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Heinrich Revisited: a New Data-Driven Examination of the Safety Pyramid

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Abstract

Although researchers have struggled to replicate Heinrich's safety triangle findings (Heinrich 1931) for various reasons (e.g., no access to his original database and it is unclear if the database was of a single establishment/operation or for an entire industry), the occupational safety community has continued to adopt and expand the applications of this theory (e.g., McSween 2003). Within the mining industry, the potential exists for operations and companies to use concepts from the safety triangle as a way to inform or challenge the practices employed within their health and safety management systems (HSMS) to prevent incidents (Backlund 2016). This paper considers data obtained from the Mine Safety and Health Administration's databases and demonstrates the validity of applying the safety triangle theory at the mine level. The results support the use of this theory and demonstrate that lower severity incidents can predict fatalities in a subsequent year where significant nuances and caveats to applying the theory are identified and discussed.

Keywords Heinrich safety triangle · Mine safety · Predictive safety modeling · Mining injury prevention models · Proactive mining safety practices

1 Introduction

In the 1930s, Heinrich conducted a study to explore the relationship between lower and higher severity injuries [3]. His work resulted in what is known now as the "safety triangle," because the database he used produced a ratio of near misses, minor injuries, and major injuries that formed a triangular shape (300:29:1). Although researchers have struggled to replicate Heinrich's findings for various reasons (e.g., no access to his original database and it is unclear if the database was of a single establishment/operation or for an entire industry), the occupational safety community has continued to adopt and expand the applications of this theory [8]. Examples include

(1) mandating/encouraging injury reporting, (2) deriving national/global estimates of injuries, (3) prioritizing areas for OH&S investment and development, (4) using root cause analysis of near misses or low severity injuries to improve occupational health and safety (OH&S) management systems, and (5) prioritizing regulatory and enforcement activities [2, 10, 11].

Within the mining industry, the potential exists for operations and companies to use concepts from the safety triangle as a way to inform or challenge the practices employed within their health and safety management systems (HSMS) to prevent incidents [1]. Despite doubts cast on the concept [6], the safety triangle can be used to generally predict those operations within a company that are at the greatest risk of experiencing high-severity incidents based on the number of lower severity incidents as well spur conversation about the relationship between major and minor types of injuries [7]. Although this may be of great value to a company when prioritizing operations to receive resources and support, the inability for theorists to replicate Heinrich's work and the lack of mining-specific research explorations both significantly detract from the application of this theory.

Recently, researchers interested in the theory itself explored the effect of different severity delineations (e.g., total days lost or average days lost) on the ability of lower severity

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Fig. 1 Research design where lower severity incidents were evaluated for their predictive ability of fatal incidents in the subsequent year

incidents to predict higher severity incidents within an establishment/operation [12]. To conduct this study, the researchers selected the US Mine Safety and Health Administration's (MSHA) databases due to the robustness of the mine-level information available. In this study, the researchers reviewed 13 years of data from more than 27,000 mines. While this study used MSHA data, it focused on the underlying theory with the results published for a theorist audience. The purpose of this current paper is to reconsider these study findings to specifically inform the use of the safety triangle within the mining industry.

2 Data Source and Analysis Methods

MSHA's Mine Address and Employment (AE) and the Mine Accident, Injury, and Illness (AII) databases were used for this study. MSHA's AII database provided information related to reportable incidents such as fatalities, injuries with the potential for death, off-site injuries due to an accident, and various unplanned events (e.g., roof fall). The AII database also provided information regarding each injury such as the degree of injury and the number of lost or restricted days. The AE database provided information such as the geographic location of the mine, mine status (e.g., active), hours worker per year, and other employment stats. At the time the data were downloaded (middle of 2015), the most recent complete year for each of the databases was 2012. Data from 2000 to 2012 were used in this study. The AE and AII databases were cross-referenced, allowing the specific injury experience of each mine to be determined.

