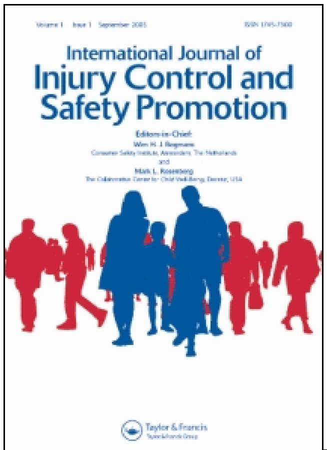


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# Risk assessment for loader- and dozer-related fatal incidents in U.S. mining

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# Risk assessment for loader- and dozer-related fatal incidents in U.S. mining

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The paper presents the results of research aimed at developing a risk assessment process that can be used to more thoroughly characterise risks associated with loader- and dozer-related fatal incidents in US mining. The assessment is based on historical data obtained from the US Mine Safety and Health Administration investigation reports, which includes 77 fatal incidents that occurred from 1995 to 2006. The Preliminary Hazard Assessment 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 prioritise risk control strategies. A total of 10 hazards were identified for loaders. The hazards 'failure to follow adequate maintenance procedure' and 'failure of mechanical/electrical/hydraulic components' were the most severe and frequent hazards and they fell into the category of 'high' risk. The same number of hazards was identified for dozers. The hazard 'failure to identify adverse site/geological conditions' was the most severe and frequent hazard and it fell into the category of 'high' risk.

**Keywords:** hazard; risk assessment; fatal incidents; mining; loaders; dozers

## 1. Introduction

Historically, mining has been one of the most hazardous work environments in many countries around the world. Although progress has been made – over 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. According to Mine Safety and Health Administration (2007) records, for the time period from 1995 to 2006, there was a total of 914 mining fatalities. The highest number is attributed to the general category of equipment – a total of 516. The proportion of total mine fatalities attributable to the equipment category ranged from 39% in 1999 to 86% in 1997. In the same period, there was a total of 43 loader- and 30 dozer-related fatalities. These data clearly indicate the need to develop effective intervention strategies to further reduce fatal incidents in the U.S. mining industry.

Risk management is a well-known loss control methodology that has been applied by many industries, including chemical, oil and natural gas, nuclear, military, aviation, environment and aerospace. These industries consider risk management as an integral part of their daily business. A number of 'generic' risk assessment and management standards and guidelines are available (European Standard, 1997; Department of Defence, 2000; Canadian Standard Association, 2002; Standards Australia/Standards New Zealand, 2004). Several countries have started to develop risk assessment approaches for mining. The UK guidance document describes procedures for carrying out risk assessment at surface mining operations (Committee on Surface Workings, 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 produced a guideline that aims to provide advice on risk assessment within the Australian mining industry (Joy & Griffiths, 2004). The Minerals Industry Cooperation Initiative project at the University of Queensland, Australia, launched a new website called MIRMgate to improve the way mining, minerals processing and quarrying industries access hazard-related information using Internet technology (Minerals Industry Risk Management Gateway, 2007; Kizil & Joy, 2005). In South Africa the mining industry has established a Hazard

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Identification and Risk Assessment programme (Safety Adviser's Office 2003) to identify and record significant risks. While the development of risk management programmes 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.

There have been many attempts to understand the fundamental causes of injury incidents related to mining equipment (Helander & Krohn, 1983; Helander, Krohn & Curtin, 1983; Butani, 1986; Phiri, 1989; Sanders & Shaw, 1989; May, 1990; Klishis et al., 1993; Turin Wiehagen, Jaspal & Mayton, 2001; Kecojevic & Radomsky, 2004; Burgess-Limerick, 2006; Kecojevic, Komljenovic & Groves, 2006; McCann, 2006; Burgess-Limerick & Steiner, 2007; Groves, Kecojevic & Komljenovic, 2007; Kecojevic, Komljenovic, Groves & Radomsky, 2007; Komljenovic, Groves & Kecojevic, 2007). However, these studies do not systematically identify, quantify and evaluate risks related to operating or being near mining equipment. Therefore, there is a need to develop a risk assessment process, which is a part of an overall risk management programme, that can be used by industry professionals to more thoroughly characterise risks associated with equipment-related fatalities. The text that follows describes the risk assessment process for loader- and dozer-related fatalities, which is a part of the study on risk assessment for equipment-related fatalities in U.S. mining operations.

