of hazards typically develop their own specific risk-related standards and guides. These documents provide industry-specific frameworks for systematically establishing the risk-assessment and management approach. Because the design and implementation of risk-management systems is influenced by the varying needs of an organization and its characteristics, it is difficult to apply these plans to other industries without significant adjustment to their particularities.

Several countries have started to develop risk-assessment approaches for mining. A United Kingdom guidance document describes procedures for carrying out risk assessment at surface mining operations (Doc. No. 5995/2/98-EN, 1999). The Minerals Council of Australia was the initiator of a project seeking to improve risk assessment in the Australian minerals industry. The University of Queensland Minerals Industry Safety and Health Centre (MISHC) produced a guideline that aims to provide advice on risk assessment within the Australian mining industry (Joy and Griffiths, 2004). The Minerals Industry Cooperation Initiative (MICI) project at the University of Queensland, Australia, launched a new Web site called MIRMgate to improve the way mining, minerals processing and quarrying industries access hazard related information using Internet technology (http://www.mirmgate.com/; Kizil and Joy, 2005). In South Africa, the mining industry has established a Hazard Identification and Risk Assessment Program (HIRA-2003) to identify and record significant risks. The outcomes from the HIRA process are inputs for the risk treatment process, which is part of the broader risk-management process.

While the development of risk-management programs for other industries, or for mining operations in other countries, provides valuable reference information, experience has shown that a simple transfer of processes is not effective due to characteristics related to specific industries and local conditions. These factors emphasize the need for the development of a risk assessment and management process specific to U.S. mining operations. Through collaboration between the University of Quebec (UQ) and the Pennsylvania State University (PSU), an initial effort was made to develop a generic risk-management program for occupational safety and health in surface mining operations (Komljenovic and Kecojevic, 2007). Additionally, PSU was awarded a grant by the Western U.S. Mining Safety and Health Training and Translation Center for the project, *Risk Assessment for Equipment-Related Fatalities in U.S. Mining Operations*. The text that follows describes the portion of the project that includes the risk assessment process for haul truck-related fatalities.

Method

Risk assessment is a part of the risk-management process. It is a formal method of defining the potential risk or risks and is used to answer the following questions:

- What can go wrong — where and when can it go wrong?
- How and why can it go wrong?
- What is the likelihood that it would go wrong?
- What are the consequences?

The ultimate goal is to examine the potential risks so that they can be controlled. According to Brauer (2006) and Haimes (2004), and various internationally recognized standards (CAN/CSA, 2002; MIL-STD, 2000; AS/NZS, 2004), the risk-assessment process involves three steps: risk identification, risk analysis and risk evaluation.

In this research study, the potential risks were identified, analyzed and evaluated based on historical fatality data for the period from 1995 through 2006. Data on haul-truck-related fatalities were obtained from the the U.S. Mine Safety and Health Administration (MSHA) investigation reports (MSHA, 2007), which are accessible from the MSHA Web site. A typical report is approximately 10-pages long and contains the age and work experience of the victim, a description of the incident investigation, discussion, root cause analysis and conclusions. Based

Table 1

Hazard severity classification.

Severity	Definition
High	Associated with more than 12 fatalities in the examined years
Medium	Associated with 6 to 12 fatalities in the examined years
Low	Associated with less than 6 fatalities in the examined years

Table 2

Hazard probability classification.

Probability	Definition
Almost certain	Fatal incident will occur with a probability of P = 1.00
Very likely	Fatal incident will occur with a probability of 0.50 ≤ P < 1.00
Likely	Fatal incident will occur with a probability of 0.16 ≤ P < 0.50
Possible	Fatal incident will occur with a probability of P < 0.16

on a review of the MSHA investigation reports, a database containing the following information was developed: ordinal number of fatalities; fatality ID; date of incident; a short narration of incident; hazard associated with the incident; hazard category; and the type, location and equipment (haul-truck) activity during the incident. However, some of the reports were incomplete and did not specify all of the required information. Therefore, this information was further reviewed and a determination was made as to whether the data could be used or whether it had to be omitted from the study. Information about "incident location" and "equipment activity during the incident" was classified according to previous studies by McCann (2006) and Burgess-Limerick (2006). Classifications and terms used in the NIOSH information circular IC 9454 were also used wherever appropriate (Turin et al., 2001).

