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Examining Factors that Influence the Existence of Heinrich's Safety Triangle Using Site-Specific H&S Data from More than 25,000 Establishments

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In the 1930s, Heinrich established one of the most prominent and enduring accident prevention theories when he concluded that high severity occupational safety and health (OSH) incidents are preceded by numerous lower severity incidents and near misses. Seventy-five years of theory expansion/interpretation includes two fundamental tenets: (1) the ratio of lower to higher severity incidents exists in the form of a "safety-triangle" and (2) similar causes underlie both high and low severity events. Although used extensively to inform public policy and establishment-level health and safety priorities, recent research challenges the validity of the two tenets. This study explored the validity of the first tenet, the existence of the safety triangle. The advantage of the current study is the use of a detailed, establishment-specific data set that evaluated over 25,000 establishments over a 13-year time period, allowing three specific questions to be explored: (1) Are an increased number of lower severity incidents at an establishment significantly associated with the probability of a fatal event over time? (2) At the establishment level, do the effects of OSH incidents on the probability of a fatality over time decrease as the degree of severity decreases—thereby taking the form of a triangle? and (3) Do distinct methods for delineating incidents by severity affect the existence of the safety triangle form? The answer to all three questions was yes with the triangle form being dependent upon how severity was delineated. The implications of these findings in regard to Heinrich's theory and OSH policy and management are discussed.

KEY WORDS: Herbert Heinrich; safety pyramid; safety triangle

1. INTRODUCTION

The administration of occupational safety and health (OSH) activities may be observed at various levels within a general ecological framework. Workers, organizational supervisors/managers/leaders, federal/state/local government, and society all play an important role in occupational injury and illness prevention. Research and development is a critical function within the OSH community and provides essential information, tools, and technology to these entities to bolster prevention efforts.

An important function of research in this regard is to conduct studies designed to contribute information relevant to pressing needs and questions. Within the OSH community, different and unique needs and questions arise as the context of work has evolved. Others, however, have, and always will, span the test of time. One such pressing question is the need to understand the precursors of high severity OSH outcomes. This understanding provides opportunities for the development of targeted, well-designed interventions to reduce the probability of such events.

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Although effective interventions are most often context specific and unique to a given process, technology, and organization of work, at the organizational level they are increasingly seen to fit into a generalized management system designed to identify, assess, and control idiosyncratic risk.[1] A prominent component to the unique derivation and ongoing management of health and safety management systems is the use of historical OSH incident data to identify and assess the risks for which interventions need to be tailored or altered.

The wide use of such data in this regard stems from a concept that originated from the work of Herbert Heinrich.[2] Heinrich postulated and showed through analysis of approximately 50,000 incidents that high severity occupational events are often preceded by larger numbers of less severe events and near misses.[3–5] Heinrich proposed a specific ratio relating the number of near miss incidents and minor harm injuries to a single major harm injury in the form of 300:29:1, respectively, and depicted the ratio in the form of a "safety triangle." Although Heinrich's ideas have been very influential to OSH policy and management, their prominent place in accident prevention theory has recently been questioned.[6–8] Recent criticisms center on the legitimacy of the fixed ratios as well as the idea that high severity OSH incidents can be prevented by controlling the hazards and risks revealed through cause analysis of lower severity OSH incidents.

Given the highly influential and debated theory, additional research on the topic is important. The current study used Mine Safety and Health Administration (MSHA) data corresponding to tens of thousands of mines over the course of a 13-year period (2000–2012) to explore whether or not the OSH incidents and injuries that a mining establishment experienced influenced the probability of a fatal accident event within that establishment in subsequent years. Taking into account the magnitude of effect sizes for each of the distinct types of lower severity OSH incidents demarcated by degree allows for the potential to explore whether or not a systematic decline in effect exists between the most and least severe incidents—thereby examining whether or not a "safety triangle" of sorts exists at the establishment level.

In the following section, Heinrich's theory, research designed to explore ideas behind the theory, and the major debate points are presented. We then present a detailed discussion of the data and methods used, the results of that analysis, and the results of a subsequent analysis that illuminate the potential difficulties of conducting related research given the existence of distinct sets of generally accepted injury severity categories. We conclude with an overall discussion of findings from an OSH policy and management perspective.

2. THEORETICAL BACKGROUND AND RESEARCH QUESTIONS

Work stemming from Heinrich[2] has produced one of the longest lasting and most influential theories in the OSH discipline the—"safety triangle".[9]

Either stemming directly from Heinrich's work or from follow-up theory-building efforts, numerous interrelated arguments have been made that provide the rationale behind the use of historical incident data and the safety pyramid assumptions to inform OSH management decisions in an effort to reduce the probability of high severity OSH outcomes.[10–17] Noted benefits span the levels of the ecological model.

At the individual level, knowledge, skills, and abilities can be enhanced by practicing risk analysis and mitigation skills for low and lower severity incidents. At the establishment level, tracking, monitoring, and communicating the analysis of less severe OSH incidents can be used to improve overall system performance and the collective awareness required for organized action. At the regulatory level, metrics associated with low and lower severity OSH incidents can be used to derive an understanding of OSH management effectiveness at a given establishment as well as the level(s) and types of industrial risks workers are exposed to. Finally, because the systemic causes of less severe incidents and high severity incidents may be similar, correcting the root causes of less severe incidents can directly decrease the probability of high severity ones. For these reasons, the assumptions inherent to the safety triangle have become a cornerstone in OSH, an important consideration in international efforts to mandate and /or encourage reporting of injury statistics, and are often used in the scientific estimation of global injury statistics.[6,18–20]

However, the prevalent use of Heinrich's safety triangle has recently been questioned. Criticisms center on two interrelated points: (1) because the causes of low and high severity OSH outcomes may or may not be similar, a proportional reduction in high severity incidents may not be experienced by analyzing and controlling the risks associated with low severity OSH events; and (2) the methodology used to develop the "safety triangle" was unclear. Both of these criticisms have led to questions regarding the legitimacy of the safety triangle and its role in OSH policy and management.