Longitudinal logistic models (described later) were used to estimate the change in probability of a fatality based on the previous year's lower severity incidents (Fig. 1). Because these models consider a mine's probability of experiencing a fatality based on the mine's injury experience the previous year, only mines that were active (as defined by MSHA) for at least two consecutive years during this 13-year period were included in the dataset ($n = 27,466$ mines). Table 1 provides a summary of the top 10 cause codes for the negative safety incidents during this 13-year period, displayed in terms of MSHA's degree of injury severity categories.

There were a total of 772 fatalities for the sample of mines included in the study during the 13-year period. The fatality variable was dichotomized (0 or 1), because 87% of the fatalities were single fatality events and dichotomization eliminated any bias that could result from a single catastrophic event (e.g., Upper Big Branch mine disaster of 2010 resulting in 29

fatalities). After dichotomization, 668 fatal events were included in the dataset and used for the analysis.

Longitudinal logistic models (described later) evaluated a mine's probability of experiencing a fatality based on that same mine's lower severity incidents from the previous year. The ability for these lower severity incidents to predict a future fatal event may be dependent upon how these lower severity incidents are defined. Therefore, three different approaches were taken to define lower severity events with each approach having four sub-categories:

1. MSHA's degree of injury severity categories—(1) reportable non-injuries (i.e., a near-miss event); (2) reportable injuries (e.g., medical treatment beyond first aid that did not result in lost days); (3) days lost injuries (injuries that resulted in lost and/or restricted days); and (4) permanently disabling injuries. The number of injuries in each severity category that a mine experienced in a given year were used to predict the probability of a fatal event in the subsequent year over the 13-year time period.

2. Total lost and restricted days—the researchers categorized all mines into four groups based on the total number of days lost during the course a year: (1) 0 days; (2) 1 to 16 days; (3) 17 to 100 days; (4) more than 100 days. This categorical variable was entered into the longitudinal regression equation predicting the likelihood of a fatal event in a subsequent year over the 13-year time period and mines with a total of zero days lost being used as the reference group for the remaining categories.

3. Average lost and restricted days per injury—the researchers categorized all mines into four groups based on the average number of days lost per injury per year: (1) 0 days; (2) 1 to 3 days; (3) 4 to 10 days; (4) more than 10 days. This categorical variable was entered into the longitudinal regression equation predicting the likelihood of a fatal event in a subsequent year over the 13-year time period and mines with an average of zero days lost per incident were used as the reference group for the remaining categories.[1]

The number of hours worked by a mine may influence the probability of that same mine experiencing a fatality and, therefore, should be controlled. However, the number of hours worked has the potential to also influence the frequency of the lower severity incidents—the predictor—as well. In this case, controlling for the number of hours worked could result in suppressing effects in the model. Exploring the effect that

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[1] The total and average days lost categories were arrived at through an iterative approach.

Table 1 Top 10 cause codes for each negative safety incident during the 13-year study period

Fatalities		Permanent disability		Injuries that resulted in lost or restricted days		Recordable injuries		Near misses	
Powered haulage	28.89%	Handling material	46.34%	Handling material	33.73%	Handling material	34.58%	Roof fall	73.22%
Machinery	18.82%	Machinery	23.92%	Slip or fall	24.66%	Handtools	21.20%	Hoisting	13.52%
Slip or fall	9.80%	Powered haulage	14.87%	Machinery	11.31%	Machinery	15.49%	Fire	3.89%
Dust Explosion	9.28%	Handtools	6.88%	Powered haulage	10.02%	Slip or fall	11.57%	Dust Explosion	3.85%
Roof fall	8.76%	Slip or fall	2.97%	Handtools	8.76%	Powered haulage	5.68%	Inundation	1.46%
Face fall	5.75%	Roof fall	2.48%	Roof fall	3.39%	Roof fall	3.51%	Entrapment	1.35%
Electrical	5.62%	Other	0.62%	Stepping or kneeling on object	2.09%	Other	3.33%	Face fall	1.01%
Rock/material slide	5.23%	Face fall	0.43%	Other (not 1–20)	1.87%	Striking or bumping	1.62%	Electrical	0.53%
Other (not 1–20)	3.14%	Nonpowered haulage	0.43%	Face fall	1.17%	Stepping or kneeling on object	0.68%	Powered haulage	0.43%
Exploding vessels	1.31%	Hoisting	0.25%	Striking or bumping	0.79%	Electrical	0.52%	Explosion	0.24%

