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# Enhancing severe injury surveillance: The association between severe injury events and fatalities in US coal mines ☆

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ABSTRACT

This report evaluates the potential of using high degree (or severe) injuries as a proxy for fatal events. Injuries occurring at bituminous coal mines within the United States during the years 1996-2006 were classified by the degree of severity according to the Abbreviated Injury Scale (AIS). Using multivariate discrete and logistic models (via generalized estimating equations) and adjusting for number of employees and underground v. surface status, high degree (AIS ≥ 3) injuries in the prior year were associated with an increased risk (OR 2.02, 95% CI 1.17 to 3.46) of fatalities within the same mine. While there is a need for improvements and standardization of injury surveillance and reporting, the findings support the study hypothesis that mining conditions resulting in high degree injuries can also result in fatalities, thus expanding the use and versatility of high degree injury surveillance data. With an improved understanding of the conditions and activities behind these two injury event types, these results enhance the ability for industry to more readily identify and develop technological advancements for safety and mitigating disasters.



## 1. Introduction

Despite improvements over time, mining remains a dangerous profession (Margolis, 2010). While prevention of all injuries is important, there is a priority on reducing the number of fatal injuries. Given their infrequent nature, there is a need to identify more common incidents that could serve as proxies for fatal injuries. The underlying conceptual model for this project is that severe injuries stem from the same mine conditions and operation parameters that cause fatalities and can perhaps be conceptually thought of as "near miss fatalities." Therefore, it is hypothesized that the occurrence of a severe injury in a mine will act as an indicator for an increased risk of a fatality at the same operation. In this approach, less severe injuries will not be associated with fatalities. If true, focusing on the causes and prevention of severe injuries should also help to prevent fatalities.

The Mine Safety and Health Administration's (MSHA) surveillance data includes injuries and illnesses with a wide range of severity up to and including fatalities. However, these data do not include a standardized measure of injury severity, necessitating application of a validated external measure of severity. First developed in 1971, the Abbreviated Injury Scale (AIS) was originally designed to assist in automotive crash investigations. It provides a consensus-driven ordinal scale to classify injury severity that is anatomically-based and highly correlated with survival and mortality (Abbreviated Injury Scale, 2008 Edition). The AIS uses the ordinal classification for coding injuries as follows: (1) minor; (2) moderate; (3) serious; (4) severe; (5) critical; and (6) maximal (currently untreatable). The MSHA surveillance system was not designed to capture the same level of injury/illness detail as a medical chart; however, there is sufficient information to score the severity of most injuries. The focus of this research was to increase the utility of current injury surveillance data managed by MSHA to enhance the identification of risk factors for severe injuries and fatalities in the coal mining sector.

## 2. Methods

Data were obtained from MSHA's *Accident, Injury and Illness* (AII) databases and from *Address/Employment* (A&E) files available online (accessed February, 2009). The National Institute for Occupational Safety and Health (NIOSH) recodes and adds several computed variables to these databases prior to their availability online. While the unit of analysis ultimately was aggregated to the individual mine level, the population in this study included non-office mine employees (i.e., non-contractors) 18 years of age or older, working in the bituminous coal mining industry and reported to have sustained an injury at an underground, surface, or surface at underground operation. Only reportable injuries that occurred to non-office, non-contracted employees at bituminous coal mines were included. Excluded from this study were mines with zero non-office employees and missing production data, injuries that required only minor

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first aid, occupational illnesses, employee natural caused fatal and non-fatal injuries and injuries occurring at mills/preparation plants, and independent shops/yards or other surface locations.

A primary objective of this study was to evaluate whether mines with severe injuries were more likely to record fatalities. Accordingly, individual cases were aggregated to the level of the individual mine. Prior to aggregation, mine data from *A&E* files were merged with the injury details from *AII* data files matching by the MSHA unique mine identifier. As such, the mine became the unit of analysis, with the primary outcome being the presence/absence of a fatality within a mine for a given year, during the period 1996-2006. If data for a mine were present in *A&E* files but not in the *AII* files, it was assumed the mine experienced no injury in the particular year. Hence, mines with injuries could be compared with mines with no injury, rather than only evaluating characteristics of mines with injuries.

