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IIE Trans Occup. Author manuscript; available in PMC 2016 November 09.

Published in final edited form as:
IIE Trans Occup. 2014 April 8; 2(1): 27–38. doi:10.1080/21577323.2014.911222.

Analysis of Fatalities During Maintenance and Repair Operations in the U.S. Mining Sector

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Abstract

Background—Maintenance and repair work in mining is particularly hazardous and yet has received little focus in ergonomics research.

Purpose—In this article, an attempt has been made to determine if patterns can be identified to categorize maintenance and repair fatalities in mining, to compare occurrence of fatalities between coal and metal/nonmetal sectors, and to use this information to identify safety deficiencies and associated proposed remedial measures.

Methods—A classification scheme was developed to identify patterns in fatalities, including proximal causes, tasks, and contributing factors. This scheme was tested to ensure adequacy of the categories, and fatalities were categorized using the scheme. All testing and categorization were done by two of the authors to ensure reliability of the coding scheme.

Results—Patterns were successfully identified to categorize the fatalities, and these patterns were different between coal and metal/nonmetal mines. Coal mines had a greater proportion of electrical-related fatalities, while more fatalities related to potential energy occurred at metal/nonmetal mines. Most of the fatalities were caused by the victim coming into contact with an object or machine or the victim falling from height, and they occurred most often while the victim was performing maintenance or repair on equipment, cleaning, or removing blockages. The most frequent factors contributing to these incidents were failure to properly de-energize or lock out/tag out equipment, violation of work procedures, missing or inadequate safety equipment, and failure to block equipment properly.

Conclusions—The classification approach used was successful in identifying hazard patterns during maintenance and repair fatalities in mining. These patterns identify areas to focus attention when developing interventions to prevent the occurrence of future fatalities.

OCCUPATIONAL APPLICATIONS

This analysis identified patterns in fatalities during maintenance and repair operations in mining. U.S. mining maintenance and repair fatal reports (2002–2011) were reviewed and used to develop

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CONFLICT OF INTEREST
The authors declare no conflict of interest.

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a classification scheme. Fatalities were classified using this scheme, and proximal causes, tasks performed, and contributing factors were identified, as well as differences in patterns between coal and metal/nonmetal mines. Based on the results, possible interventions to reduce fatality occurrences are discussed. Primary suggestions include ensuring that workers are knowledgeable about and understand the importance of following proper de-energizing and lock out/tag out procedures, particularly in coal mines where the proportion of electrical-related deaths is significantly higher than in metal/nonmetal mines, and proper blocking procedures. Effort should be made to ensure that safety equipment and personal protective equipment are available and used where needed, especially in metal/nonmetal mines where a greater chance exists for objects or miners to fall from heights.

Keywords

Hazard classification; maintenance and repair; mining; fatalities

INTRODUCTION

Mining is a hazardous sector characterized by morbidity and mortality associated with risk posed by heavy physical work, large equipment, confined spaces, and challenging environmental conditions. U.S. mining has the second highest fatal work injury rate across industries, with 15.6 fatalities per 100,000 full-time workers (U.S. Department of Labor, Bureau of Labor Statistics, 2013). The work is less routinized than in other sectors, such as manufacturing and service, due to the changing location and properties of material being mined. This is especially true of maintenance and repair activities that are carried out in a variety of underground and surface locations, and performing atypical tasks such as these can increase the risk of fatal incidents (Villanueva & Garcia, 2011). Despite these risks, little ergonomics research has been carried out on maintenance and repair activities whether in mining or other industry sectors.

As part of a larger project to develop ergonomics audits for maintenance and repair activities (Dempsey et al., 2012), the research team needed to understand tasks performed and potential mechanisms for failure of those tasks to provide the basis for specific audit questions. Traditional surveillance analyses of non-fatal injuries were carried out (Santos et al., 2010; Pollard et al., 2014;) to understand the most frequently reported sources of injuries and to define tasks to be studied either in the field or laboratory in more depth. One shortcoming of surveillance analyses is that they typically identify high frequency injury classes. While the results are especially beneficial for suggesting further in-depth studies that address frequently reported sources of injury, there is often limited information on how specific tasks lead to failures that result in injury. The current study was partially motivated by a need to understand the scope of fatalities that occurred during maintenance and repair in U.S. mining, as well as to determine if there were hazard patterns that could be addressed by the eventual audit.