In regard to the first criticism, Manuele's[7] theoretical work sought to "debunk" the connotation that reducing the frequency of less severe incidents equivalently reduces severe injuries. He argued that fatality and severe injury events often occur without any prior evidence or forewarning obtained through the analysis of less severe and near miss OSH incidents, and, thus, ratios of OSH incident counts delineated by degree are not realistic. Mixed empirical findings in regard to the first criticism have provided fodder for the arguments that undergird it. For example, although studies have found support for the notion that OSH incidents delineated by degree have distinct causes (e.g., Saloniemi and Oksanen)[15] others (e.g., Wright and van der Schaaf)[13] found consistent causes between low and high severity events.

In regard to the second criticism, Rebbit[9] suggested that, given that Heinrich's original data are not available, it is not possible to "verify or categorically refute" the specific ratio within the triangle. He further argued that the general way in which Heinrich categorized the OSH incidents demarcated by severity (i.e., *major*, *minor*, and *incident*) makes it difficult to conduct replicable studies. Similarly, Taxis *et al.*[6] argued that because of the absence of the methodological clarity with which it was derived, the validity of a ratio and its use in OSH policy and management should be questioned, and, based on the results of their study in the context of healthcare, the authors found no evidence of a fixed ratio of OSH incidents. Still, numerous additional studies have uncovered a proportional ratio of OSH incidents delineated by degree.[2,12,21–23]

Criticisms and mixed findings have caused questions to surface regarding not only the legitimacy of specific ratios of OSH incidents delineated by degree, but also the idea that controlling the risk(s) uncovered through causal analysis of low and lower severity OSH incidents can reduce the likelihood of high severity events.[9,24,25] It seems that in the OSH community we lack agreement on the fundamental assertion that decreasing the number of low and lower severity OSH incidents can decrease the probability of a high severity OSH event over time. The answer to this question seems requisite prior to the conclusion that the number of incidents preceding high severity OSH events increases as the severity of those events decrease (i.e., whether or not there is evidence of the classic safety triangle shape in the proportion of OSH incidents delineated by degree of severity). Thus, the first two research questions explored in this study were:

(1) Are increased numbers of OSH incidents delineated by degree significantly associated with an increased probability of a single catastrophic OSH event (i.e., an occupational event that resulted in a fatality) over time?
(2) Do the effects of OSH incidents on the probability of a fatality decrease as the degree of severity decreases?

In relation to the second research question, in order to conclude that the results conform to the safety triangle concept, we needed to find the largest increase in the probability of a fatal event to be associated with OSH incidents of higher severity (e.g., a permanent disabling injury)—and conversely the smallest increase in the probability of a fatal event to be associated with OSH incidents of low severity or reportable events with no injuries (i.e., near misses).

Based on previous research, an important consideration that needed to be taken into account when exploring these research questions was the incident severity delineation used. Within the literature two general methods have been used: (1) delineations based on categorical descriptions of degree such as "near misses," "minor injuries," "major injuries," "recordable injuries," and/or "days away from work injuries"[2,12,21,22]; and (2) delineations based on the number of days.[23] This leads to a third and final research question:

(3) In a single context (i.e., U.S. mining establishments), do different OSH incident categorization schemes lead to different results in regard to the first two research questions?

Finally, it can be noted that most studies are unclear about the level of application for which the derived ratio is expected to generalize and/or how the ratio could be expected to be used in OSH management and practice at the establishment level. Because previously developed ratios were derived from large groups of establishments, industry-level incident data, or incident data across industrial sectors, an important consideration is whether the ratios should be conceived to apply across or within establishments. This lack of clarity appears to be a serious limitation to the findings offered in previous studies given that the application of the triangle is most appropriate with risk management and accident prevention efforts at the establishment level. Thus, we sought to derive answers to these three research questions with an explicit application at the level of the establishment.

After a search of existing databases of OSH outcomes, the database developed and maintained by the Mine Safety and Health Administration (MSHA) was selected. The MSHA databases were selected because of the detail provided regarding incident and injury statistics corresponding to each mining establishment in the United States. Because the databases include a fixed unique mine identification code over time, a fatality that a given mine experienced corresponding to a given year can be regressed on the number of near misses and injuries delineated by degree that same mine experienced in a previous year, over the course of multiple years, and across tens of thousands of mining establishments. A properly designed analysis, therefore, can be used to derive a single effect for the probability for a mining establishment to experience a high severity OSH outcome (i.e., a fatality) for a single unit increase in the number of near misses and injury types experienced in a previous year. Within the current study, these effects were estimated over the 2000–2012 time period, for each mining establishment, and across all applicable mines in the sample derived from the databases.

3. METHODS

3.1. Data

Two of MSHA's publicly available databases were used to create a data set appropriate for the research questions and analytical approach. These were the Mine Address and Employment (AE) and the Mine Accident, Injury, and Illness (AII) databases. At the time the data were downloaded (middle of 2015) the most recent complete year for each of the databases was 2012.

The AE database is a list of all the existing mines within the United States and is compiled from a mine-level required quarterly report (MSHA Form 7000–2). Each case within the AE database represents an existing mine; therefore, each case exists at the level of the mine. The database is organized by a unique mine identification code and contains information pertaining to the geographic location of the mine, the mine's status (e.g., active, inactive), hours worked throughout the year, and other employment statistics. Because the number and status of mines can change over time, a distinct AE database is available by year. The AII database contains information related to each reportable OSH incident that a mine experienced throughout the course of a given year. Distinct from the AE database, each case within the database represents an individual OSH incident; therefore, each case exists at the worker level within each mine. Similar to the AE database, however, each reportable OSH incident is linked to a specific mine through the unique mine identification code, thus the set of OSH incidents are linked to the mine that they occurred in. Also similar to the AE database, the AII database is distinct by year.