controlling and not controlling for number of hours work has on the probability of a fatality is important to understand how much influence hours worked has and allows an upper and lower bound for the effects to be derived. Therefore, to evaluate the ability each sub-category within the three severity delineations to predict a fatality in the subsequent year, the following models were fit using generalized estimating equations:

1. Simple longitudinal logistic regression models were fit for each sub-category (a–c) within each severity level

    – Severity level 1 (lowest severity): (a) reportable non-injuries, (b) mines that experienced zero total lost and restricted days during a given year, and (c) mines that experienced an average of zero lost and restricted days in a given year.
    – Severity level 2: (a) reportable injuries, (b) 1 to 16 total lost and restricted days, and (c) 1 to 3 average lost and restricted days.
    – Severity level 3: (a) days lost injuries, (b) 17 to 100 total lost and restricted days, and (c) 4 to 10 average lost and restricted days.
    – Severity level 4 (highest severity level): (a) permanently disabling injuries, (b) more than 100 total lost and restricted days, and (c) more than 10 average lost and restricted days.

2. Multiple longitudinal logistic regression model that controlled for the log of non-office employee hours were fit for the following combinations of parameters

    – MSHA's degree of injury severity categories: permanent disabling injuries, days lost injuries, reportable injuries, and reportable non-injuries.

    – Total lost and restricted days: 0, 1 to 16, 17 to 100, and more than 100 total lost or restricted days.
    – Average lost and restricted days per injury: 0, 1 to 3, 4 to 10, and more than 10 average lost or restricted days.

The models were not run for smaller partitions of data (e.g., top 10 cause codes for the various severity delineations and their sub-categories), because the number of fatalities in these smaller partitions of the data were too limited for a meaningful analysis. More detail on the methodology and mathematical models used in the current study can be obtained in the reference by Yorio and Moore [12].

3 Results

3.1 MSHA's degree of injury severity categories (Fig. 2)

For permanently disabling injuries, each addition resulted in a high likelihood for a fatality within the mine in a later year. In the model not adjusted for hours worked, there was a 663% (6.63 times) greater likelihood for a mine to experience a fatal event in a given year for each additional permanent disabling injury experienced in a preceding year. When controlling for hours worked, there was a 37% greater probability. For each additional days lost injury, there was a 10% increased probability for a mine to experience a fatal event in a subsequent year in the unadjusted model. When controlling for hours worked, the effect size dropped to ~1% and was not significant. An additional reportable injury resulted in a 19% increased probability for a mine to experience a fatal event in a subsequent year in the unadjusted model. When controlling

for hours worked, this effect size also dropped to ~1% and was not significant. Each additional reportable non-injury (i.e., near miss) resulted in an 8% increased probability for a mine to experience a fatal event in a subsequent year in the unadjusted model. When controlling for hours, there was a significant 2% increase in the probability of a fatal event.

3.2 Total Lost and Restricted Days (Fig. 3)

Compared to mines that experienced zero (0) total lost and restricted days, mines that experienced more than 100 total lost and restricted days in a given year were 17.34 times more likely to experience a subsequent year fatal event in the unadjusted model and 2.69 times more likely when controlling for hours worked. Mines that experienced 17 to 100 total lost and restricted days in a given year were 6.30 times more likely to experience a fatal accident event in a subsequent year in the unadjusted model and 1.79 times more likely when controlling for hours worked. And, mines that experienced 1 to 16 total lost and restricted days in a given year were 2.55 times more likely to experience a fatal event in a subsequent year in the unadjusted model. When controlling for hours worked, there was no significant difference in the probability between mines that experienced 1 to 16 total lost and restricted days and those that experienced 0 total lost and restricted days.