Although not as common as epidemiological investigations, human factors and ergonomics (HFE) analyses of traumatic incidents in occupational settings have been carried out to

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successfully identify systematic patterns of mismatches between human capabilities and limitations and task demands. Epidemiological findings alone cannot lead to the solutions to human performance mismatches that require an understanding of detailed sequences of events leading to injury or death (Drury & Brill, 1983). Drury and Brill (1983) used an HFE approach to develop accident scenarios, or hazard patterns, for numerous consumer products. The scenarios included characteristics of the victim, task being performed, consumer product, and environment at the time of the accident. The scenarios were considered useful if a maximum of six scenarios accounted for 90% of the in-depth investigations of previous injuries. The scenarios were mutually exclusive, and each scenario had human factors as a major parameter of description. Examples of successful scenarios for chain saws and swimming pools showed the viability of the approach. By comparing task demands at the time of failure (i.e., the accident) to the relevant limiting human subsystem, interventions to prevent future incidents can be suggested.

This concept was used to categorize fatal fall accidents in the construction industry by Chi et al. (2005), where task, individual, tools/equipment, and environment/management factors were noted for 621 fatal accidents. For each scenario, prevention measures were developed for use by the construction industry. Similarly, Drury et al. (2012) used detailed fatal accident reports for U.S. mining haul truck accidents to develop repeating patterns of accidents. Classifying these accidents into repeating patterns helped to reduce the volume of information in the detailed fatality investigations to be considered in progressing toward a valid ergonomics audit program. The patterns were used to supplement a more traditional analysis of a broader dataset that included non-fatal incidents (Santos et al., 2010).

This type of analysis has also been carried out specifically for maintenance fatalities. Lind and Nenonen (2008) studied fatalities and "severe accidents" that occurred in Finland during industrial maintenance between 1985–2004 and 1994–2004, respectively, and characterized causes and contributing factors of the sample. Crushing or being trapped (36%), falling (23%), and falling objects (13%) were the most frequently characterized causes; working while machine is in motion (24%), dangerous working practice (21%) and ignoring the rules and instructions (16%) were the most frequently characterized contributing factors. Lack of attention to ergonomics during maintenance activities, as well as during the design of equipment and the workplace, was cited as one of the major sources of risk.

The availability of a significant number of related fatality accident investigation reports creates the potential for a bottom-up analysis of the fatalities from a human factors standpoint (Drury et al., 2012). With these reports available for mining fatalities, the purpose of the current analysis was to identify patterns of fatal incidents during maintenance and repair operations in mining and, specifically, to identify patterns in tasks performed during fatal incidents as well as factors that contributed to the incidents. The ultimate goal was to use the patterns to understand the HFE implications for inclusion in an ergonomics audit to prevent future fatalities. Fatalities from the mining subsectors of coal and metal/nonmetal (M/NM) were analyzed separately due to potential differences in exposures.

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METHODS

Case Selection

The fatalities used for analysis were selected from all U.S. mining fatalities from 2002 to 2011 that occurred during maintenance and repair activities. The U.S. Mine Safety and Health Administration (MSHA) publishes preliminary accident reports, fatalgrams (short summaries of the fatality used to alert the mining industry), and detailed fatal accident reports for each fatality (MSHA, 2012). Each of the 575 (307 coal, 268 M/NM) fatalities between 2002 and 2011 were reviewed to determine if maintenance and repair were involved. Maintenance activities in mining greatly vary depending on the work environment and object/machine being maintained (Lind, 2008), and they have been defined as unscheduled repairs, inspections, planned preventative operations, and calibration/testing (Reason, 1997). For the purposes of this study, maintenance activities also include building/property maintenance, resulting in a broad definition of maintenance and repair as any tasks or activities required to repair equipment that stopped working or was not working properly, to replace or recondition components (scheduled maintenance), or to complete upkeep of facilities (e.g., cleaning up spillage). Victims were not necessarily part of a maintenance crew or full-time maintenance workers, but rather any employee who was performing maintenance activities during the fatal incident. Maintenance tasks ranged from splicing 4000-volt trailing cables to shoveling spillage from a conveyor.

Only fatalities that clearly involved maintenance activities were included; any records without sufficient information to determine if activities were maintenance related were excluded from the analysis, and any related to construction or dismantling of facilities were also excluded. All fatalities were considered for inclusion independently by at least two of the authors. For cases where there was disagreement or difficulty determining whether maintenance and repair was involved, all three authors discussed the issues to reach consensus. A total of 172 fatalities were identified for the coal ($n = 47$) and M/NM ($n = 125$) subsectors.

The fatalities used for the current study are listed in the Appendix. Detailed fatal investigation reports can be downloaded from MSHA's website (http://www.msha.gov/fatals/fab.htm). The fatalities for the coal and M/NM subsectors are listed separately in the Appendix as well as on the MSHA website. Within subsector, the fatalities are identified by year and a number that refers to the numerical order of fatalities (e.g., 2002–11 refers to the 11th fatality during 2002 in the respective coal or M/NM subsector).