## 2. Methodology

This study is based on historical fatality data for the period from 1995 to 2006. Data on loader- and dozer-related fatalities were obtained from the Mine Safety and Health Administration (MSHA) investigation reports (Mine Safety and Health Administration, 2007), which are publicly accessible from the MSHA website. More than 700 pages of investigation reports were examined. 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.

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

According to Haimes (2004), Brauer (2006) and various internationally recognised standards (Department of Defence, 2000; Canadian Standards Association, 2002; Standards Australia/Standards New Zealand, 2004), the risk assessment process involves three steps: 1) risk identification; 2) risk analysis; 3) risk evaluation. 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 mining equipment. Hazard is defined as something with the potential to cause harm (Canadian Standards Association, 2002; Standards Australia/Standards New Zealand, 2004). Hazard is also known as 'immediate cause' or 'symptom' in the Heinrich (1959) incident dominos sequence. The Committee on Underground Coal Mine Safety (National Research Council, 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. The Hazard Inventory Table containing all identified hazards was compiled and is shown later in this paper. This table can be updated each time a new hazard is identified.

Risk analysis is the second stage of the risk assessment process. It 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 frequency (probability 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 judgement or opinion, then a qualitative or semi-quantitative risk assessment can be performed. In this study, quantitative risk analysis was considered to be appropriate. The risk (R) associated with a particular activity is judged by estimating both the probability (Pr) and the severity (S), in relative terms such as 'low', 'medium', 'high' or 'very high'. This way of expressing the risk is adequate for many types of evaluation, allowing a structured approach to be adopted in situations where more quantitative methods would be difficult to implement. In the context of this study, probability is considered as the likelihood that the hazard will cause a fatality in a future year and is calculated as the number of years in the study period to which a fatality was attributed a given hazard divided by the total number of years. Severity 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 Table 3 shows the resulting Risk Assessment Matrix.

Risk evaluation is the final step in the risk assessment process and focuses on the decisions required to address the analysed 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 behavioural principles and technological advances. 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. It is appropriate that those levels be applied for the mining industry as a whole. However, the main objective of this research was to develop a risk assessment process that can be used to more thoroughly characterise risks associated with loader- and dozer-related fatalities 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 hazards were used to identify and rank risks that have to be addressed and in what order to prioritise control efforts. Risks in the highest priority cells are located in the upper left part of Table 3, 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 prioritise resource allocations and control strategies.

Table 1. Hazard Severity Classification.

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

Table 2. Hazard Probability Classification.

| Probability | Definition |
|---|---|
| Almost certain | Fatal incident will occur with a probability of $Pr = 1.00$ |
| Very likely | Fatal incident will occur with a probability of $0.50 \leq Pr < 1.00$ |
| Likely | Fatal incident will occur with a probability of $0.16 \leq Pr < 0.50$ |
| Possible | Fatal incident will occur with a probability of $Pr < 0.16$ |

Table 3. 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 = very high; H = high; M = medium; L = low.

## 3. Results and discussion

### 3.1. Loaders

According to Mine Safety and Health Administration (2007) records, there was a total of 43 fatalities between 1995 and 2006. It was determined that all reports indicated the causes of the fatalities. The study also determined that 25 out of 43 victims were not equipment operators. Figure 1 shows the distribution of loader-related fatalities for the study period. The highest (7) and lowest (0) number of fatalities were recorded in 2002 and 2001, respectively.

A total of 10 hazards were identified in the Hazard Inventory Table. The identified hazards, their probability and severity are shown in Table 4.