3.3 Average Lost and Restricted Days per Injury (Fig. 4)

Compared to mines that experienced zero (0) total lost and restricted days, mines that experienced more than 10 average lost and restricted days were 3.20 times more likely to experience a fatal event in a subsequent year in the unadjusted model and 1.64 times more likely when controlling for hours worked. Mines that experienced 4 to 10 average lost and restricted days were 2.22 times more likely to experience a fatal event in a subsequent year in the unadjusted model. When controlling for hours worked, this effect size dropped to 1.26 and was not statistically significant. For mines that experienced 1 to 3 average lost and restricted days, the difference was not statistically significant when controlling or not controlling for hours worked.

4 Discussion

The study findings demonstrate that near misses and lower severity events within a mine predict future higher severity events within that same mine, with some caveats. Evidence from each of the unadjusted models presented in Fig. 2 suggest that an increase in near misses and each of the lower severity injuries within a mine relates to an increased

Fig. 2 Analysis using MSHA's degree of injury severity categories. The probability reported represents the increased likelihood that mine experienced a fatal injury event in a given year considering a 1-unit increase in the previous year's number of a given injury type. *Significant probability at the $p < .05$ level

probability for that same mine to experience a fatality in a subsequent year. In general, this predictive power indicates that fatalities may not exist in a vacuum but can be anticipated through patterns of lower severity incidents before the event. In addition, Fig. 2 shows that the size of the increased probability can be quite large—up to 6.63 times for each added permanent disabling injury experienced in a previous year. Further, near misses were significantly associated with an increased probability of a fatal event in a subsequent year in both the unadjusted and size-adjusted models presented in Fig. 2. Consistent with previous studies examining the effect of near miss reporting programs over time [4, 5, 9], this provides support for a continued emphasis on near miss reporting, investigation and corrective action.

In the models that adjusted for hours worked, permanently disabling injuries and near misses remained significant predictors of a subsequent year fatal event—while the number of days lost and reportable injuries dropped from significance. One possible explanation for this is that the significant effects seen in the unadjusted models may have been masked by the strong predictive effect of hours worked combined with moderate associations among the hours worked, days lost injuries, and reportable injuries in the dataset—all of which can suppress the resulting statistical effects for these injuries. Another possible explanation is that, when compared with the permanently disabling injuries and the near misses reported, the causes of days lost and reportable injuries may have less in common with the causes of fatal events. However, even with

these two possible explanations, the results suggest that the lower bound predictive effect for injuries categorized as days lost and reportable may be zero (adjusted models) and the upper bound may be approximately a 10–19% increased likelihood (unadjusted models).