Development and Refinement of Classification Scheme

The M/NM fatality reports were examined by one of the authors to develop the initial hierarchical classification scheme of repeating accident patterns (Wenner & Drury, 2000; Drury et al., 2012). This was done by sorting hard copies of the fatality reports into mutually exclusive groups of fatalities with similar circumstances. The fatalities were categorized at the first level according to energy source, including potential energy, electrical energy, and mechanical energy. Within these, subcategories were identified based on the proximal causes of the fatalities and added when warranted; proximal cause here is defined as the event

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immediately preceding the fatal incidents (Beavers et al., 2006). Within potential energy, the subcategories were "victim falls from height" and "object contacts victim"; within electrical energy, the subcategories were "victim contacts energized object" and "arc flash"; and subcategories for mechanical energy were "victim contacts operating machine" and "idle machine is activated."

Once the initial scheme was completed, the entire set of fatalities was categorized to determine the adequacy of the coding scheme; adequacy was measured by the number of fatalities that could not be classified by the scheme (Drury et al., 2012). The scheme was largely adequate, although there were 20 fatalities remaining that did not fit any of the categories well. Thermal energy, pressure, and toxic vapors or substances were added as categories to fit these additional fatalities. One remaining fatality did not fit any of the categories and was classified as "other." Once these categories and subcategories were finalized, all fatalities were again classified into the final scheme (Fig. 1). The final categorization hierarchy included seven first-level categories (potential energy, electrical energy, mechanical energy, thermal energy, toxic vapors or substance, pressure, other; Fig. 1). "Potential energy" refers to cases where gravity caused an object to contact the victim or for a victim to fall. "Electrical energy" refers to cases where the victim was electrocuted, whereas "mechanical energy" refers to cases where the victim died as the result of being physically contacted by or contacting powered (gasoline, diesel, or electric) machines or equipment.

Final subcategories for potential energy were "object contacts victim" ("object falls from prop onto victim," "object falls from height onto victim," "victim engulfed by material," or "object swings and strikes victim") and "victim falls from height." The "object falls from prop onto victim" category refers to fatalities that occurred as the result of an object supported from above or below unintentionally moving and striking the victim (where the prop is what provides the support). For example, the report for fatality 2010–24 in the M/NM sector included the following: "Martinez was attempting to replace a hydraulic lift arm cylinder on the loader when the lift arms accidentally lowered and pinned him against the frame of the loader …. The lift arms were not secured to prevent them from accidentally lowering." For mechanical energy, subcategories were "operating machine strikes the victim or strikes object against victim," "victim contacts operating machine," "idle machine is activated" (unknown to the victim), and "powered vehicle overturns." For electrical energy, subcategories were "victim contacts energized object" (e.g., live wire) and "arc flash." The remaining categories were not subcategorized based on low frequency counts.

Fatalities were also classified according to the tasks and contributing factors involved in the incidents. Tasks were defined as the activity the victim was involved in immediately prior to the incident, and a single task was identified for each fatal incident. Contributing factors were defined as mistakes or failures that could have prevented the incident from occurring, if corrected (Paradies & Unger, 2008). Due to the complexity of many of the fatal incidents, there were often many factors involved in the individual fatalities. Therefore, where needed, multiple contributing factors were identified for a single fatality. However, each factor involved in the fatalities was assigned to a single contributing factor category (i.e., contributing factor categories are mutually exclusive). Two of the authors independently

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reviewed the fatalities to determine appropriate categories for tasks and contributing factors. The researchers then discussed the categories and made changes as needed. Tasks and contributing factors were analyzed for coal and M/NM mines combined.

Redundant Coding of Fatalities

Using the developed scheme, 2 authors independently categorized each of the 172 fatalities. The categorization was done by two of the authors to ensure that the coding scheme could be used reliably. The research team then compared categorizations, and where discrepancies occurred, the team reviewed each fatality together to reach a consensus. As the entire set was categorized, it became apparent that additional subcategories for proximal causes would be beneficial, and these were added.

Statistical Analysis

A Pearson chi-squared test was used to compare the occurrence of fatalities between coal and M/NM mines. Post hoc testing was performed using a z-test with Bonferroni correction to the p-values. All statistical analysis was performed using IBM SPSS Statistics Version 19 (Armonk, New York, NY). Significance was determined when $p < 0.05$. The test was performed at the first level of the hierarchical scheme (i.e., potential energy, mechanical energy, electrical energy, thermal energy) to ensure sufficient cell sizes.

RESULTS

Categorization of Accident Patterns

Potential energy was the largest category, accounting for almost half of the total fatalities (Table 1). Within potential energy, most accidents were due to objects falling from a prop (~19% of total fatalities) or were due to the victim falling from height (~13% of total fatalities). Mechanical and electrical energy were the next largest categories, accounting for ~28% and ~13% of total fatalities, respectively. Mechanical energy cases were most often due to an operating machine striking the victim or striking an object against the victim or the victim coming into contact with an operating machine. Similarly, most accidents involving electrical energy were due to the victim contacting an energized object.