The AII database is derived through compilation of MSHA-required form 7000–1 (MSHA's Mine Accident, Injury, and Illness Report). MSHA requires that mines record and report each of the following events using the form:

- a fatality;
- an injury with the potential to cause death;
- a worker entrapment of 30 minutes or more;
- an unplanned mine inundation by liquid or gas;
- an unplanned ignition or explosion of dust or gas;
- an unplanned mine fire not extinguished within 30 minutes of discovery;
- an unplanned ignition of a blasting agent or explosive;
- an unplanned roof fall;
- a coal or rock outburst that causes the withdrawal of miners;
- an unstable condition at an impoundment, refuse pile, or culm bank;
- hoisting equipment failure or damage;
- any off-site injuries due to an accident event.

In many instances, these reportable events do not actually result in worker injury. In these cases the AII database indicates that no injury resulted from the reportable accident.

The AII database includes numerous variables associated with each reported incident, including information related to its degree. The degree of injury variable is a single variable in the AII database populated using multiple entries from Form 7000–1. It codes each OSH incident as a reportable noninjury event, a fatal event, an injury that resulted in days lost or restricted duty, or a reportable injury (those without lost or restricted days). An additional variable in the AII database shows the actual number of lost or restricted days corresponding to that particular injury event.

As discussed, the degree of injury categories used in previous studies vary widely. It is generally accepted that the Heinrich's *incident* category refers to an OSH event that did not result in an injury (i.e., a near miss) and it can be argued that the most severe OSH incidents are those that resulted in an occupational fatality—thus a placeholder for the top and bottom of the triangle are assumed. However, the categorization of severity delineated injuries that fall in between the top and the bottom tiers of the triangle are not necessarily clear. Thus, an important consideration needs to be made in relation to the injury severity categories used in this regard. Given that, according to the MSHA record-keeping requirements, the AII database *a priori* classifies injuries according to severity within the degree of injury variable, we choose to initially use this categorization scheme. As a result, each OSH incident in the AII database was classified as: (1) a fatality; (2) an injury that resulted in a permanent disability; (3) an injury that resulted in lost and/or restricted days (herein referred to as a *days lost injury*); (4) an injury that resulted in medical treatment beyond first aid, but did not result in death, days away, or restricted duty/job transfer (herein referred to as a *reportable injury*); and (5) a reportable incident that did not result in an injury (herein referred to as a *reportable noninjury*).[1] Dummy variables were created for each of the degree categories and each reported OSH incident was then coded within the AII database. We also reserved the variables pertaining to lost and restricted days per incident for subsequent analysis related to research question number 3.

For each year individually (2000–2012), the databases were then aggregated to the mine level (by mine identification code) by summing each of the dummy coded degree category variables as well as the number of lost and restricted days associated with the injuries. The resulting databases included the total number of each type of OSH incident a given mine experienced throughout the year and the total number of lost and restricted days associated with those incidents for each year 2000–2012. All of the individual yearly databases were then merged to create a data set that included the total number of each type of OSH incident and the total number of lost/restricted days a given mine experienced by year 2000–2012.

Importantly, the AII database only includes a case for a particular mine if a reportable OSH incident was experienced by a mine during a given year. An active and operating mine with zero reportable OSH incidents during a given year would not have any associated cases in the AII database. Thus, a case for each year that a mine was active and operating, but had zero accidents or injuries needed to be added. This was accomplished by isolating all active and operating mines from the AE database for each year 2000–2012 and merging it with the AII database. Zeros were then imputed for each of the dummy coded OSH incident degree variables for the years in which a mine was active but had no case identified within the AII database. This step ensured that relevant statistics were included for each mine during the years they were active between the 2000–2012 time period. Finally, due to the longitudinal nature of the research question, mines with only one active year and nonconsecutive mine x year cases during the 2000–2012 time period were removed.

Given that the research question of interest was to test the effect of OSH incidents by degree on fatalities over time, the fatalities variable was lagged within each mine by one year.[2] This step allowed fatalities that a mine experienced during a given year to be included in the same case as the counts of degree delineated OSH incidents the same mine experienced in the preceding year.

Upon descriptive analysis of the resulting data set, it was noted that the large majority of mine x year cases represented a year that a mining establishment did not experience a fatal event; 86.3% of the cases in the data set. Further, of the mines that experienced

[1]Illnesses were omitted from the analysis given that they may not directly materialize from a single event that occurred during the course of a given year in question. Illnesses were therefore not used as a relevant variable.

[2]It should be noted that an explicit consideration of the amount of time lag between lower and high severity OSH incidents is not integral to original theory related to the derivation of the safety pyramid. We chose a one-year time lag given the structure of the data after considering alternative options. Time lags greater than one year would result in: (1) multiple counting of predictor years so that each year of the dependent variable (i.e., fatalities) could be modeled; or (2) skipping years of the dependent variable to avoid biasing the results. Further, models explored with time lags less than a year (i.e., by month) significantly increased the number of zeros on both the predictor and the dependent variable sides of each statistical model, resulting in a null effect for each predictor.

a fatality in a given year (2000–2012), very few of them experienced more than a single fatality in that year; only .05 percent. Given the low frequency of mine x year fatality cases, coupled with the rare case in which a mine experienced more than one fatality in a single given year, we dichotomized the fatality variable (i.e., 0 in the case where zero fatalities were experienced in a given year and 1 in the case where one or more fatalities were experienced in a given year). This step also eliminates potential bias that could be introduced due to a single, catastrophic event that resulted multiple fatalities.