There are many risk-assessment methods available, including preliminary hazard analysis (PHA), hazard and operability study (HAZOP), human error analysis (HEA), level of protection analysis (LOPA), job hazard analysis (JHA) and workplace risk assessment and control (WRAC). The preliminary hazard analysis (PHA) method was selected for this study based on the nature of the information available from MSHA investigation reports and the ability of PHA to assist in preventing fatal incidents that occur in identical and repeatable systems such as mining. This method is usually applied early in the design stages. However, it can be used at any time

FIGURE 2

Distribution of haul-truck-related fatalities between 1995 and 2006.

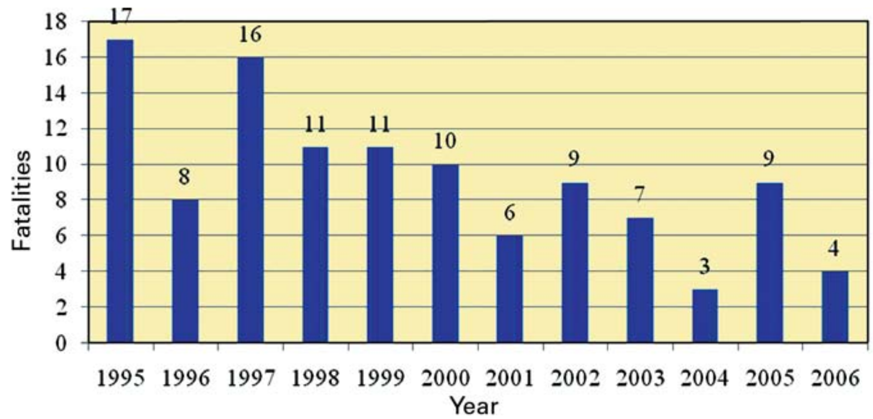

Table 3

Hazard inventory table.

Hazard	1995	'96	'97	'98	'99	2000	'01	'02	'03	'04	'05	'06	Severity	Probability
1 Failure of mechanical/electrical/ hydraulic components	7	1	2	3	4	2	3	2	2	2	2	2	32	1.00
2 Failure of victim to respect truck working area	3	2	2	1	1	4	0	1	2	0	0	0	16	0.66
3 Failure to provide adequate berm at dump or haul roads	1	3	3	1	1	2	0	1	1	0	1	0	14	0.75
4 Failure to control truck	3	0	1	2	0	0	0	0	1	0	4	0	11	0.42
5 Failure to set parking brake/ chock when leaving truck	1	0	1	2	1	0	1	1	0	0	2	1	10	0.66
6 Failure to follow adequate maintenance procedure	0	1	0	0	1	1	2	2	1	0	0	0	8	0.50
7 Failure to identify adverse site/ geological conditions	1	0	1	1	1	0	0	1	0	0	0	0	5	0.42
8 Failure to use safety line while working on the truck bed	0	0	1	0	0	1	0	0	0	1	0	0	3	0.25
9 Intoxicated or sick	1	0	1	0	0	0	0	0	0	0	0	0	2	0.17
10 Activity near power line	0	0	2	0	0	0	0	0	0	0	0	0	2	0.08
11 Failure to switch on head light	0	0	0	1	1	0	0	0	0	0	0	0	2	0.17
12 Failure to provide hazard signs	0	0	1	0	0	0	0	0	0	0	0	1	2	0.17
13 Failure to obey hazard signs	0	0	1	0	0	0	0	0	0	0	0	0	1	0.08
14 Lack of illumination at working area	0	0	0	0	0	0	0	1	0	0	0	0	1	0.08
15 Failure to give warning before moving truck	0	0	0	0	1	0	0	0	0	0	0	0	1	0.08
16 Failure to lower truck bed after dumping	0	1	0	0	0	0	0	0	0	0	0	0	1	0.08

Note: Two incidents are caused by unknown hazards.

FIGURE 3

Risk assessment matrix table for haul trucks.

PROBABILITY				
	Almost certain	- Failure of mechanical / electrical / hydraulic components		
	Very likely	- Failure of victim to respect truck working area - Failure to provide adequate berm at dump sites or haul roads	- Failure to set parking brake/ chock when leaving the truck - Failure to follow adequate maintenance procedure	
	Likely		- Failure to control truck	- Failure to provide hazard signs - Failure to switch on head light - Failure to use safety line - Intoxicated or sick - Failure to identify adverse site/geological conditions
	Possible			- Failure to obey hazard signs - Lack of illumination - Failure to give warning before moving truck - Failure to lower truck bed - Activity near power line
		High	Medium	Low
		SEVERITY		

Risk: VH – VeryHigh H – High M – Medium L- Low

throughout the life of the mine as a tool in a continuous safety-improvement program.