Identification of Tasks and Contributing Factors

Tasks involved in the fatalities were classified using the 12 categories shown in Table 2. In this analysis, “equipment maintenance and repair” refers to repairing or replacing a part on equipment or troubleshooting an equipment problem, “cleaning” refers to removing spillage/excess material, “removing blockage” refers to the removal of material blocking the flow of other material, “relocating equipment” refers to moving equipment from one location to another, and “maintenance and repair preparation” refers to discussing work or gathering tools/supplies.

Factors contributing to the fatalities were identified using seventeen categories (Table 3); these factors are defined in Table 4. Percentages in Table 3 are of total fatalities involving the contributing factor. It should be noted that although fatalities are often attributed to violations in work procedures, here this category was only used if the factor could not be

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placed in any other category (e.g., if a block was used incorrectly, this was assigned to the "blocking" category and not to "work procedures"). Further, for consistency, "training" was included as a contributing factor each time there was any required training inadequacy, although there was not enough information in the fatal reports to determine if these inadequacies contributed to the fatality.

Chi-Squared Test Results of Comparison Between Coal and M/NM Mines

A significant association between mine type (coal and M/NM) and first-level category was found from the chi-squared analysis (χ^2 (3) = 12.3, $p = 0.006$). Due to the required sample size for chi-squared testing, only four of the first-level categories were included in the analysis; the remaining categories were not included due to their low frequency counts. Post hoc testing showed that both potential and electrical energy categories were significantly different between coal and M/NM mines (both $p < 0.05$; Fig. 2). As shown, M/NM mines had more fatalities due to potential energy, and coal mines had more fatalities due to electrical energy.

DISCUSSION

The analysis of U.S. mining fatalities showed that there are indeed repeatable hazard patterns that result in loss of life. The classification scheme that was developed had mutually exclusive categories, and only one fatality, which involved a medical complication (pulmonary embolism) from a non-fatal leg injury, did not fit any of the categories. Due to its unique nature, the authors were content to have this fatality classified as other. Conversely, almost 90% of fatalities were due to the broad classifications of potential, mechanical, or electrical energy. Mutually exclusive subcategories for proximal causes and tasks were also created that covered all of the fatalities; ~88% of the fatalities were included in seven categories of proximal causes, and ~90% of the fatalities were included in six categories of tasks. Each of these categorization schemes meets or approaches the usefulness criteria of a maximum of six mutually exclusive scenarios accounting for 90% of the incidents set by Drury and Brill (1983). Successfully categorizing the fatalities in this way supports the argument that the patterns identified in the fatalities are meaningful and can be used to suggest intervention strategies.

When creating categories, effort was made to ensure that they were broad enough to identify patterns in the fatalities and yet provide specific and meaningful information about the fatalities to propose intervention strategies. Similar approaches—beginning with broad classifications and using subcategories to identify specific, but shared, characteristics of fatalities—have been used previously to analyze occupational injuries and fatalities (Lincoln et al., 2004; Chi et al., 2005; Beavers et al., 2006).

The most common causes of fatal incidents were objects or machines coming into contact with victims and victims falling from height. These causes are also common of overall fatal injuries across occupations, with 16% of overall fatalities caused by people coming into contact with objects or equipment, and 12% caused by falls to a lower level (U.S. Department of Labor, Bureau of Labor Statistics, 2013). Within objects or machines coming into contact with victims, a large number of the fatalities occurred while the machine was

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operating or the object was energized (~30% total) and could have likely been prevented through proper de-energizing and lock out/tag out procedures, which was the most common contributing factor seen. A similar finding was reported by Lind and Nenonen (2008), who cited working while the machine is in motion as one of the most common contributing factors to fatalities during industrial maintenance. Another primary cause of objects coming into contact with victims was the object falling from a prop (~20%), largely due to a failure in properly using blocking techniques. Many fatal incidents were caused by a failure to block equipment in all directions (e.g., weight of equipment shifts during work and equipment falls off blocks), a misuse of jacks (e.g., using a jack alone to support an object), or failing to block equipment when needed (e.g., removing bolts that support part of the equipment without putting blocks in place). The importance of proper blocking should be emphasized to miners, including ensuring that miners are knowledgeable about all hazards associated with blocking and understand all scenarios during which blocks are needed. More information about when blocking is required can be found in MSHA Regulation 30 CFR 56.14211 (MSHA, 2013).