The resulting database included 27,446 distinct mines that were active at least two consecutive years during the 2000–2012 time period:[3] 5,606 coal mines (20.4%); 660 metal mines (2.4%); 1,163 nonmetal mines (4.2%); 7,301 stone mines (26.6%); and 12,716 sand and gravel mines (46.3%). During this time period, there were 668 cases in which an active mine included in the data set experienced at least one fatality during the course of a year. The large majority of these fatal events occurred at a mine that experienced only 1 fatality in a year during the 2000–2012 time period (505 mines); 52 mines experienced 2 fatal event years during the time span; 11 mines experienced 3 fatal event years; 5 mines experienced 4 fatal event years; and 1 mine experienced 6 distinct fatal event years.

3.2. Analytical Approach

The primary research question concerns how counts of OSH incidents delineated by degree effect the probability of an establishment experiencing a fatal OSH incident in a subsequent year over the course of the 2000–2012 time period. Consistent with the manner in which the data set was derived, the nature of this question requires time-dependent variables to be nested within each establishment. Therefore, the potential dependence within mines over time must be considered when choosing an appropriate analytical technique. Due to the dichotomized nature of the outcome and the dependence within mines over time, longitudinal logistic statistical models were used to estimate the change in probability for an establishment to experience a fatality in a given year by counts of reportable OSH incidents in the previous year (t–1).

Five distinct models were initially fit—four simple longitudinal logistic models and one multiple longitudinal logistic model—each in SAS version 9.3 using generalized estimating equations (GEE). Previous ratio research has not explicitly included a consideration of generalizability in relation to organizational size. Consistent with previous studies that model the impact of predictor variables on OSH incidents over time,[1,15,26] it appears relevant to include a multiple logistic regression model that controls for the consideration that an increased number of hours worked during the year at a given establishment can influence the probability for a fatal event to occur within the same establishment. However, given that mine size is also likely to influence the lower severity OSH incident predictors (perhaps unequally), its inclusion as a control could act as a suppressor variable and impact the ability to adequately interpret their relative effects. Given the core research is to examine the relative effects in relation to the pyramid assertion, a thorough examination of both the independent and controlled effects was examined. Further, noted differences between the independent and controlled model coefficients have the potential to highlight the possible contingencies and challenges involved with deriving a fixed ratios.

The four simple longitudinal logistic regressions executed included each of the distinct lower severity OSH incident variables (i.e., permanent disabling injuries; days lost injuries; reportable injuries; and reportable noninjuries) entered as individual independent variables to predict the probability of a subsequent fatal event year. Models 1–4 took the form of:

$$logit(P[fatality_{it}]) = B_0 + B_1(number\ of\ injuries\ of\ given\ degree)_{i,t-1}$$

where i is the individual mining establishment, and t is the year.

In the fifth model, all four degree of injury variables were entered in a multiple longitudinal logistic regression model with the natural log of the total number of nonoffice employee hours during the year the fatal event took place and took the form of:

$$logit\ (P[fatality_{it}]) = B_0 + B_1(Permanently\ disabling\ injuries)_{i,t-1} + B_2(Days\ lost\ injuries)_{i,t-1}$$

[3]Of these mines, 12.5% were active for two consecutive years only; 9.9% for three years only; 8.9% four years only; 7.4% five years only; 5.9% for six years only; 5.7% for seven years only; 5.1% for eight years only; 4.7% for nine years only; 3.9% for ten years only; 3.6% for 11 years only; 3.0% for 12 years only; and 29.5% or 8,089 mines that were active each year in the 2000 to 2012 time period.

$$+ B_3(Reportable\ injuries)_{i,t-1}$$
$$+ B_4(Reportable\ non\ injuries)_{i,t-1}$$
$$+ B_5 * log(employee\ hours)_{ij}$$

Each of the models allows for a single odds ratio to be generated for each of the representative OSH incident categories for the 2000–2012 time span. In all models, the OSH incident predictor variables were entered into the regression equation untransformed to allow for straightforward interpretation of the results. Additionally, given the longitudinal nature of the data set, the correlation structure was defined as autoregressive. Thus, for the simple logistic models, the interpretation for each exponentiated coefficient (the odds ratio) represents the change in probability for a mining establishment to experience a fatal event in a given year for every one additional OSH incident (of the given degree) in a previous year for the 2000–2012 time period. For the multiple longitudinal logistic models, the odds ratio is interpreted as the change in probability for a mining establishment to experience a fatal event in a given year for every one additional OSH incident (of a given degree) in a previous year (2000–2012) while controlling for the effects of the other three OSH incident types included in the model and mine size (Model 5).

4. RESULTS

4.1. Preliminary Analysis Results

Prior to executing the longitudinal logistic models, two preliminary analysis steps were undertaken in an effort to determine if the pattern of OSH incidents that mines experienced in a given year differed depending upon whether or not they experienced a fatality the subsequent year. Table I shows the average number of OSH incidents a group of mines experienced per year depending upon whether they experienced a fatal event in the subsequent year (the fatal group) or they did not experience a fatal event in a subsequent year (the nonfatal group) during the 2000–2012 time period. Table II shows the average OSH incidence rates between the same two groupings. Rates were analyzed in this case to preliminarily explore the prospective pattern of OSH incident differences while accounting for the number of hours an establishment worked during the course of the year. Both tables also include a nonparametric test for the difference between the average counts (Table I) and average rates (Table II) between the two groups.