The fatal incident, for example, when a maintenance helper tried to remove a loader tyre by heating the lug nut to loosen them, causing the tyre to explode and fatally injure the worker was attributed to hazard ‘failure to follow adequate maintenance procedure’. The fatal incident, for example, when a loader operator was dumping the rock material on a stockpile and the loader burst into flames was attributed to hazard ‘failure of mechanical/electrical/hydraulic components’. The hazards ‘failure to follow adequate maintenance procedure’ and ‘failure of mechanical/electrical/hydraulic components’ contributed to 11 and 10 fatalities, respectively, or almost 50% of the loader-related fatalities. They were also the most frequent hazards ($Pr = 0.50$). These are the two most hazardous

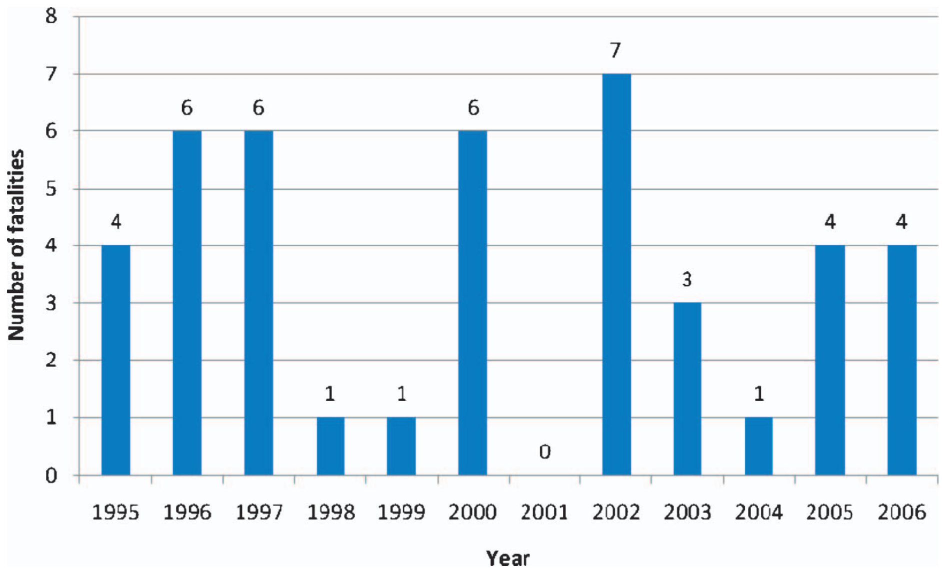


Figure 1. Distribution of loader-related fatalities between 1995 and 2006. (Available in colour online.)

Table 4. Hazard Inventory Table – Loader.

| | Hazard | Year | | | | | | | | | | | | S | Pr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | '95 | '96 | '97 | '98 | '99 | '00 | '01 | '02 | '03 | '04 | '05 | '06 | | |
| 1 | Failure to follow adequate maintenance procedure | 0 | 2 | 3 | 0 | 0 | 2 | 0 | 0 | 1 | 0 | 1 | 2 | 11 | 0.50 |
| 2 | Failure of mechanical/electrical/hydraulic components | 1 | 2 | 2 | 1 | 0 | 0 | 0 | 3 | 0 | 1 | 0 | 0 | 10 | 0.50 |
| 3 | Failure to identify adverse site/geological conditions | 2 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 2 | 0 | 7 | 0.42 |
| 4 | Failure to respect equipment working area | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 2 | 0 | 0 | 2 | 6 | 0.33 |
| 5 | Failure to provide adequate sign/signal | 1 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0.17 |
| 6 | Failure to set parking brake before leaving equipment | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 0.17 |
| 7 | Failure to provide adequate illumination | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.08 |
| 8 | Failure to wear seatbelt | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.08 |
| 9 | Unfavourable weather conditions | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0.08 |
| 10 | Failure to provide adequate berm | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0.08 |

S = severity; Pr = probability.

conditions, contributing to almost 50% of the loader-related fatalities.

The study found that loaders, in some cases, were working on uneven ground, particularly near the hopper and stock pile, or near the unstable slopes. Hazard identified as 'failure to identify adverse site/geological condition' contributed to seven fatalities in the study period (S = 7). The fatal incident, for example, when a worker inadvertently walked into the path of the loader as it was backing up was attributed to the hazard 'failure of victim to respect equipment working area'. The fatal incident that occurred, for example, when the bucket of the loader struck and ruptured a buried natural gas line causing a gas explosion was attributed to the hazard 'failure to provide adequate sign/signal'. These two hazards contributed to six and three fatalities, respectively. However, the former was more frequent (Pr = 0.33).

Figure 2 shows identified hazards 'failure of mechanical/electrical/hydraulic components' and 'failure to set parking brake before leaving equipment', while Figure 3 shows hazards 'failure to identify adverse site/geological conditions' and 'failure to provide adequate sign/signal'.