Cleaning and removing blockages were among the most common tasks being performed during fatal incidents, occurring during ~30% of the fatalities. Many of these fatalities were caused by the victim coming into contact with an operating machine (e.g., while cleaning around an operating conveyor belt) or from the victim failing to wear proper personal protective equipment (PPE) and falling from height or becoming engulfed by material (e.g., falling while cleaning a roof, falling into material while removing a blockage from a crusher). A lack of safety equipment contributed to many of these fatalities, particularly missing conveyor guards and barriers (e.g., unguarded openings). Unguarded openings have also been cited as a leading cause of fall incidents in the construction industry (Chi et al., 2005). To reduce the risk of future fatalities, all conveyor guards should be kept in place while a conveyor is operating, per MSHA Regulation 30 C.F.R 56.14112 (MSHA, 2013). If a guard is not present, all cleaning should be performed with the conveyor de-energized and locked/tagged out. Further, any time there is a risk of falling, barriers should be in place or workers should wear and tie off fall protection. MSHA Regulation 30 C.F.R. 56.20011 requires that barricades or warning signs be present in any area where safety hazards exist (MSHA, 2013) and that safety belts and lines are worn when there is a danger of falling, per MSHA Regulation 30 C.F.R. 56.15005 (MSHA, 2013).

The broadest finding was that there are significantly different distributions of fatalities in the coal and M/NM subsectors of U.S. mining. The coal fatalities indicated a higher proportion due to electrical energy, whereas M/NM showed a higher percentage due to potential energy. This finding confirms differences in exposures between coal and M/NM mine environments. Regarding electrical energy, there is a higher concentration of high-voltage equipment in coal mines compared to M/NM mines, possibly explaining the increase in electrical-related fatalities and emphasizing the importance of proper de-energizing and lock out/tag out procedures in coal mines. Further, there is limited potential energy in underground coal mines due to lower working heights compared to M/NM mines. As such, particular attention should be paid to the availability and use of safety equipment and PPE in M/NM mines, where a greater proportion of fatalities occur due to objects or victims falling from heights.

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From these findings, questions were developed for the ergonomics audit mentioned in the Introduction to help mines identify safety deficiencies that need to be addressed, as well as recommendations to prevent future fatalities. For example, a series of yes/no questions was added to the audit to identify specific issues that may be present in lock out/tag out procedures (e.g., “Are all workers involved in a maintenance or repair activity required to put their lock and tag on equipment?”) given the findings reported in Table 3. The current study, as well as several recent analyses of occupational fatalities (Chi et al., 2009, 2012), stresses the importance of de-energizing equipment prior to maintenance and carefully following required lock out/tag out procedures.

CONCLUSION

Though mining maintenance and repair work is particularly hazardous, it has been given little attention in ergonomics research. In this analysis, a classification scheme to identify patterns in fatalities during maintenance and repair in mining was created and used to identify areas to target interventions to reduce the occurrence of fatalities. Overall findings are that mines should ensure that workers are knowledgeable and understand the importance of following safe procedures for de-energizing, lock out/tag out, and blocking, and that mines need to ensure that safety equipment and PPE are available and used where needed.

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APPENDIX

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TABLE A1

Coal maintenance and repair fatalities 2002–2011

Potential energy					Mechanical energy				Electrical energy		Object contacts victim			
Object falls from prop onto victim	**Object falls from height onto victim**	**Victim engulfed by material**	**Object swings and strikes victim**	**Victim falls from height**	**Operating machine strikes victim or strikes object against victim**	**Victim contacts operating machine**	**Idle machine is activated**	**Powered vehicle overturns**	**Victim contacts energized object**	**Arc flash**	**Thermal energy**	**Pressure**	**Toxic vapors or substance**	**Other**
2002–11	2007–26	2004–06		2005–01	2002–27	2002–14	2005–06		2002–02	2002–15	2003–01	2004–28	2008–03	
2002–17				2007–10	2004–12	2004–08	2006–43		2002–13	2004–17	2003–02	2004–29	2008–29	
2003–18				2007–33	2005–04	2004–19	2007–32		2003–16		2003–03			
2008–06				2007–34	2007–11	2007–25			2003–21		2003–12			
2009–05					2011–15	2009–04			2004–04		2006–37			
2010–01									2004–18					
2011–05									2006–45					
2011–16									2008–09					
									2011–12					