Risk is defined as the likelihood or probability that a hazard will cause harm. According to Kates and Kasperson (1983), risk is a hazard measurement, taking into consideration its likelihood and consequences. In the current study, the first step consists of identifying the situations that have the potential to cause a fatality, i.e. identifying hazards associated with operating or being near a haul truck. The committee on underground coal mine safety (NRC, 1982) defined hazard as an unsafe situation in mines. This definition was further developed by Ramani (1992) to include unsafe acts. In this study, hazard is defined as the immediate cause of the fatality. MSHA defines immediate cause as a causal factor that if eliminated, would have either prevented the incident or mitigated its consequences. A hazard inventory table containing all identified hazards, their probability and the associated number of fatalities was compiled.

Risk analysis is the second stage of the risk-assessment process. Risk analysis may be performed quantitatively, semi-quantitatively or qualitatively. According to Joy (2004), if the severity (consequence) of the loss can be measured objectively and the probability (frequency or likelihood) of the event can be determined from the historical data, then a quantitative risk assessment can be performed. If the severity and frequency cannot be specified but can be estimated based on judgment or opinion, then a qualitative or semi-quantitative risk assessment can be performed. The risk associated with a particular activity is judged by estimating both the probability and the severity, often in relative terms such as "low," "medium," "high" or "very high." This approach to the expression of risk is adequate for many types of evaluation, allowing a structured approach to be adopted in situations where more precise numerical methods would be difficult to implement. In the context of this study, probability (P) is considered as the likelihood that the hazard will cause a fatality in a future year. It is calculated as the number of years in the study period in which a fatality was attributed to a given hazard divided by the total number of years. Severity (S) was judged from the total number of fatalities associated with the hazard in the 12-year study period. The proposed severity and probability classifications are shown in Tables 1 and 2, respectively, while Fig. 1 shows the resulting risk assessment matrix. The severity classification represents an adaptation of a severity rating introduced in the ISO 17776 standard (2000).

Risk evaluation is the final step in the risk-assessment process and focuses on the decisions required to address the analyzed risks. Brauer (2006) suggested that this step consists of two components: risk aversion and risk acceptance. Risk aversion involves estimating how well risk can be reduced or avoided through various strategies such as behavioral principles and technological advances as recommended by Kecojevic and Radomsky (2004). Risk acceptance involves creating standards for deciding what risks are acceptable for miners, companies or society. However, setting a standard is a complicated task, as an acceptable level of risk may differ for each group. In the underground coal mine commission report (Grayson et al., 2006), it was proposed that the only acceptable levels were zero fatalities and zero serious injuries and it is appropriate that those levels be applied for the mining industry as a whole. However, the main objective of this study was to assess risks so that resources can be allocated appropriately and, therefore, no attempt was made to define acceptable levels of risk.

The first step of risk evaluation is to identify the locations of hazards in the risk-assessment matrix. These locations were used to identify and rank risks with the highest priority. Risks in the highest-priority cells are located in the upper left part of the table, while risks in the lowest-priority cells are in the lower right corner. It should be noted that at the end of the risk-assessment process, risks are ranked according to their probability and severity in a relative manner rather than in an absolute form. This will help to avoid underestimating or overestimating risks involved in this assessment. The resulting relative risk rankings are sufficient to prioritize resource allocations and control strategies.

To explore differences in the number of fatalities attributed to different types of hazards and locations, hazards identified in the hazard inventory table were sorted into three hazard categories: human error, equipment failure and working environment. These categories were later used to examine the relationship among other factors believed to be involved in the incidents, namely "incident location" and "equipment activity before the incident happened."

Results and analysis

According to MSHA (2007) records, there were 516 fatalities between 1995 and 2006 attributed to the general category of equipment. A total of 113 fatalities or 21.8

Table 4

Hazard categories and associated number of fatalities.