As injury severity increases, a systematic increase in the effect on predicting future fatal events is experienced, with caveats based on the severity delineation approach used. The effect size for the analysis discussed in the preceding paragraphs was strongest for each additional permanent disabling injury and weakest for each additional near miss. According to the unadjusted reported in Fig. 2, it would require approximately 83 near misses to equal the same effect on the probability of fatality as one permanent disabling injury. 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 two severity levels between them did not follow suit to provide a *systematic* decline— there was a larger likelihood of fatality in a given year for each additional reportable injury experienced in a previous year when compared to the increased probability for each additional days lost injury (a relatively more severe injury compared to reportable injuries). Further, when controlling for hours worked, only permanently disabling injuries and near misses were significant. Thus, when delineating severity using the categories of permanently disability injuries, days lost injuries, reportable injuries, and near misses a strict triangle form was not seen.
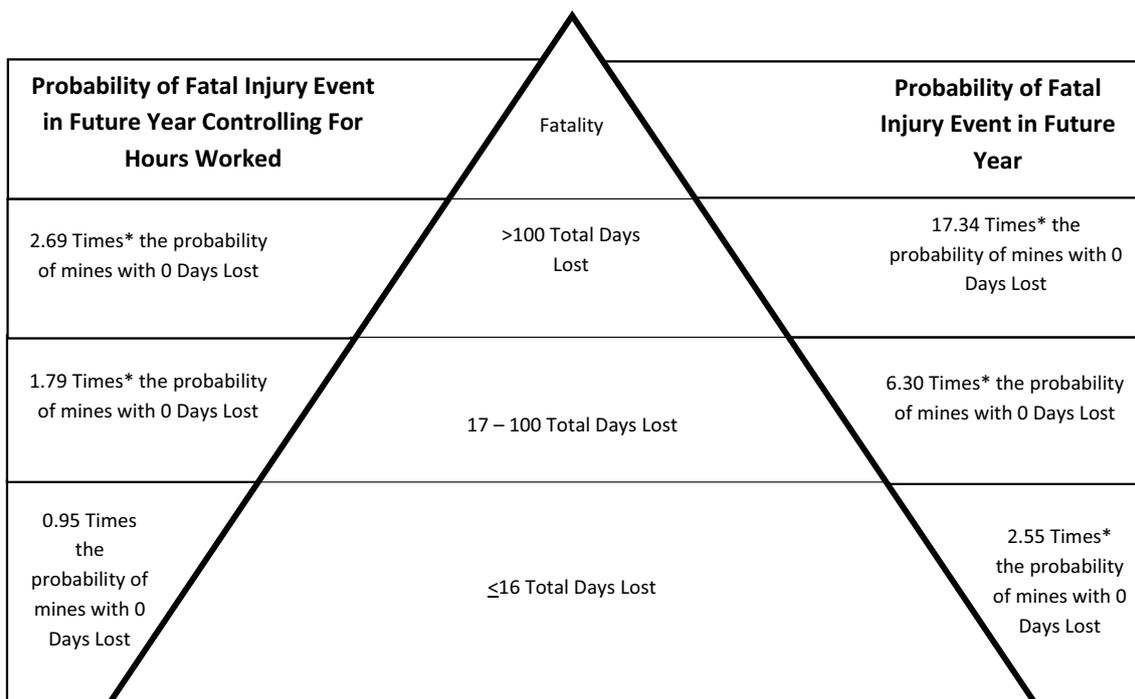

Fig. 3 Analysis using total lost and restricted days. The probability reported represents the increased likelihood that a mine experienced a fatal injury event in a given year considering the previous year's total number of days lost compared to a 0 days lost year. *Significant probability at the $p < .05$ level

For the unadjusted and adjusted models that used total lost and restricted days and average lost and restricted days per injury shown in Figs. 3 and 4, a systematic decline in effect was observed as severity decreased. Therefore, the triangular formulation does exist, but it is dependent upon the manner in which severity levels are defined.

5 Practical Implications and Conclusions

This work found that, when evaluating mine-level data from the MSHA AE and AII databases, (1) lower severity injuries within a mine may be used to predict the probability of a fatal event within the same mine in a subsequent year and (2) the safety triangle exists. However, safety professionals must exercise caution when applying these predictive models or the safety triangle theories, because the strength of the prediction and existence of the triangle is directly dependent upon the severity delineation approach used.

Based on the three severity delineations explored by this work, the injury severity delineation with the strongest predictive ability of a fatality in the subsequent year—regardless of whether or not hours worked is controlled for—was the total lost or restricted days delineation: (1) 0 lost or restricted days, (2) 1 to 16 total lost or restricted days, (3) 17 to 100 total lost or restricted days, and (4) more than 100 total lost or restricted days. This severity delineation also provided the triangular

shape, again, regardless of whether or not hours worked is controlled.