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TABLE A2

M/NM maintenance and repair fatalities 2002–2011

Potential energy					Mechanical energy				Electrical energy		Object contacts victim			
Object falls from prop onto victim	**Object falls from height onto victim**	**Victim engulfed by material**	**Object swings and strikes victim**	**Victim falls from height**	**Operating machine strikes victim or strikes object against victim**	**Victim contacts operating machine**	**Idle machine is activated**	**Powered vehicle overturns**	**Victim contacts energized object**	**Arc flash**	**Thermal energy**	**Pressure**	**Toxic vapors or substance**	**Other**
2002–09	2002–11	2002–03	2005–34	2002–28	2002–17	2002–16	2002–04	2002–14	2002–27	2005–12	2002–12	2002–34	2007–01	2002–42
2002–10	2002–18	2004–11	2006–03	2003–02	2002–32	2002–41	2005–10	2002–15	2003–10	2006–23	2002–22	2005–35	2011–11	
2002–19	2004–19	2004–25	2007–04	2003–03	2003–25	2003–08	2010–07	2003–19	2005–06	2010–16	2003–01	2009–03		
2002–29	2006–24	2005–03	2007–13	2003–14	2004–06	2005–01	2010–18	2008–08	2006–10		2003–04	2010–06		
2002–40	2007–26	2008–06		2003–23	2004–14	2005–18	2010–22		2007–33		2004–01			
2003–05	2008–02	2008–17		2004–04	2005–04	2005–20	2011–03		2008–13					
2003–06	2009–01	2009–02		2004–16	2005–07	2006–05			2009–04					
2003–12	2009–12	2011–14		2005–25	2005–17	2006–09			2011–09					
2003–17	2010–13			2005–28	2005–33	2007–25								
2004–18	2010–14			2005–30	2006–08	2008–09								
2004–22				2006–12	2006–11	2011–13								
2004–23				2006–16	2008–22	2011–16								
2005–08				2006–19	2009–11									
2005–14				2007–19	2010–20									
2006–01				2007–22										
2006–14				2008–15										
2006–21				2010–10										
2006–26				2011–06										
2007–07				2011–10										
2007–28														
2007–30														
2008–14														
2008–18														

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Potential energy					Mechanical energy				Electrical energy		Object contacts victim			
Object falls from prop onto victim	Object falls from height onto victim	Victim engulfed by material	Object swings and strikes victim	Victim falls from height	Operating machine strikes victim or strikes object against victim	Victim contacts operating machine	Idle machine is activated	Powered vehicle overturns	Victim contacts energized object	Arc flash	Thermal energy	Pressure	Toxic vapors or substance	Other
2010–21														
2010–24														

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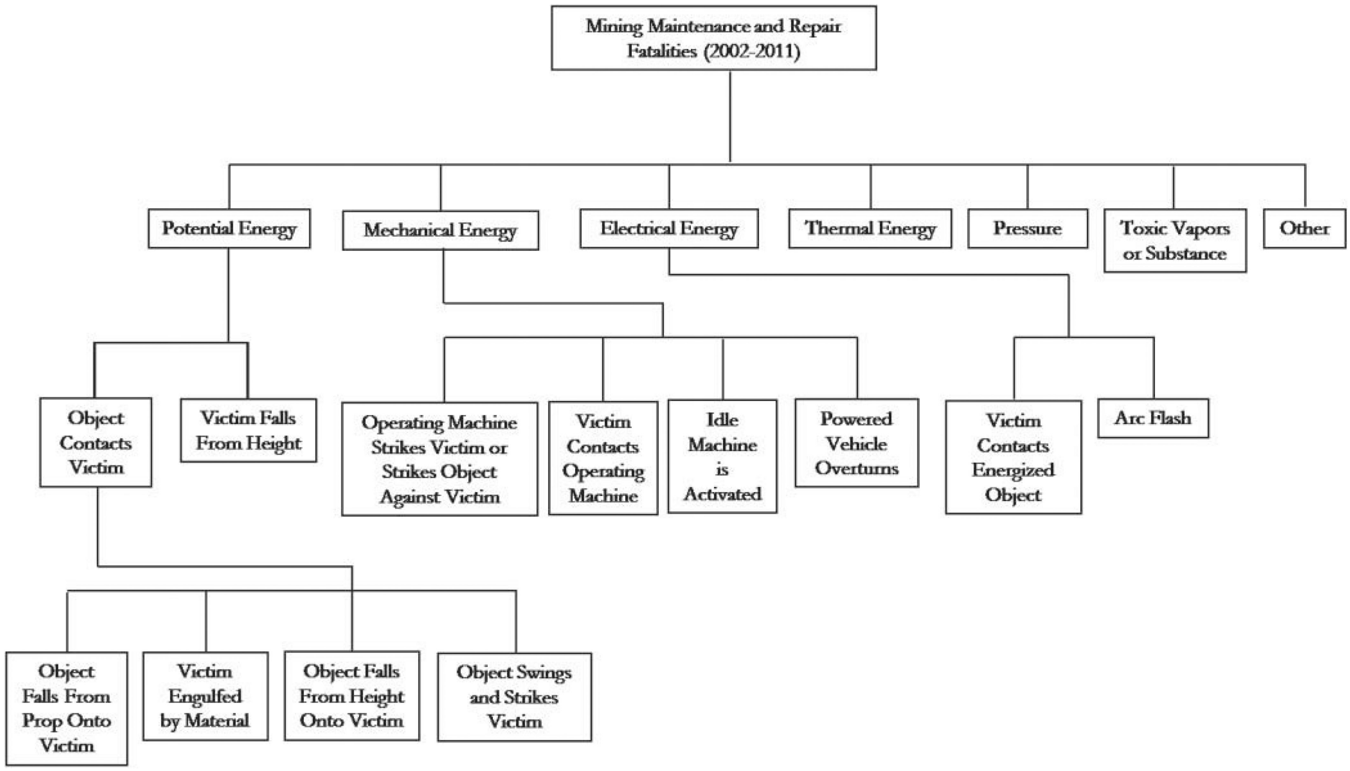