The *nature of injury* and *body location* variables were used to code for severity. AIS was scored by a trained, certified coder. Due to the nature of the data and limited details on the extent of injury, conservative score criteria were used. It was not possible to assign an AIS value to injury events defined in MSHA data as "multiple injuries" (*nature of injury* code 370) although 107 (3.66%) of the 2,925 injuries so labeled were fatal.

Fatal events were identified by the NIOSH variable *injury type*. Statistical models were fitted on mine-year level data, with an outcome measure of the presence/absence of a fatal injury. The primary independent variable (presence/absence or number of high degree injuries) was replaced with the prior year's observation to avoid having a single injury incident being coded as both a severe injury and a fatality in the same mine in the same year, which would have falsely inflated the odds ratio. The use of a "lag year" methodology necessitated that each mine identification have any combination of two or more consecutive years worth of observations, and necessitated that the initial year of a mine series was excluded from analysis.

### 2.1. Statistical modeling

To account for the repeated measurements within mines, generalized estimating equations (GEE) were used to assess the association between fatalities and injury severity over the duration of the study period. In this analysis, the binomial response was fitted with a logit link (i.e., the natural log of the odds) and an exchangeable working correlation structure. The variance-covariance matrix for the regression parameters in each model was then obtained by a sandwich estimator through GEE. Several potential confounding factors related to mine characteristics were evaluated. These factors included the size by employees of the mine, tons of coal produced, type of mine (underground or surface), and time. Correlations among covariates were checked for collinearity. Variables with marginal significance ($p<0.2$) in univariate models were included in multivariate GEE regression analyses using a forward selection model building process. The possibility of non-linear time trends were assessed using quadratic functions of time (i.e., year) in the GEE models. Estimates between linear and non-linear time trends were not significantly different when collinear covariates were excluded from models. Consequently, time was evaluated only as a linear covariate and estimates in all models were found to be non-significant. The prior year high degree injury variable was evaluated as both a dichotomous (presence/absence) and discrete (i.e., number of high degree injuries) variable type. Due to the highly skewed nature of high degree injury counts, the count variable was transformed by taking the base 2 log of the count plus 1. All statistical analyses and models were run using Stata software version 10.1 (College Station, Texas).

In general, the term "severe" injury is not standardized among the various sources of data used in this study. To evaluate whether the occurrence of more damaging injuries were associated with fatalities, AIS was used to create a binary variable defining "high degree" injuries. High degree injuries were defined a priori as having an AIS score of three or greater (i.e., serious, severe, critical and maximal injuries). Minor and moderate injuries (AIS 1-2) were considered lesser-degree injuries, and labeled "low degree." For the sake of comparison, other models were evaluated using different cut points for "high degree" injuries.

## 3. Results

During the years 1996-2006, there were 56,526 reported injuries from 2,442 mines meeting the study inclusion and exclusion criteria. Of these injuries, 274 were fatal and occurred at 207 separate mines. Twenty-five mines reported at least one fatality in multiple years. There were 5,845 mines identified in the *A&E* database that did not record (or report) any injury during the study period. Of the 56,526 injuries, 10,625 (18.8%) did not contain sufficiently detailed information (in either the nature of injury, part of body, or both variables) to generate an AIS score. Table 1 describes the nature of injury for each of the known AIS levels. Using the MSHA variable *part of body*, the ten standard body regions in the calculation of Injury Severity Scores (which is AIS based) were used to show the distribution of AIS injuries (Fig. 1). Injuries with incomplete detail to generate an AIS score are not displayed ($N=10,625$). Using Spearman's rank correlation, there was a small, but significant positive correlation ($\rho=0.1139$, $p<0.001$) between AIS and the average number of actual days lost.

Potential confounding factors that showed statistical significance in univariate regression models were mine type (underground versus surface operations, the reference group) and the number of non-office employees (using a natural log transformation to normalize the distribution). Coal production was found to be highly correlated (collinear) with the number of employees, and hence, was excluded from analyses. In multivariate analysis, Table 2 compares our a priori definition of high degree injury (AIS 3-6), which demonstrated a significantly elevated odds ratio, to two other models neither of which reached statistical significance. For the significant multivariate model, underground mine status had an elevated odds ratio (3.10, 95% CI 2.16-4.42) for a mining fatality as did the natural log of the number of employees (2.15, 95%CI 1.92-2.41). Adjusting for mine type and number of employees, the odds ratio of fatality in a given mine-year was 2.02 (95% CI: 1.17-3.46) times greater in mines with a two-fold increase in the number of high degree injuries (adjusted by $+1$) during the prior year.