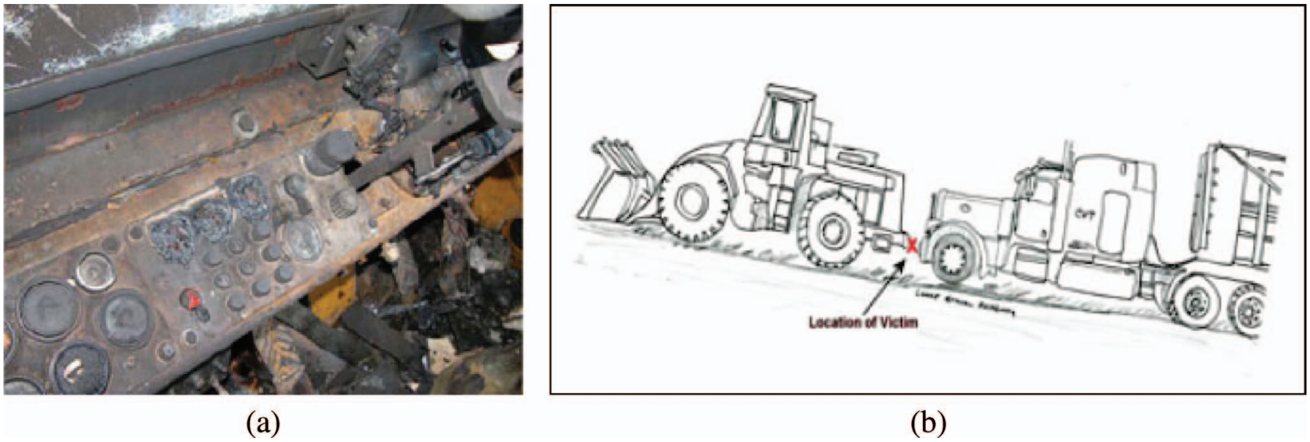


Figure 2. The hazards 'failure of mechanical/electrical/hydraulic components' (a) and 'failure to set parking brake before leaving equipment' (b). Source of photo and drawing: Mine Safety and Health Administration, 2007, www.msha.gov. (Available in colour online.)

Figure 3. The hazards 'failure to identify adverse site/geological conditions' (a) and 'failure to provide adequate sign/signal' (b) Source of photos: Mine Safety and Health Administration, 2007, www.msha.gov. (Available in colour online.)

The completed Risk Assessment Matrix for the loader is shown in Figure 4. It is based on the generic risk matrix shown in Table 3. There is no hazard categorised as 'almost certain' in the probability category. Two hazards are categorised as 'very likely', four as 'likely' and four hazards as 'possible'. There is no hazard categorised as 'high' in the severity category. Four hazards are categorised as 'medium' and six as 'low'.

It can be noted that 'failure to follow adequate maintenance procedures' and 'failure of mechanical/electrical/hydraulic components' were the only two hazards placed into the category of 'high' risk. The Risk Assessment Matrix indicates that these two hazards should be given highest priority. Therefore, the largest portion of the available resources should be allocated to control these hazards. Four other hazards that need more attention are 'failure to identify adverse site/geological conditions', 'failure to respect equipment working area', 'failure to provide adequate sign/signal' and 'failure to set parking brake before leaving equipment'. These hazards fall in 'medium' risk category. 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 can also lead to an increase in their frequency and severity in the future.

Figure 5 shows relationship between number of fatal incidents and the type of mining operations. It can be noted that 16 fatalities occurred in surface crushed stone mines, 13 in sand and gravel mines and