The results of this preliminary analysis suggest that there are significant differences in OSH incident counts and rates between the group of mining establishments that experienced a fatal subsequent year and those that did not for each of the incident types. This suggests that the pattern of OSH incidents is different for mining establishments depending upon whether or not they experienced a fatal event in a subsequent year when considering both raw counts and incident rates. Collectively, these results provide some preliminary justification for running the more complex longitudinal logistic models designed to answer the primary research inquiries.

4.2. Longitudinal Logistic Results

The linearity assumption was tested by examining the box-cox transformations between each of the independent variables and the logit. For the multiple longitudinal regression models, multicollinearity was assessed by observing the correlations among the

Table I. Difference in Prior Year OSH Incident Count Between Fatal and Nonfatal Establishment Years

Severity of OSH Incident	Fatal vs. Nonfatal Groups	Prior Year Mean Count	SE	Kruskal–Wallis χ^2 and Significance Level
Permanently disabling injuries	Nonfatal	0.01	>0.00	392.46***
	Fatal	0.09	0.01	
Days lost injuries	Nonfatal	0.53	0.01	1139.61***
	Fatal	5.48	0.38	
Reportable injuries	Nonfatal	0.26	0.01	1069.18***
	Fatal	2.66	0.20	
Reportable noninjury	Nonfatal	0.12	0.01	1489.08***
	Fatal	1.76	0.20	

Note: Degrees of freedom Kruskal–Wallis tests are equal to 1 (comparing two groups).
***$p < 0.001$.

Table II. Difference in Prior Year Average OSH Incident Rate Between Fatal and Nonfatal Event Years

Severity of OSH incident	Fatal vs. Nonfatal Groups	Prior Year Mean Rate	SE	Kruskal–Wallis χ^2 and Significance Level
Permanently disabling injuries	Nonfatal	0.03	>0.00	251.77***
	Fatal	0.05	0.02	
Days lost injuries	Nonfatal	1.70	0.03	547.22***
	Fatal	3.62	0.30	
Reportable injuries	Nonfatal	0.87	0.01	486.32***
	Fatal	1.44	0.16	
Reportable noninjuries	Nonfatal	0.18	0.01	1153.62***
	Fatal	1.21	0.19	

Note: Rates computed using the following formula $\frac{\text{(number of OSH incidents x 200,000)}}{\text{number of employee hours worked}}$; degrees of freedom Kruskal–Wallis tests are equal to 1 (comparing two groups).
***$p < 0.001$.

independent variables and formally tested through collinear diagnostics in a regression model. Correlations among the independent variables range from small to medium and are reported in Table III. Because collinear diagnostics are not available directly within logistic models, the variance inflation factor (VIF) for each regression coefficient was generated by executing a multiple linear regression with each of the degree of injury variables entered as predictors with an arbitrary outcome. Consistent with the correlations among the predictor variables, the VIF is highest for the days lost injuries and reportable injuries (1.99 and 1.80, respectively); however, these derived VIF statistics are below the lower bound of recommended VIF values.[27]

Table III also reports the correlations of each of the accident and injury categories with the natural log of mine hours worked. Each of the correlations is positive and significant, suggesting that as the relative number of mine hours worked increased so did the number of OSH incidents reported. This correlation was strongest between mine hours and days away injuries (r = .36) and mine hours and reportable injuries (r = .34).

Table III. Correlations Among Predictor Variables

	(1)	(2)	(3)	(4)
(1) Permanent disabling injuries	–			
(2) Days lost injuries	0.25	–		
(3) Reportable injuries	0.21	0.66	–	
(4) Reportable noninjuries	0.14	0.43	0.34	–
(5) Log worker hours	0.14	0.36	0.34	0.17

Note: All correlations significant, $p < 0.05$ level.

Table IV shows the total number of low and lower severity OSH incidents by degree over the sample between 2000 and 2012 along with the results of the four simple longitudinal logistic models and the multiple longitudinal logistic model. The results of Models 1–4 suggest that a one unit increase in each of the degree of injury variables resulted in a higher probability for a mine to experience a fatality in a subsequent year during the 2000–2012 time period. The probability was highest for permanently disabling injuries. There was a 6.6 times greater probability for a mine to experience a fatality in a given year for each additional permanent disabling injury it experienced in a preceding year. For each additional days lost injury, there was a 10% increased probability for a mine to experience a fatal event in a subsequent year. An additional reportable injury resulted in a 19% increased probability for a mine to experience a fatality in a subsequent year. Lastly, each additional reportable noninjury resulted in an 8% increased probability for a mine to experience a fatal event in a subsequent year.

Model 5 was executed to examine the effect of each type of injury while controlling for the other three degree of injury types along with the natural log of the number of employee hours worked. As in Models 1–4, the coefficients for permanent disabling injuries and reportable noninjuries were significant. However, when controlling for the number of employee hours and other OSH incident types, the coefficients corresponding to the days lost injuries and reportable injuries were not. When controlling for days lost injuries, reportable injuries, reportable noninjuries, and employee hours there was a 1.37 times increased probability for a mine to experience a fatal year for each additional permanent disabling injury

Table IV. Estimated GEE Odds Ratios for Simple and Multiple Longitudinal Logistic Models

		Models 1–4		Model 5	
OSH Incident Type	*N*	Odds Ratio (95% CI)	*P*-Value	Odds Ratio (95% CI)	*p*-Value
Permanently disabling injuries	1,613	6.63 (4.84–9.09)	<0.001	1.37 (1.05–1.82)	0.020
Days lost injuries	99,643	1.10 (1.07–1.14)	<0.001	1.01 (0.99–1.02)	0.369
Reportable injuries	47,643	1.19 (1.12–1.26)	<0.001	1.01 (0.98–1.04)	0.431
Reportable noninjuries	22,140	1.08 (1.04–1.12)	<0.001	1.02 (1.01–1.03)	0.020
Log (employee hours worked)				2.16 (2.00–2.34)	<0.001

Note: *N* is the total number of OSH incidents by type experienced across all mines in the sample. Models 1–4 report the results of each OSH incident type regressed independently on subsequent year fatalities. Model 5 reports the results of the multiple longitudinal logistic model in which each predictor and the log(employee hours worked) was entered simultaneously into the equation.

it experienced in a preceding year. The odds ratio for experiencing a fatal event due to an increase of one reportable noninjury in a previous year was 1.02. Additionally there was a significant prediction of the log of employee hours on the probability of fatality (OR = 2.16).