Table 3 shows the unadjusted two-by-two table of mine-year fatal events and high degree injuries in the prior year. As can be seen in the table, there were 13 pairs of mine-years with fatality in one year and a high degree injury in the prior year. In order to determine whether the same conditions ever resulted in both high degree injuries and fatalities in consecutive mine years, the 13 concordant pairs were individually evaluated. A review of the injury narratives showed that many of the contributory factors between the fatality and the accident that occurred in the preceding year were distinctly similar. Of these pairs, only one involved a surface operation. Both incidences involved experienced mechanics tasked with the repair and maintenance of equipment, where the injuries were the result of failures in rigging and temporary supports. Of the 12 concordant pairs that occurred in underground mining, five had similar conditions and contributory factors. The first pair involved the fall of rock from the roof, while the second pair involved employees getting caught or pinched by a piece of equipment. The third pair involved employees being struck by a system or machine part that was being supported or moved while repair work was being performed. The details of the fourth pair are incomplete, but both incidents involved the fall of rock that led to the high degree injury. The fifth concordant pair both involved the fall of rib at, or near, the working face that caused the high degree injury.

The similarities of these incidents for an individual mine has significant implications with regards to maintenance procedures, task training, and supervision at the operation. It also provides a basis

**Table 1**
Nature of injury distributions for injuries with known AIS score, 1996-2006.

| Nature of Injury | Low Degree Injuries | | High Degree Injuries | | | | Total† |
|---|---|---|---|---|---|---|---|
| | AIS 1 minor | AIS 2 moderate | AIS 3 serious | AIS 4 severe | AIS 5 critical | AIS 6 maximal | |
| Crushing | 410 | 123 | 20 | 11 | 1 | 42 | 607 |
| Fracture, chip | 3,437 | 3,841 | 74 | 0 | 0 | 0 | 7,352 |
| Asphyxia, strangulation, drowning, etc | 0 | 0 | 33 | 0 | 0 | 0 | 33 |
| Amputation or enucleation | 304 | 35 | 24 | 0 | 0 | 0 | 363 |
| Cerebral hemorrhage | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| Sprain, strains | 19,285 | 0 | 0 | 0 | 0 | 0 | 19,285 |
| Cut, laceration, puncture | 10,830 | 1,061 | 0 | 0 | 0 | 0 | 11,891 |
| Contusion, bruise | 5,054 | 0 | 0 | 0 | 0 | 0 | 5,054 |
| Scratches, abrasions | 376 | 0 | 0 | 0 | 0 | 0 | 376 |
| Dislocation | 86 | 176 | 0 | 0 | 0 | 0 | 262 |
| Non-contact electric | 83 | 124 | 0 | 0 | 0 | 0 | 207 |
| Joint, tendon, or muscle inflammation | 196 | 0 | 0 | 0 | 0 | 0 | 196 |
| Concussion – brain, cerebral | 126 | 0 | 0 | 0 | 0 | 0 | 126 |
| Electrical injury* | 0 | 111 | 0 | 0 | 0 | 0 | 111 |
| Electrical burn | 0 | 31 | 0 | 0 | 0 | 0 | 31 |
| Hearing loss or impairment | 6 | 0 | 0 | 0 | 0 | 0 | 6 |
| *Total* | *40,193* | *5,502* | *152* | *11* | *1* | *42* | *45,901* |

† 10,625 injuries with incomplete details to score for AIS.
* The "nature of injury" code 210 for MSHA/NIOSH classifies the observed injury as "electric shock, electrocution".

for implementing interventions to mitigate the potential likelihood of similar incidents occurring in the future.