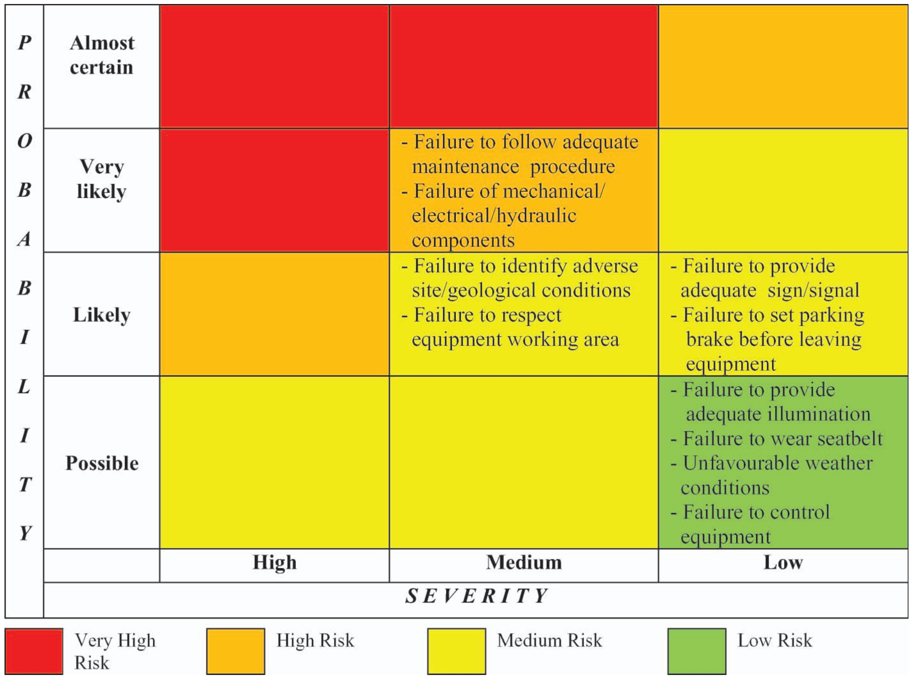


Figure 4. Risk Assessment Matrix for Loaders. (Available in colour online.)

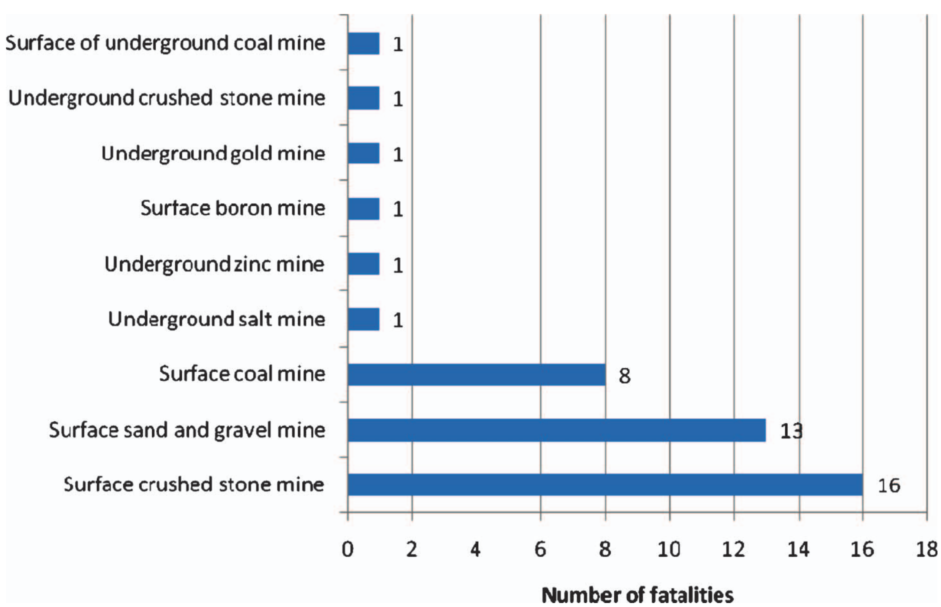


Figure 5. Relationship between mining type and number of fatalities for loaders. (Available in colour online.)

eight in surface coal mines. The remaining six fatalities occurred in underground zinc, salt, gold and crushed stone mines, one in surface boron mine and one at the surface of underground coal mine. The distribution of fatalities across mining types is somewhat consistent with the relative proportion of the total number of operations that the categories represent, e.g. surface crushed stone, surface sand and gravel and surface coal mines represent 97% of total surface mining operations and account for 86% of the fatalities. However, other factors such as the number of front-end loaders involved in the different types of mining operations would also likely influence the number of fatalities, but this information is not readily available.

### *3.2. Dozers*

There was a total of 30 fatalities between 1995 and 2006. It was determined that two fatalities were caused by unknown hazards and they were excluded from the analysis. Figure 6 shows the distribution of dozer-related fatalities for the study period. There were zero fatalities in 1996, 1997 and 2003. The highest number of fatalities occurred in 1995 and 1998 – five fatalities in every year.