From the models executed, there is evidence that a single unit increase in each of the OSH incidents delineated by severity significantly increases the probability of a fatal injury in a subsequent year at the establishment level. Based on the effect sizes derived, a one unit increase in the most severe injury severity category (i.e., permanently disabling injuries) had the largest effect and a one unit increase in the least severe category (i.e., reportable noninjuries) had the smallest effect. This pattern of results is consistent with a triangle type structure of ratios derived in previous studies. However, the results also suggest that a one unit increase in reportable injuries (those without associated lost or restricted days) had a larger influence on the probability of a subsequent year fatal event than the effect of days lost injuries (those with associated lost or restricted days). When controlling for the number of hours worked and other OSH incident predictors, both displayed an approximate null effect and dropped from significance.

Taken on its face, these results somewhat undermine the premise contained in the triangle structure: that the proportion of lesser degree OSH incidents preceding a single catastrophic occupational accident event is greater than that of higher degree OSH incidents. It would require a greater number of days lost injuries to equal the effect of reportable injuries on the probability of subsequent year fatality, and when controlling for hours worked and the other predictors, both effects are approximately equal and null.

In order to address research question number 3 additional severity categories were explored. As noted, the initial approach took the severity categories *a priori* established within the MSHA database. In order to derive additional possibilities, we referred to the previous ratio research conducted by the U.K. Health and Safety Executive and reported in Gordon and Risley.[23] The study used a unique set of OSH incident severity anchors in which injuries were differentiated based on the number of days lost. This approach is also consistent with recent methods used to evaluate the severity of nonfatal injuries.[28]

4.3. Additional Analysis

Grounded in the previously mentioned approach, the total number of lost and restricted days each mine experienced were used to derive relevant categories. We explored two different ways to categorize this variable: (1) the total number of lost and restricted days the mining establishment experienced during the year; and (2) the average number of lost and restricted days per OSH incident the mining establishment experienced during the year—computed by dividing the total number of lost and restricted days by the total number of reported OSH incidents.[4] For this analysis, we explored the categorical effect of the variable—with zero lost/restricted days as the reference group—using the longitudinal logistic model approach.

Gordon and Risley[20] used categories associated with three or fewer days and greater than three days lost. In order to derive the reported categorical groupings of severity based on lost and restricted days, we imposed a variety of categorical groupings

[4]We also explored the additional groupings as a function of the total number of days lost only. We found the pattern and relative magnitude of effect sizes to be consistent across the models.

Table V. Estimated GEE Odds Ratios for Simple and Multiple Longitudinal Logistic Models for the Total Lost and Restricted Days Categorical Predictor

	Simple Logistic Model		Multiple Logistic Model	
Total Lost and Restricted Days	Odds Ratio (95% CI)	*p*-Value	Odds Ratio (95% CI)	*p*-Value
1–16 days	2.55 (1.86–3.12)	<0.001	0.95 (0.64–1.35)	0.766
17–100 days	6.30 (4.25–8.79)	<0.001	1.75 (1.32–2.30)	<0.001
>100 days	17.34 (15.35–19.71)	<0.001	2.69 (2.09–3.44)	<0.001
Log(employee hours worked)			1.94 (1.81–2.07)	<0.001

Note: In both the single and multiple logistic models total Lost and Restricted days was entered as a categorical predictor where the reference group is the zero total lost or restricted duty days category. The simple logistic model includes only the categorical predictor in the model. The multiple logistic model includes the categorical predictor along with the log(employee hours worked).

and executed a number of longitudinal logistic models in order to pinpoint noticeable delineations in effect. When examining the effect of the mine's total number of lost and restricted days on subsequent year fatalities the reported groupings were: 1–16 days, 17–100 days, and greater than 100 days. We report these final groupings given the derived effect was relatively stable within the categories based on the exploratory analysis (e.g., the effect of 1–5 total days was nearly equivalent to effect of 6–16 days, etc.).

Table V reports the odds ratios for each of the final categories based on the total number of lost and restricted days a mining establishment experienced during the course of the year as an individual categorical predictor and while controlling for the number of hours worked during the course of the year. In both models, the reference group is the circumstance in which the mine had zero lost or restricted days during the year. The odds ratio for each category reflects the increased probability for a given establishment to experience a fatal event in a subsequent year when compared to a year with zero lost and restricted days.

Table V shows a significant difference between each of the categories and the reference group in a simple logistic regression model. There is also a large increase in probability between each of the categories as the number of total days lost/restricted increases (1–16 days, OR = 2.55; 17–100 days, OR = 6.30; >100 days, OR = 17.34). This finding suggests, for example, that mines with a total number of days lost/restricted that exceeds 100 in a given year are 17.34× more likely to experience a subsequent year fatal event when compared to mines with zero lost/restricted days. When controlling for the number of hours worked, the model suggests that there is no significant difference in the probability of a subsequent year fatal event between mining establishments that had a total of 16 or less total lost/restricted days and those that had none. When controlling for hours worked, a significant difference remained between zero total days lost/restricted and mines with a total of 17–100 days (OR = 1.75) and those with a total of 100 days or more (OR = 2.69).