Hazard category	Hazard	Severity
	Failure of victim to respect truck working area	16
	Failure to control truck	11
	Failure to set parking brake/chock when leaving the truck	10
	Failure to follow adequate maintenance procedure	8
Human error (49.5%)	Failure to use safety line while working on the truck bed	3
	Intoxicated or sick	2
	Failure to switch on head light	2
	Failure to obey hazard signs	1
	Failure to give warning before moving truck	1
	Failure to lower truck bed after dumping	1
Equipment failure (28.8 percent)	Failure of mechanical/electrical/hydraulic components	32
	Failure to provide adequate berm at dump sites or haul roads	14
Working environment (21.7 percent)	Failure to identify adverse site/geological conditions	5
	Activity near power lines	2
	Failure to provide hazard signs	2
	Lack of illumination at working area	1

percent were haul-truck-related. It was determined that two fatalities were caused by an unknown hazard and they were excluded from the analysis. The highest (17) and the lowest (3) number of fatalities were recorded in 1995 and 2004, respectively. Figure 2 shows the distribution of haul-truck-related fatalities for the study period.

A total of 16 hazards were identified in the hazard inventory table. The hazard category "failure of mechanical/electrical/hydraulic components," particularly the braking system, contributed to almost 30 percent of all haul-truck-related fatalities. The categories "failure of victim to respect haul-truck working area" and "failure to provide adequate berm at dump sites or haul roads" contributed to 16 and 14 fatalities, respectively. These are the three most hazardous conditions, contributing to more than 50 percent of the fatalities. The identified hazards, their probability and severity are shown in Table 3. It can be noted that "failure of mechanical/electrical/hydraulic components" of haul trucks was not only the most severe, but it was also the most frequent hazard. It occurred every year during the last 12 years. The number of fatalities associated with "failure of victims to respect haul-truck working area" was greater than that attributed to "failure to provide adequate berm at dump sites or haul roads." However, the former occurred slightly less frequently.

The completed risk-assessment matrix for haul trucks is shown in Fig. 3. It is based on the generic risk matrix shown in Fig. 1. Hazards including "failure of mechanical/electrical/hydraulic components," "failure of victim to respect equipment working area," and "failure to provide adequate berm at dump sites or haul roads" were categorized as "high" in the severity category. Three hazards were categorized as "medium" and the other 10 were categorized as "low." It can be noted that "failure of mechanical/electrical/hydraulic components" was the only hazard categorized as "almost certain" in the probability category. Four hazards were categorized as "very likely," six hazards as "likely" and five others as "possible." Thus, the hazards "failure of mechanical/electrical/hydraulic components," "failure of victim to respect truck working area" and "failure to provide adequate berm at dump sites or haul roads" are placed into the category of "very high" risk (Fig. 3). Two hazards that fall in the "high" risk category are "failure to set parking brake/chock when leaving truck" and "failure to follow adequate maintenance procedure."

The risk-assessment matrix indicates that the hazard "failure of mechanical/electrical/hydraulic components" should be given highest priority. It can almost certainly happen once or more in a given year, and it can contribute to a high number of fatalities. Therefore, the largest portion of the available resources should be allocated to prevent and control this hazard. Other hazards that need more attention are "failure of victim to respect truck working area" and "failure to provide adequate berm at dump sites or haul roads." These two hazards can contribute to a high number of fatalities. Additional resources can be allocated to control hazards located in the lower probability and severity cells. Although having a lower probability of occurrence, they contribute to fatalities. Ignoring these hazards could also increase their probability and severity in the future.

Hazards identified in this study were sorted among three categories: human error, equipment failure and working environment. Referring to Table 4, it can be seen that human errors contributed to almost half of the fatalities. Some of these errors include "failure of victim to respect truck working area" (16 fatalities), "failure to control truck" (11 fatalities) and "failure to set parking brake/chock while leaving the truck" (10 fatalities). Almost one-third of the fatalities were directly attributed to failure of haul trucks to function properly. There was only one hazard associated with this category ("failure of mechanical/electrical/hydraulic components"). However, this hazard contributed to a disproportionate share of fatalities. It contributed to 32 fatalities, almost 30 percent of the total fatalities. Hazards attributed to the working environment such as "failure to provide adequate berm

Table 5

Distribution of fatalities by hazard category and location of incident.

Hazard category	Location of incident					
	Location 1	Location 2	Location 3	Location 4	Other	Total
Human	20	23	1	9	1	54
Equipment	3	25	1	1	2	32
Environment	17	8	0	0	0	25
Total	40	56	2	10	3	111

Other: washing bay (1), security checkpoint (1), scale house (1)

at dump sites or haul roads” contributed to 14 fatalities. Other working environment hazards include “failure to identify adverse site geological conditions” (five fatalities), “activity near power lines” (two fatalities), “failure to provide hazard signs” (one fatality) and “lack of illumination at working areas” (one fatality).