Although the total lost and restricted days severity delineation provided the best results in this study, this is not to suggest that all other severity delineations should be ignored. Rather, that dependence of the predictive ability and triangular shape on severity delineation suggests that the most robust approach would be to consider not only this severity delineation approach but others as well while searching for overlap among the results. Furthermore, underreporting is a common challenge for health and safety databases that must be considered for all applications of the data. Given MSHA's reporting requirements and enforcement practices for the safety type events that were the focus of this study, it is unlikely that fatalities or higher and moderate severity injuries would suffer from significant underreporting. However, consistent with other industries, lower severity events are expected to be underreported. For the model that explores the MSHA severity delineation, the data are shown as the probability of a fatality in the subsequent years for every 1-unit increase in the injury category of interest. Thus, this probability would be expected to decrease. For the average and total number of days of lost or restricted work models, the probability of a fatal event in the subsequent years used mines with 0 lost or restricted days as the point of comparison. Some of these 0 lost or restricted days mines will also be subject to the same underreporting resulting in no impact on the data or conclusions. Others may have a superior safety culture that

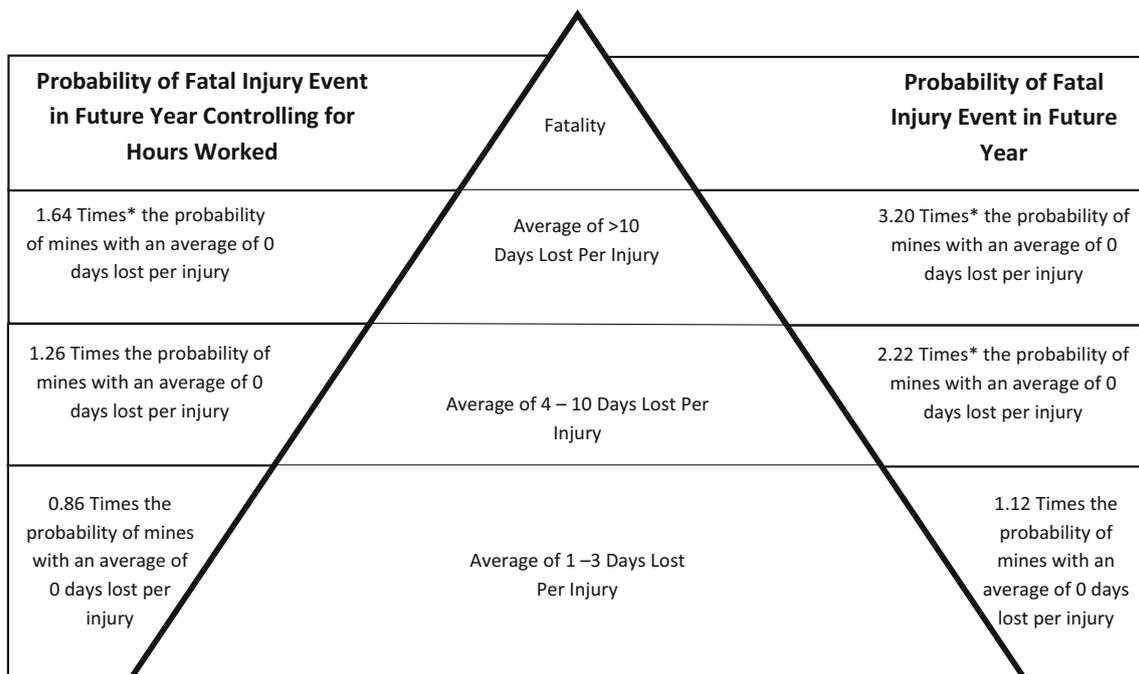| Probability of Fatal Injury Event in Future Year Controlling for Hours Worked	Fatality	Probability of Fatal Injury Event in Future Year
1.64 Times* the probability of mines with an average of 0 days lost per injury	Average of >10 Days Lost Per Injury	3.20 Times* the probability of mines with an average of 0 days lost per injury
1.26 Times the probability of mines with an average of 0 days lost per injury	Average of 4 – 10 Days Lost Per Injury	2.22 Times* the probability of mines with an average of 0 days lost per injury
0.86 Times the probability of mines with an average of 0 days lost per injury	Average of 1 –3 Days Lost Per Injury	1.12 Times the probability of mines with an average of 0 days lost per injury