A similar approach was taken in the derivation of the reported categories according to the average number of days lost/restricted per reported OSH incident. The final groupings were: 1–3 days lost/restricted per incident; 4–10 days lost/restricted per incident; and greater than 10 days lost/restricted per incident. Similar to the models used to analyze the total number of lost/restricted days, the reference group is the circumstance in which the mine had an average of zero lost or restricted days per incident during the year. Table VI reports the odds ratios for the each of the final categories based on the average number of lost and restricted days per OSH incident a mining establishment experienced during the course of the year along with the odds ratios while controlling for the number of hours worked during the course of the year.

In both the simple and multiple logistic models, there was no significant difference in the probability of a mine experiencing a subsequent fatal year between the reference category (an average of zero days lost/restricted per incident) and contexts in which a mine experienced an average of one to three days lost/restricted per incident. In the simple logistic model, there was a significant difference between the reference category and the remaining two categories (an average of 4–10 days lost/restricted per incident, OR = 2.22; and >10 days lost per incident, OR = 3.20). When controlling for the number of hours worked, there was no significant difference between the reference group and the average of 4–10 days lost/restricted per incident category; however,

Table VI. Estimated GEE Odds Ratios for Simple and Multiple Longitudinal Logistic Model for the Average Lost and Restricted Days per Incident Categorical Predictor

	Simple Logistic Model		Multiple Logistic Model	
Average Lost and Restricted Days	Odds Ratio (95% CI)	*p*-Value	Odds Ratio (95% CI)	*p*-Value
1–3 days	1.12 (0.74–1.67)	0.569	0.86 (0.57–1.29)	0.476
4–10 days	2.22 (1.57–3.12)	<0.001	1.26 (0.88–1.80)	0.197
>10 days	3.20 (2.50–4.15)	<0.001	1.64 (1.26–2.16)	<0.001
Log(employee hours worked)			2.18 (2.02–2.36)	<0.001

Note: In both the single and multiple logistic models average Lost and Restricted days was entered as a categorical predictor where the reference group is the zero average lost or restricted duty days category. The simple logistic model includes only the categorical predictor in the model. The multiple logistic model includes the categorical predictor along with the log(employee hours worked).

the difference between the >10 days lost/restricted per incident and the reference group remained significant (OR = 1.64).

5. DISCUSSION

The current analysis set out to explore three primary research questions:

(1) Are increased numbers of OSHs delineated by degree significantly associated with an increased probability of a single catastrophic OSH event (i.e., an occupational event that resulted in a fatality) over time?
(2) Do the effects of OSH incidents on the probability of a fatality over time decrease as the degree of severity decreases?
(3) In a single context (i.e., U.S. mining establishments), do different OSH incident categorization schemes lead to different results in regard to the first two research questions?

By running numerous statistical models a more thorough examination of the research question was obtained.

5.1. Research Question #1

A few things can be noted in relation to research question number 1 from the five distinct models reported above. First, the overall evidence suggests that the increased occurrence of low and lower severity OSH incidents within a mining establishment is associated with an increased probability for that mine to experience a fatality in a subsequent year over time. A consistent null finding for the effect of OSH incident on fatalities over time would have suggested that fatalities may exist in a vacuum; unable to be anticipated through patterns of lower severity OSH incidents preceding the event. The current results, however, suggest that mining establishments that experience larger numbers of low and lower severity OSH incidents are more likely to experience a fatality in the future.

Second, the association of low and lower severity OSH incidents with future fatalities can be quite large, especially in the case of injuries that resulted in a permanent disability. The models suggest that the probability of a mine experiencing a fatal event increases by a minimum of 37% and up to 660% for each additional permanent disabling injury experienced in a previous year.

Third, reportable noninjury events (near misses) were consistently significantly associated with an increased probability of a fatal event in a subsequent year. In the models executed, reportable noninjuries significantly increased the probability of a future fatal event. When entered individually into the simple regression, each additional reportable noninjury event was associated with an 8% increase in the probability of a fatality in a subsequent year. When controlling for the other three injury variables and mine size, each additional reportable, noninjury event was associated with a 2% increase. From a practical perspective, and consistent with previous studies examining the effect of near miss reporting programs over time,[3,14,29] this result provides support for a continued emphasis on near miss reporting, investigation, and corrective action.

These findings provide an answer to the first research inquiry stated in this study and support the conclusion that establishments that are able to reduce low and lower severity OSH incidents can reduce the probability of experiencing a fatal OSH event in subsequent years. This finding provides support for the practical emphasis on the use of information obtained from low and lower severity incidents to inform risk management decision making in mining organizations.

5.2 Research Question #2

Considering Models 1–4 (reported in Table IV) the effect size was strongest for each additional permanent disabling injury (OR = 6.63) and weakest for each additional reportable noninjury (OR = 1.08). According to Models 1–4, it would require approximately 83 near misses to equal the same effect on the probability of fatality as one permanent disabling injury. Further, as would be anticipated given the theory, the effect sizes for the days lost and reportable injuries fall in between the injury of highest and lowest degree. However, the results suggest that there was a larger probability of fatality in a given year for each additional reportable injury experienced in a previous year (OR = 1.19) when compared to the increased probability for each additional days lost injury (OR = 1.10). In Model 5 (also reported in Table IV) when controlling for number of employee hours worked, only permanently disabling injuries and reportable noninjuries were significant (OR = 1.37 and 1.02, respectively)—while the days away and reportable injuries displayed a nearly null effect and dropped from significance.