According to Grayson (2001), hazards can differ by location and depend on the operational system and the interaction of people within the mining complex. Table 5 shows the association between three hazard categories and location of incidents. Several locations are grouped together based on their natural similarities and physical designs. Dump site and loading area are grouped together and named as Location 1; haul road, ramp and cross cuts as Location 2; working bench and working face as Location 3; and maintenance and parking area as Location 4. Locations that have unique properties are grouped under “other.”

A total of 56 fatalities occurred at Location 2, where 25 fatalities were contributed to equipment failures, 23 to human errors and eight to the working environment. A total of 40 fatalities occurred at Location 1, mostly contributed to human errors and the working environment. These hazards contributed to a disproportionate number of fatalities in spite of the fact that equipment likely spent less time at this location. These findings are consistent with those reported by May (1990) and by Turin et al. (2001). Ten fatalities occurred at Location 4 and two at Location 3.

This study also examined the association between number of fatalities and haul-truck activity just before they were involved in the incidents. The results are tabulated in Table 6. As expected, the activity “moving forward” was associated with the highest number of fatalities (>40 percent). The activity “backing up” was associated with 20 fatalities despite the fact that this activity likely represents a relatively small portion of the total time in operation.

Hazards identified in this study are a symptom of failures in the safety system involving haul trucks in the U.S. mining operations. Generally, an incident resulting in injury or fatality is multi-causal. Hence, it is imperative that all hazards associated with operating or being near a piece of equipment be identified and understood. However, in a previous study (Levens, 1998) it was noted that only the immediate circumstances associated with an incident were listed in MSHA reports, and no discussion of the preceding events leading to the incidents was provided. Further, significant variability in the format and level of detail provided in incident investigation reports for the period examined in this study was noted; therefore, only the most immediate contributors to a fatality could be considered for analysis. This is a limitation of the data used in this study, which serves to emphasize the need for additional research to better characterize the “root cause” of the fatalities and the need for a systematic and thorough approach to incident investigation.

Conclusions

Risk assessment is a useful and effective method to identify, quantify and evaluate risk. In this study, risks related to haul trucks were assessed and ranked. The most frequent and severe hazard associated with this mining equipment was “failure of mechanical/electrical/hydraulic components.” Therefore, resources should be allocated to control this hazard. Additional hazards identified as requiring significant control efforts included “failure of victim to respect truck working area” and “failure to provide adequate berm at dump sites and haul roads.” These three hazards fall into the category of “very high” risk. Finally, because risk assessment is just a part of an entire risk-management process, future research effort should be focused on risk control and on implementing and maintaining control measures. ■

Table 6

Distribution of fatalities by hazard category and equipment activity.

Hazard category	Equipment activity							
	Moving forward	Backing up	Unsecured	Loading	Maintenance	Dumping	Other	Total
Human error	15	6	9	7	9	4	4	54
Equipment failure	27	2	1	0	2	0	0	32
Working environment	5	12	0	2	0	5	1	25
Total	47	20	10	9	11	9	5	111

Other: training (4), switching driver (1)

Acknowledgments

The Western U.S. Mining Safety and Health Training and Translation Center financially supported the research work in this paper, and its contribution is gratefully acknowledged. The authors also thank the reviewers for their valuable comments on an earlier version of this paper.

References

Anon, 1982, "Toward Safer Underground Coal Mines," National Research Council, Committee on Underground Coal Mine Safety, Washington, D.C. 190 pp.

Burgess-Limerick, R., 2006, "Identifying injury risks associated with underground coal mining equipment," Proceedings of the International Ergonomics Association Congress 2006, Pikaar, R.N., Koningsveld, E.A.P., and Settels, P.J.M., eds., Elsevier, Amsterdam.

Brauer, R.L., 2006, *Safety and Health for Engineers*, 2nd edition, John Wiley & Sons, Inc., Hoboken, NJ..

CAN/CSA Q850-97, 2002, *Risk Management: Guideline for Decision Makers*, Canadian Standard Association, Standard.

Doc. No 5995/2/98-EN, 1999, "Guidance for Carrying out Risk Assessment at Surface Mining Operations," Safety and Health Commission for The Mining And Other Extractive Industries, Committee on Surface Workings, England.

DIN EN 1050, 1997, Safety of Machinery – Principles for Risk Assessment; Version EN 1050:1996, DIN-adopted European Standard.