A total of 10 hazards were identified in the Hazard Inventory Table. The identified hazards, their probability and severity are shown in Table 5.

In many instances, the equipment was used at exploration sites. Many of the incidents were associated with failure to obtain prior knowledge of physical and geological conditions of the area. This hazard was very significant and it is categorised as 'failure to identify adverse site/geological conditions'. It contributed to a total of nine fatalities (S = 9) or almost one third of all dozer-related fatalities. At the same time, it was the most frequent hazard (Pr = 0.50).

The fatal incident, for example, when a dozer operator was pushing the material off the edge of a hillside, over-travelled the edge, turned sideways and

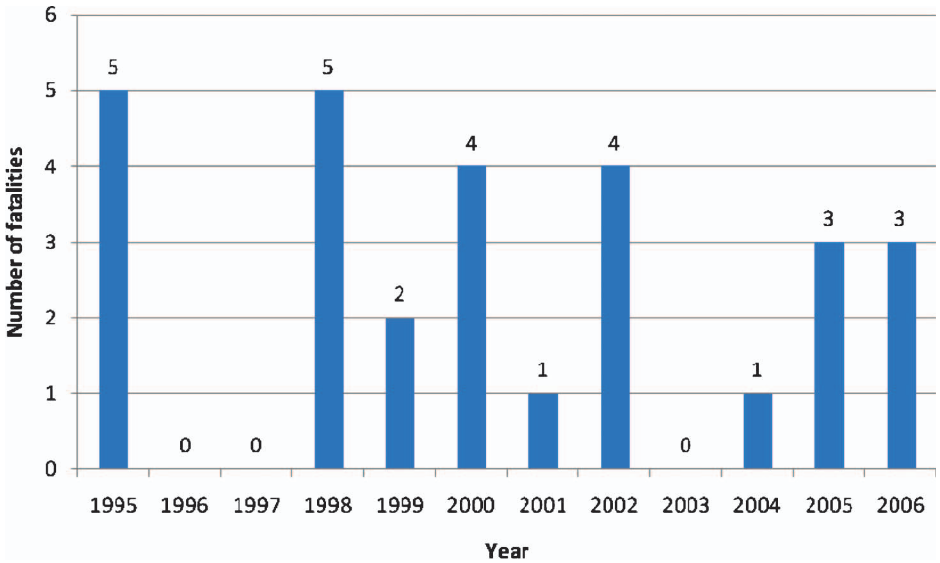


Figure 6. Distribution of dozer-related fatalities between 1995 and 2006. (Available in colour online.)

Table 5. Hazard Inventory Table – Dozer.

| Hazard | | Year | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | '95 | '96 | '97 | '98 | '99 | '00 | '01 | '02 | '03 | '04 | '05 | '06 | S | Pr |
| 1 | Failure to identify adverse site/geological conditions | 0 | 0 | 0 | 2 | 1 | 0 | 1 | 3 | 0 | 0 | 1 | 1 | 9 | 0.50 |
| 2 | Failure to control equipment | 1 | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 1 | 0 | 5 | 0.33 |
| 3 | Standing on track while operating equipment | 2 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 4 | 0.25 |
| 4 | Failure to follow adequate maintenance procedure | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 2 | 0.17 |
| 5 | Inappropriate task for equipment | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 0.17 |
| 6 | Failure to provide adequate illumination | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 0.17 |
| 7 | Failure of victim to respect equipment working area | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.08 |
| 8 | Failure of mechanical/electrical/hydraulic components | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.08 |
| 9 | Pushing material above hopper while loading | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0.08 |
| 10 | Failure to provide adequate sign/signal | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0.08 |

S = severity; Pr = probability.
*Note*: Two incidents are caused by unknown hazards.

rolled down the hill was attributed to hazard 'failure to control equipment'. This hazard contributed to a total of five fatalities (S = 5). A new hazard categorised as 'standing on track while operating equipment' was established. This hazard was associated with the operator standing on the dozer and/or accidentally engaging the equipment in motion. This hazard contributed to four fatalities in the examined period (S = 4). The fatal incident, for example, when a dozer was used to pull the truck out, the chain broke and struck the dozer operator in the temple was attributed to the hazard 'inappropriate task for equipment'.