Given the differences in effect sizes and significance levels across the models executed, suggesting that a certain ratio exists among the accidents and injuries delineated by degree is not realistic. However, given the pattern of effect size and significance, there is evidence to suggest that the most severe type of injury examined in the current study had the largest effect on a fatality in a subsequent year when compared to the other three OSH incident variables in the models. There is also evidence to suggest that reportable noninjuries had the smallest effect size. A conclusion that all incidents delineated by degree conform to the safety triangle premise, however, is tainted given the inversed effect for days lost and reportable injuries found in Models 1–4 coupled with the results of the Model 5—when controlling for the number of mine hours, only the odds ratio for permanent disabling injuries and reportable, noninjury events were significant.

There are a few possible explanations for this finding. First, the effect for days lost and reportable injuries seen in the previous models could have been somewhat masked by the significant effect of the number of employee hours worked on the probability of fatality coupled with the moderate correlation among hours worked, days lost injuries, and reportable injuries in the sample. Although speculative, a second possible explanation may be that the causes of permanent disabling injuries and reportable, noninjury events were more common with the types of causes likely to result in a fatal event. For example, in the current sample of 22,140 reportable noninjury cases that occurred between 2000 and 2012, about 75% were due to unplanned roof and face falls. Indeed, if the circumstances were different, these 16,445 reportable, noninjury events could have easily resulted in a fatality.

5.3 Research Question #3

A third explanation, which was examined with an additional analysis, was the premise that the *a priori* specified delineations of injuries based on "degree" may not be defined such that they account for important variations in severity in relation to the future probability of catastrophic OSH incidents. The results of analysis using the actual number of days lost/restricted as the basis for severity determination (reported in Tables V and VI) revealed a noticeable increase in the probability of a subsequent year fatality as the number of days associated with the injuries an establishment experienced increased—the results of which conform to the historical safety triangle. They also revealed that the effect of a good portion of days lost injuries (those with an average of three or less days lost/restricted) is not significantly different than the effect of an OSH incident or injury with zero days lost on the probability of subsequent year fatalities. This may, indeed, be the source of the inverted effect between reportable and days lost injuries reported in Models 1–4 and the null finding for these two variables reported in Model 5.

The finding that different severity coding schemes used in the current research produced a distinct pattern of results highlights the challenges involved in conducting research related to Heinrich's safety triangle. These results suggest that the mere choice of how to delineate low and lower severity OSH incidents can result in different ratios. This challenge is exponentiated given the fact that, in many cases, researchers are forced to conform their study to available surveillance data, which can carry significant limitations. As stated by Coleman and Kerkering:[30] "Researchers are frequently faced with drawing conclusions from data that has been collected primarily for purposes other than research, including regulatory, administrative, and legal requirements" (p. 530). Without going beyond the severity categories *a priori* specified within the MSHA database, there is minimal evidence to support the idea of a safety triangle in the context of mining. However, with some modest data manipulation, stronger evidence to support the premise of the triangle's ratios is realized.

6. LIMITATIONS AND CONCLUSIONS

There are a few limitations that need to be noted regarding the current study. First, although not integral to the core research inquiry, the current study did not seek to provide an exhaustive analysis as to whether or not a consistent pattern of causes existed between reportable noninjures, reportable injuries, days lost injuries, and permanent disability incidents and fatalities. Future studies may seek to explore whether or not there are common causes in the context of mining establishments between OSH incidents and fatalities. In lieu of the findings of the current study, it would be interesting to explore whether similar patterns of causes exist between reportable and day lost injuries and between the various levels of days lost injuries delineated by the actual number of days lost. This analysis may help explain additional considerations in regard to the findings of the current study. Second, we relied solely on the MSHA databases between 2000 and 2012 to derive the results of the current study. As must be noted, an additional limitation is the potential for underreporting of OSH incidents in this context.

Given the noted limitations, there is evidence to suggest that the probability of experiencing a fatality was increased for each additional low and lower severity OSH incident type experienced in a previous year during the 2000–2012 time span in the U.S. mining industry. In addition, the current study provided evidence to suggest that numerous reportable noninjuries are required to obtain the same effect of as a permanently disabling injury on the probability of a subsequent year fatality. There is also evidence to suggest that a safety triangle of sorts can be derived in the mining context depending on the severity coding scheme considered. However, given the various models explored, there is a lack of concrete evidence to support the premise that a hard and fast ratio exists in this regard. Consistently, we can in no way suggest that reducing the number of no, low, and/or lower severity OSH incidents produces a known proportional decline in high severity events. However, we can say that a decline of an unknown proportion should be expected.

In the context of U.S. mining, the continued analysis of low and lower severity OSH incidents and near misses to inform decisions related to the OSH management systems certainly seems warranted. The results of this study also provide evidence to suggest that a disciplined effort to reduce these OSH incidents can help decrease the probability of more serious OSH incidents in the future. Consistent with the potential benefits that can result from a disciplined risk management focus on low and lower severity OSH incidents for each stakeholder in the ecological model, there may be a number of mechanisms through which this probability reduction is realized and the true mechanisms accounting for this decline are most likely all of them working interdependently in any given context.

For the general practitioner audience the findings of the current study suggest that the safety triangle is not as obvious and straightforward as many assume it to be—our findings suggest that its existence is quite complex and depends primarily on how the incident/injury severity is delineated and statistical controls. These findings seem critical for the many that use or rely on historical numbers of safety incidents to predict future incidents. The attraction to Heinrich's theory is its assumed "ease of use" with the general perception that one need only know the number of lower severity injuries or illnesses to make predictions about higher severity events. However, our findings challenge that notion by demonstrating the complexity of implementing this theory in a manner that will yield accurate predictions. By using a highly granular and robust data set, we provide empirical evidence that demonstrates that the validity of the theory is highly dependent upon severity delineation and controlled factors.

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