## 4. Discussion

To our knowledge, the empirical association of mining fatalities with high degree injuries has not been previously established. Fortunately, high degree injuries (as defined by an AIS score ≥ 3) are relatively rare among this population. With the data presented here, it is reasonable to state that mines sustaining high degree injuries have an increased likelihood for fatal events. It is important to note, however, that the interpretation is not meant to be temporal. That is, the results do not suggest that high degree injuries precede (or cause) fatal events. Rather, the results demonstrate an association between high degree injuries and fatalities at the individual mine level in consecutive years. It is therefore possible that severe injuries may be suitable proxies or indicators of conditions that have the potential to facilitate disasters, although the infrequent nature of disasters prevents appropriate analysis. In addition to their association with fatalities, it is important to note that high degree injuries are themselves consequential and identify areas requiring improved occupational safety management.

As previously stated, we are not aware of any other studies associating severe injuries with a subsequent fatal injury in the mining industry, and in addition we were not able to find a similar analysis in any other industry. However, there have been a number of studies of fatalities in the mining industry and in other industries. In Australia, mining has a higher injury rate than in the general occupational workforce, and specific activities, tasks, mechanisms and work practices were found to be common contributing factors (Mitchell, Driscoll, & Harrison, 1998). In the U.S., equipment-related mining fatalities are common, particularly related to haul trucks, belt conveyers and front-end loaders (Kecojevic, Komljenovid, Groves, & Radomsky, 2007). Although not specifically addressing fatal injuries, we have previously shown a marked decline in lost-time injuries associated with the introduction of risk management regulations for the Australian coal-mining industry (Poplin et al., 2008). Some studies have evaluated risk factors for fatal occupational injuries in other industries, including but not limited to race and foreign workers in all occupations combined (Ahonen & Benavides, 2006; Loomis & Richardson, 1998) and age and ethnicity among specific subgroups including ironworkers and roofers, as well as smaller company size in the construction industry (Buskin & Paulozzi, 1987; Sorock, Smith, & Goldoft, 1993).

Limited detail was the principal limitation to this study. Overall, 18.8% of the reported injuries lacked enough information to score for AIS, including those categorized as multiple injuries. Anecdotally, review of the fatalities recorded as multiple injuries suggest that the injuries suffered from such events would likely be severe. Revising the MSHA coding process for multiple injuries to include information on the three most severe injuries would be expected to markedly increase the power to detect associations between fatal and high degree

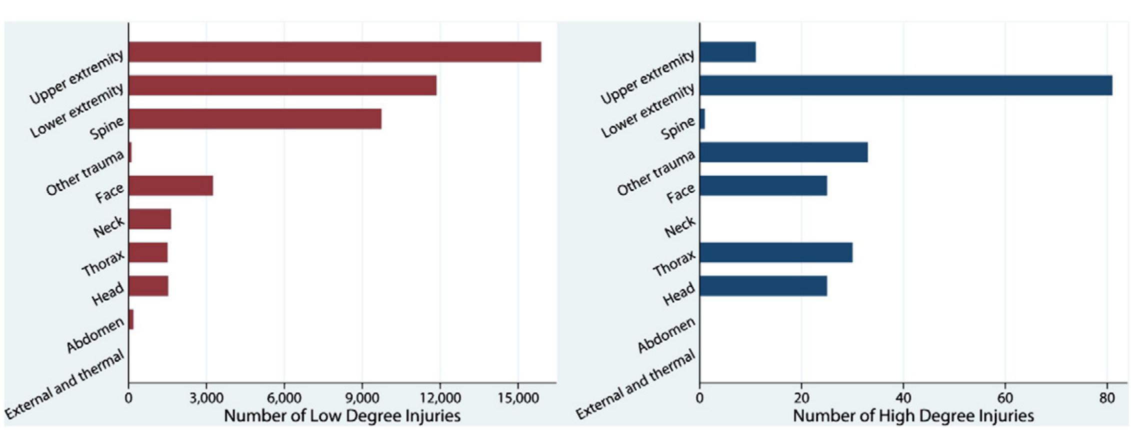


**Fig. 1.** Distribution of low and high degree injuries by body region.

**Table 2**
Estimated odds ratios of fatal events with increasing restrictions to the definition of a high degree injury.