Figure 7 shows identified hazards 'failure to identify adverse site/geological conditions' and 'failure to control equipment', while Figure 8 shows hazards 'standing on track while operating equipment' and 'inappropriate task for equipment'.

The completed Risk Assessment Matrix for the dozer is shown in Figure 9. There is no hazard categorised as 'almost certain' in the probability category. One hazard is categorised as 'very likely', five as 'likely' and four hazards as 'possible'. There is no hazard categorised as 'high' in the severity category. One hazard is categorised as 'medium' and nine as 'low'.


Figure 7. The hazards 'failure to control equipment' (a) and 'failure to identify adverse site/geological conditions' (b) Source of photos: Mine Safety and Health Administration, 2007, www.msha.gov. (Available in colour online.)

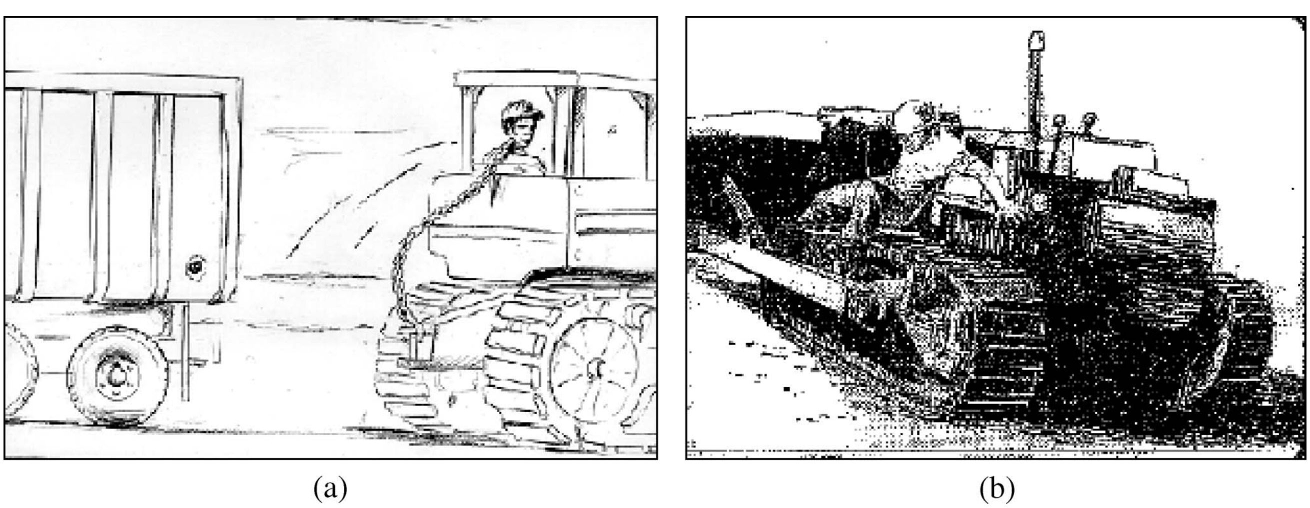


Figure 8. The hazards 'inappropriate task for equipment' (a) and 'standing on track while operating equipment' (b) Source of drawings: Mine Safety and Health Administration, 2007, www.msha.gov.

It can be noted that 'failure to identify adverse site/geological conditions' was the only hazard placed into the category of 'high' risk. Therefore, the largest portion of the available resources should be allocated to control this hazard. Five other hazards that fall in the category of 'medium' risk, which need more attention, are 'failure to control equipment', 'standing on track while operating equipment', 'failure to follow adequate maintenance procedure', 'inappropriate task for equipment' and 'failure to provide adequate illumination'. Additional resources can be allocated to avoid or mitigate hazards located in the lower probability and severity cells. Although having a lower probability of occurrence, they contribute to fatalities. Ignoring these hazards can also increase their frequency and severity in the future.