FIGURE 1.
Accident patterns in mining maintenance and repair fatalities.

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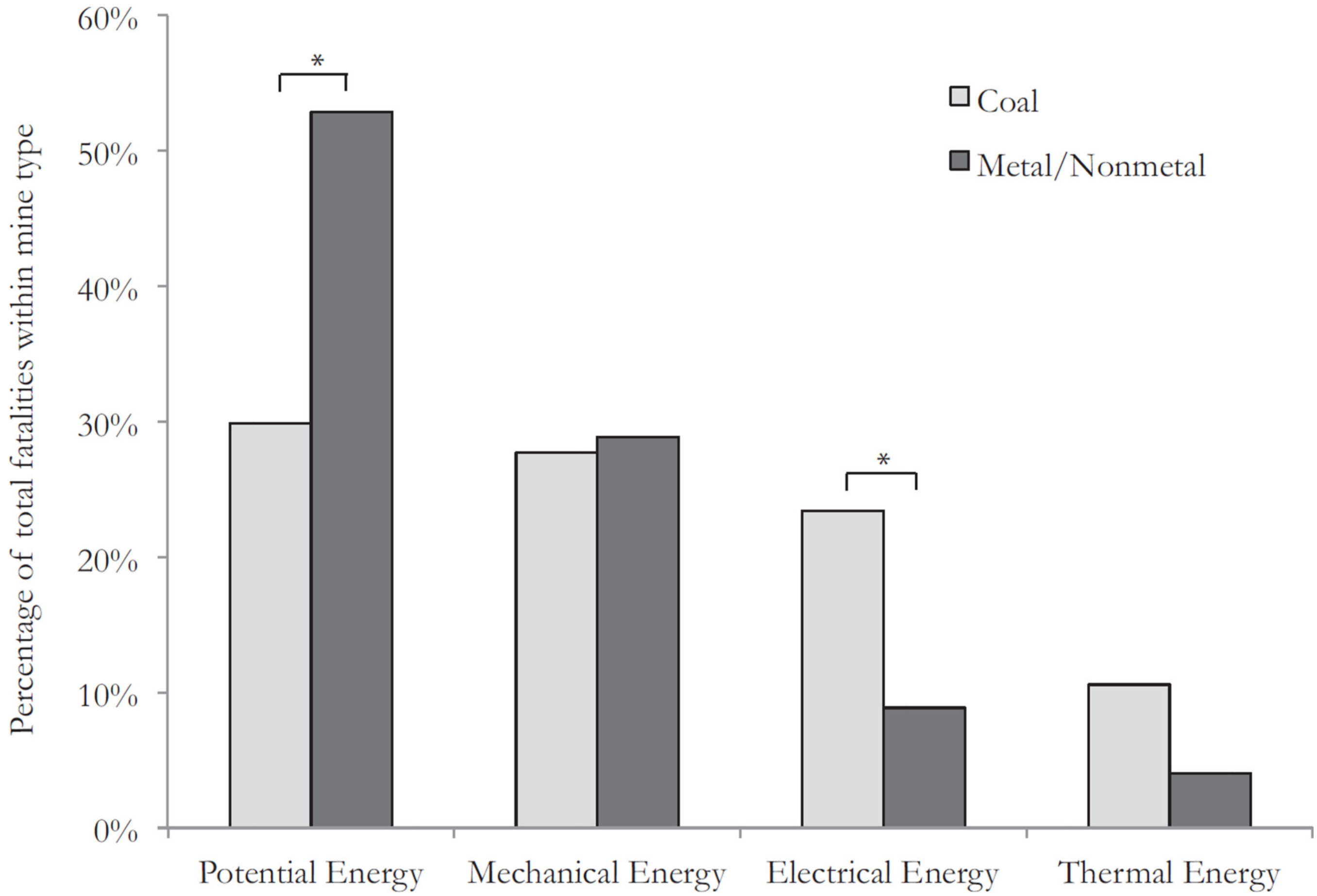

FIGURE 2.