| High Degree Injury Model | N* | OR† (95% CI) | p-value |
|---|---|---|---|
| AIS 1-6 | 7,248 | 1.08 (0.95 – 1.23) | 0.237 |
| AIS 2-6 | 2,731 | 1.15 (0.95 – 1.41) | 0.156 |
| AIS 3-6 | 153 | 2.02 (1.17 – 3.46) | 0.011 |

* Number of mine-year observations with respective AIS injury type recorded (out of 16,008).
† Prior years' count transformed by log2(#high degree injuries + 1), adjusted for underground status and the number of employees.

injuries. Our process included a review of the majority of high degree injuries (155 of 206; 75.2%), defined from two variables: *nature of injury* and *body part*. Upon review of the narrative sections, inconsistencies between the narrative and classified nature of injury were periodically observed. While these cases were few, there is a potential for misclassification; however, the possibility of these cases producing a significant differential bias is unlikely.

In this study, a "high degree" injury was one with an AIS score of three or greater. Results shown in Table 2 demonstrate that expanding the inclusion criteria for a "high degree" injury to AIS 2 + (as well as all injuries) produces greater variation and no discernible distinctions. In both cases, the odd ratios were of lesser magnitude and of no statistical significance. Given the limited details specific to injury, some coding for AIS could be considered subjective; however, this potential was hopefully reduced by having a trained AIS coder scale the injuries. While having multiple coders would be ideal, the general lack of injury details resulted in conservative coding, reducing the benefit of multiple coders. The more important aspect of injury research is that the methods accounting for degree of severity use a standardized method to judge/score/rank injury severity. AIS is one of the most widely accepted tools to determine injury severity (MacKenzie, Steinwachs, & Shanikar, 1989; Peitzman, Rhodes, Schwab, Yearly, & Fabian, 2002). The level to which AIS can be utilized will depend on the original data source and how well information on the injury is detailed. Since the MSHA/NIOSH data collection systems are not trauma or medically oriented, noteworthy limitations are introduced to the scoring from the lack of specificity.

Much of this research was fundamentally based on classifying the severity of injuries based on the nature and type of injury to specific body locations. It is clear that improvements can be made to enhance the collection of specific injury details using standardized methods and reporting schemes that augment the versatility and robustness of mining injury data. Most information currently reported pertains to the event itself, with far less detail regarding the sustained injury and potential factors involved in the injury process. It is therefore recommended that MSHA reports provide more complete details on the injury (or injuries) incurred, particularly the nature and anatomical site of each injury sustained by the individual. Enhancing the capability to properly classify injury severity for individuals sustaining both single and multiple injuries will improve the management of health and safety resources aimed at injury prevention. In particular, more complete description of injuries currently coded as "multiple injury" should greatly increase the number of identifiable high degree injuries. As previously noted, 2,925 injuries were coded as multiple injuries. If information is collected and made available for the three most severe components of a multiple injury case, the scoring for injury severity (by the AIS) would be possible. We anticipate that through this process the number of identified high degree injuries would increase markedly. Given the high frequency of multiple injury cases, in addition to the conservative nature of injury reporting and collection, the reported odd ratios are likely to underestimate the actual risk associated between separate fatality and high degree injury events within the same mine.

**Table 3**
Two-by-two table for unadjusted odds ratio estimate.

| | | Mine-year with fatal injury | | |
|---|---|---|---|---|
| | | Yes | No | Total |
| Prior mine-year with a high degree injury | **Yes** | 13 | 140 | 153 |
| | **No** | 182 | 15673 | 15855 |
| | **Total** | 195 | 15813 | 16008 |

## 5. Summary and industry impact

These study findings expand the use and versatility of mining injury/illness surveillance data by enabling mines to capitalize on information derived from high degree injuries in order to help identify the root causes responsible for fatalities and develop appropriate injury reduction and prevention strategies. Discerning operations and identifying activities that are associated with an increase in the risk of injury enable data-driven intervention strategies to be developed to help mitigate hazards and reduce the potential for adverse events. In addition, through the remediation of the hazards associated with these more severe injuries, it is expected that the mine will reduce the likelihood of high degree injuries, thus reducing the direct and indirect costs attributed to accidental loss, litigation and labor, while maintaining and improving their employee's production, quality of life, and functionality.

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