Fotta, B., and Bockosh, G., 2000, "The aging workforce: an emerging issue in the mining industry," Proceedings of the 31st Annual Institute of Mine Health Safety Research, Blacksburg, VA, Virginia Polytechnic Institute and State University, Dept of Mining and Minerals Engineering, pp. 33-45

Grayson, R.L., 2001, "Hazard identification, risk management, and hazard control," *Mine Health and Safety Management,* Karmis, M., ed., SME, pp.247-259.

Grayson, L.R., et al., 2006, "Improving Mine Safety Technology and Training: Establishing U.S. Global Leadership," National Mining Association and Mine Safety and Training Commission Report.

Haimes, Y.Y., 2004, *Risk Modeling Assessment, and Management, 2nd Edition*, John Wiley & Sons, Inc., Hoboken, NJ.

ISO-17776, 2000, "Petroleum and Natural Gas Industries – Offshore production installations – Guidelines on Tools and Techniques for Hazard Identification and Risk Assessment," International Organisation for Standardization, Geneva, Standard.

Joy, J., and Griffiths, D., 2004, "National Industry Safety and Health Risk Assessment Guideline," Minerals Industry Safety and Health Centre (MISHC), University of Queensland, Australia, 157 pp.

Joy, J., 2004, "Occupational safety risk management in Australian mining," *Occupational Medicine*, Vol. 54, No. 5, pp. 311-315.

Kates, R.W., and Kasperson, J.X., 1983, "Comparative risk analysis of technological hazards (a review)," Proceedings of the National Academy of Sciences of the United States of America, Vol. 80, No. 22, Part 2: Physical Sciences.

Kecojevic, V. and Radomsky, M., 2004, "The causes and control of loader- and truck-related fatalities in surface mining operations," *Injury Control and Safety Promotion*, Vol. 11, No. 4, pp. 239-251.

Kizil, G.V., and Joy, J., 2005, "The development and implementation of a minerals industry risk management gateway," Proceedings of 32 conference on Application of Computers and Operation Research in Mineral Industry, Dessureault, Ganguli, Kecojevic and Girard-Dawyer, eds., 2005, Tucson, AZ, Francis and Taylor.

Komljenovic, D., and Kecojevic, V., 2007, "Risk management program for occupational health and safety in surface mining operations," *International Journal of Risk Assessment and Management*, Vol. 7, No. 5, pp. 620-638.

Kowalski-Trakofler, K., Steiner, L., and Schwerha, D., 2005, "Safety considerations for the aging workforce," *Safety Science*, Vol. 43, No. 10, pp. 779-793.

Leigh, J., Waehrer, G., Miller, T., Keenan, C., 2004, "Cost of occupational injury and illness across industries," *Scandinavian Journal of Work Environment and Health*, Vol. 30, No. 3, pp. 199-205.

Levens, R., 1998, "A general framework for prioritizing research to reduce injuries and diseases in mining," *Human and Ecological Risk Assessment*, Vol. 4, No. 6, pp. 1285-1290.

May, J.P., 1990, "Analysis of Dump-Point Accidents Involving Mobile Mining Equipment," Information Circular 9250, U.S. Dept. of the Interior, Bureau of Mines, Pittsburgh Research Center, 19 pp.

McCann, M., 2006, "Heavy equipment and truck-related death on excavation work sites," *Journal of Safety Research*, Vol. 37, pp. 511-517.

MIL-STD-882D, 2000, Military Standard, Standard Practice for System Safety, Department of Defence, Standard.

Minerals Industry Risk Management Gateway (MIRMgate), Hazard-Related Database for Mineral Industry, available from http://www.mirmgate.com.

Mine Safety and Health Administration, 2007, Equipment safety and health information, available from: <www.msha.gov>.

Ramani, R.V., 1992, "Personnel health and safety," *Mining Engineering Handbook*, Hartman, H., ed., Vol. 2, 995 pp.

South African Mining Industry Guide to Hazard Identification & Risk Assessment (HIRA), 2003, SA Safety Adviser's Office Chamber of Mines of South Africa, Standard.

Standards Australia, Standards New Zealand, 2004, AS/NZS 4360:2004 Risk Management, Homebush, Wellington, Standard. ISBN 073372647 X.

Turin, F.C., Wiehagen, W.J., Jaspal, J.S., and Mayton, A.G., 2001, "Truck dump site safety: an examination of reported injuries," Information Circular 9454, U.S. Dept of Health and Human Service, Public Health Service, CDC.