Comparison of coal and M/NM fatalities by first level categories. Significant differences are indicated by asterisk ($p < 0.05$).

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TABLE 1

Frequency counts (*n*) and percentage of total fatalities (%) within mine type and for all fatalities for first-level categories and proximal causes

First level	Proximal cause—first level	Proximal cause—second level	Coal		M/NM		Total	
			n	**Percent**	***n***	**Percent**	***n***	**Percent**
Potential energy			14	29.8%	66	52.8%	80	46.5%
	Object contacts victim		10	21.3%	47	37.6%	57	32.9%
		Object falls from prop onto victim	8	17.0%	25	20.0%	33	19.1%
		Object falls from height onto victim	1	2.1%	10	8.0%	11	6.4%
		Victim engulfed by material	1	2.1%	8	6.4%	9	5.2%
		Object swings and strikes victim	0	0.0%	4	3.2%	4	2.3%
	Victim falls from height		4	8.5%	19	15.2%	23	13.3%
Mechanical energy			13	27.7%	36	28.8%	49	28.3%
	Operating machine strikes victim or strikes object against victim		5	10.6%	14	11.2%	19	11.0%
	Victim contacts operating machine		5	10.6%	12	9.6%	17	9.8%
	Idle machine is activated		3	6.4%	6	4.8%	9	5.2%
	Powered vehicle overturns		0	0.0%	4	3.2%	4	2.3%
Electrical energy			11	23.4%	11	8.8%	22	12.7%
	Victim contacts energized object		9	19.1%	8	6.4%	17	9.8%
	Arc flash		2	4.3%	3	2.4%	5	2.9%
Thermal energy			5	10.6%	5	4.0%	10	5.8%
Pressure			2	4.3%	4	3.2%	6	3.5%
Toxic vapors or substance			2	4.3%	2	1.6%	4	2.3%
Other			0	0.0%	1	0.8%	1	0.6%
Total			47		125		172	

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TABLE 2

Frequency counts (*n*) and percentage of total fatalities (%) of total fatalities for tasks

Task	*n*	%
Equipment maintenance and repair	79	45.9
Cleaning	29	16.9
Removing blockage	23	13.4
Relocating equipment	9	5.2
Maintenance and repair preparation	7	4.1
Welding	6	3.5
Dismantling equipment	5	2.9
Supervising/inspecting	5	2.9
Installing equipment	3	1.7
Adjusting equipment	2	1.2
Excavating	2	1.2
Greasing	2	1.2

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TABLE 3

Frequency counts (*n*) and percentage of total fatalities (%) of total fatalities for contributing factors

Contributing factor	*n*	Percent
De-energizing or lock out/tag out	44	25.6%
Work procedures	36	20.9%
Safety equipment	35	20.3%
Blocking	34	19.8%
Training	33	19.2%
PPE	26	15.1%
Work environment	21	12.2%
Equipment	19	11.0%
Previous error	10	5.8%
Suspended load	8	4.7%
Communication	7	4.1%
Structural failure	6	3.5%
Inspection	4	2.3%
Work overhead	4	2.3%
Medical complication	3	1.7%
Modified equipment	2	1.2%
Substance abuse	1	0.6%

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TABLE 4

Contributing factor definitions

Contributing factor	Definition
Communication	Failure of person-to-person communication through inadequate communication channels or misunderstood communication
Equipment	Equipment failure or poor equipment design
Inspection	Failure to properly inspect equipment during routine inspection
Medical complication	Victim had a medical complication
Safety equipment	Safety equipment missing, inoperative, or improperly used (e.g., guard, barrier, fault protection, emergency stop, warning sign, audio alarm)
Modified equipment	Equipment was modified
De-energizing or lock out/tag out	Failure to properly de-energize and/or lock out/tag out equipment
PPE	PPE missing, inadequate, or improperly used (e.g., seat belt, fall protection, electrical gloves)
Previous error	Previous maintenance or installation error (e.g., known problem not corrected)
Structural failure	Failure of permanent structure (e.g., building, walking surface, equipment)
Training	Worker (not necessarily the victim) lacking required training (e.g., overall mine training, task specific training)
Work procedures	Did not follow procedures or no safe procedures provided (e.g., improper use of equipment)
Work environment	Worker did not have a safe environment to perform work (e.g., inadequate lighting/ventilation/ space, wet conditions, poor housekeeping, no safe access to work area)
Work overhead	Working or traveling underneath work
Substance abuse	Victim under the influence of a substance (e.g., alcohol)
Blocking	Failure to properly support raised object from beneath (e.g., missing or misused jack stands, blocks, or wheel chocks)
Suspended load	Failure to properly support raised object from above (e.g., missing or misused hoist, person working underneath or close to suspended load)