Fig. 4 Analysis using average lost and restricted days per injury. The probability reported represents the increased likelihood that a mine experienced a fatal injury event in a given year considering the previous year's average number of days lost per injury compared to an average of 0 days lost per injury year. *Significant probability at the $p < .05$ level

experiences and, as a result, reports fewer lower severity injuries as their culture continues to permeate employee's decision making—in this case, the probability of a fatal event in subsequent years would decrease somewhat. Thus, an examination of underreporting further supports the authors' assertion that the most robust approach would be to consider multiple severity delineation approaches while searching for overlap among the results.

While the results of this study cannot suggest that reducing the number of near misses and lower severity safety incidents produces a known/fixed decline in high severity events, they suggest that a decline of an unknown proportion can be expected. Additionally, even without establishing that events with different severity levels have a common cause, near miss and lower severity events were demonstrated to be significant predictors of future fatalities. Therefore, efforts that reduce these near miss and lower severity events should be expected to reduce the probability of future fatalities regardless of whether a common cause is shared. Although not initially intuitive, this phenomenon may be occurring as a result of culture changes triggered by mine leadership efforts to reduce risk in other safety areas such as increasing worker risk management and accident prevention knowledge, skills, abilities, awareness and motivation and/or improving the overall organizational safety culture.

Although a common cause is not needed for this predictive relationship to exist, organizational efforts related to investigating and correcting the root causes of near misses and lesser severe accidents in an effort to reduce the probability of future incidents are well grounded and should continue. Additionally, tracking near misses and lesser severe safety incidents—and using them as a leading indicator within an organizational health and safety management system—is a valid practice.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

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References

1. Backlund M (2016) Comparing the Heinrich triangle theory to real world data of a modern drilling. Presentation provided at the 2016 oil and gas safety conference. Contractorhttps://www.isnetworld.com/Events/ugm/Osha2016/Sessions/Micah%20Backlund%20-%20Comparing%20the%20Heinrich%20Triangle%20Theory.pdf
2. Bhattacharya S (2012) Sociological factors influencing the practice of incident reporting: the case of the shipping industry. Empl Relat 34(1):4–21
3. Heinrich HW (1931) Industrial accident prevention: a scientific approach. McGraw Hill Book Company, New York
4. Jones S, Kirchsteiger C, Bjerke W (1999) The importance of near miss reporting to further improve safety performance. J Loss Prev Process Ind 12:59–67
5. Lander L, Eisen EA, Stentz T, Spanjer KJ, Wendland BE, Perry MJ (2011) Near-miss reporting system as an occupational injury prevention intervention in manufacturing. Am J Ind Med 54:40–48
6. Manuele FA (2011) Reviewing Heinrich: dislodging two myths from the practice of safety. Pro Safe 56(10):52–61
7. McSween T, Moran DJ (2017) Assessing and preventing serious incidents with behavioral science: enhancing Heinrich's triangle for the 21st century. J Organ Behav Manag 37(3–4):283–300
8. McSween TE (2003) The values based safety process: improving your safety culture with behavior-based safety, 2nd edn. John Wiley, New York
9. Powell NB, Schechtman KB, Riley RW, Guilleminault C, Chiang RP, Weaver EM (2007) Sleepy driver near misses may predict accident risks. Sleep 30(3):331–342
10. Takala J (1999) Global estimates of fatal occupational accidents. Epidemiology 10(5):640–646
11. Taxis DK, Gallivan S, Barber N, Franklin BD (2005) Can the Heinrich ratio be used to predict harm from medication errors? Report to the patient safety research programme (Policy Research Programme of the Department of Health)
12. Yorio PL, Moore SM (2018) Examining factors that influence the existence of Heinrich's safety triangle using site-specific H&S Data from more than 25,000 establishments. Risk Anal 38(4):839–852

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