Figure 10 shows relationship between number of fatal incidents and the type of mining operations. It can be noted that nine fatalities occurred in surface crushed stone mines, eight in surface coal mines, five at coal preparation plants, four in surface sand and gravel mines, two in surface phosphate mines, one in a

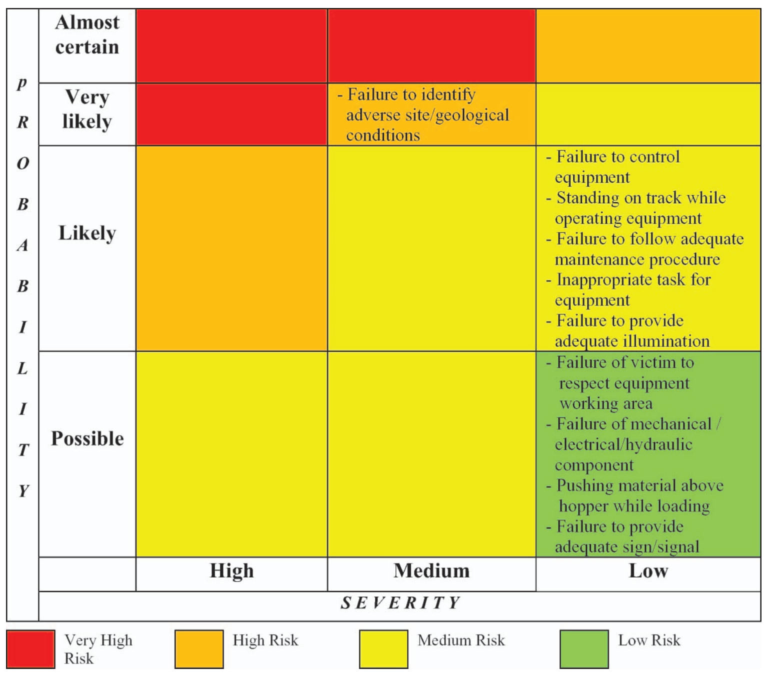


Figure 9. Risk Assessment Matrix for Dozers. (Available in colour online.)

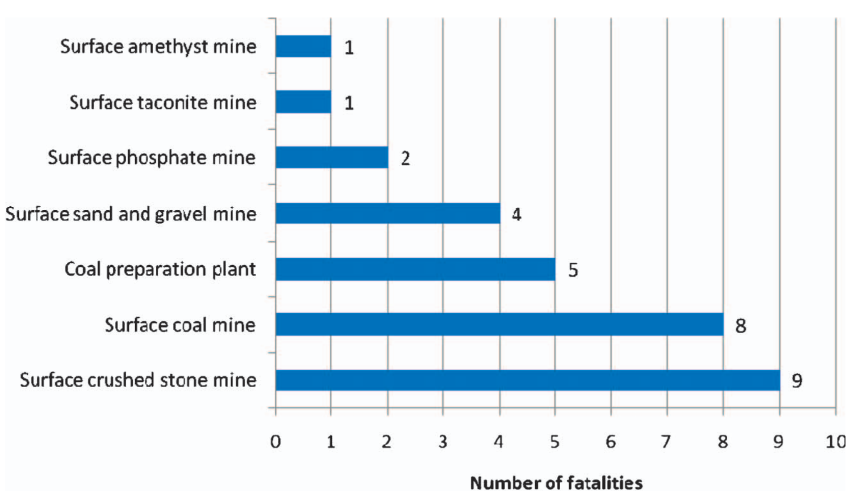


Figure 10. Relationship between mining type and number of fatalities for dozers. (Available in colour online.)

surface taconite mine and one in a surface amethyst mine.

Hazards identified in this study are a symptom of failures in the safety system involving loaders and dozers in US 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 emphasise the need for: 1) additional research to better characterise the 'root cause' of the fatalities; 2) a systematic and thorough approach to incident investigation.

## 4. Conclusions

Risk assessment is a useful and effective method to identify, quantify and evaluate risk. In this study, risks related to loaders and dozers were assessed and ranked. The hazards 'failure to follow adequate maintenance procedure' and 'failure of mechanical/electrical/hydraulic components' were the most severe and frequent hazards for the loaders and they fell into the category of 'high' risk. The hazard 'failure to identify adverse site/geological conditions' was the most severe and frequent hazard for the dozers and it fell into the category of 'high' risk. Therefore, the largest portion of the available resources should be allocated to control these hazards. Finally, since risk assessment is just a part of an entire risk management process, future research effort should be focused on risk control and implementing and maintaining control measures.

### Acknowledgement

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