Measuring mining safety with injury statistics: Lost workdays as indicators of risk [☆]

Patrick J. Coleman , John C. Kerkering

National Institute for Occupational Safety and Health, Spokane Research Laboratory

Abstract

Problem: Mining in the United States remains one of the most hazardous industries, despite significant reductions in fatal injury rates over the last century. Coal mine fatality rates, for example, have dropped almost a thousand fold since their peak in 1908. While incidence rates are very important indicators, lost worktime measures offer an alternative metric for evaluating job safety and health performance. The first objective of this study examined the distributions and summary statistics of all injuries reported to the Mine Safety and Health Administration from 1983 through 2004. Over the period studied (1983 2004), there were 31,515,368 lost workdays associated with mining injuries, for an equivalent of 5,700 person years lost annually. The second objective addressed the problem of comparing safety program performance in mines for situations where denominator data were lacking. By examining the consequences of injuries, comparisons can be made between disparate operations without the need for denominators. Total risk in the form of lost workday sums can help to distinguish between lower and higher risk operations or time periods. *Method:* Our method was to use a beta distribution to model the losses and to compare underground coal mining to underground metal/nonmetal mining from 2000 to 2004. *Results:* Our results showed the probability of an injury having 10 or more lost workdays was 0.52 for coal mine cases versus 0.35 for metal/nonmetal mine cases. In addition, a comparison of injuries involving continuous mining machines over 2001 2002 versus 2003 2004 showed that the ratio of average losses in the later period to those in the earlier period was approximately 1.08, suggesting increasing risks for such operations. *Discussion:* This denominator free safety measure will help the mining industry more effectively identify higher risk operations and more realistically evaluate their safety improvement programs. *Impact on Industry:* Attention to a variety of metrics concerning the performance of a job safety and health program will enhance industry's ability to manage these programs and reduce risk.

Keywords: Mining injuries; Mining safety and health; Incidence rates; Denominator-free methods; Lost time measures; Trends; Statutory days lost; Job safety and health metrics

1. Problem

Researchers in occupational safety and health fields who use surveillance data rely on a small number of risk measurement methods for evaluating the performance of preventive programs. The raw numbers of reported injuries and illnesses plotted over time provide the first indications of higher-than-average risk problems, or lower-than-average risk success stories. Calculating incidence rates when denominator data (i.e., number of workers exposed) are available is a more standardized measure, particularly if employment is changing over time or if differently-sized sectors or risk groups need to be compared. The severity of injuries and illnesses (i.e., statistics based on number of lost workdays, statutory days, and restricted workdays per case of injury or illness charged to an individual accident) is a less-used measure that may be undervalued. This study examined the use of lost workdays per case as a metric separate from the traditional ones of case counts and incidence rates.

In the mining sector, data on reported injuries from the Mine Safety and Health Administration (MSHA) allow researchers to develop mine-specific and subunit-specific incidence rates for a variety of injury types. Several reasons for using lost workdays as an alternative metric include the fact that denominator data are generally collected only for the broadest and most general categories. MSHA provides hours worked by miners at each mine location and for each subunit that a mine operates. But hours worked are not categorized by years of experience or the amount of training a miner has, making it difficult to assess risk among new and less-trained workers. Hours worked are also not categorized by other variables of interest such as machine type, activity, occupation, or gender.

However, MSHA also provides three different lost workday indices: the number of workdays an injured miner takes before returning to work, the number of days of restricted work activity after returning to work, and the number of statutory days lost. The latter has assigned values or "scheduled charges" for fatalities and permanent partial or total disabilities resulting from loss of a member.

2. Literature review

The use of statistics in job safety and health has a long history, and in particular, MSHA's use of so-called statutory days has its origin in a 1920 Bureau of Labor Statistics Bulletin No. 276, Standardization of Industrial Accident Statistics (U.S. Bureau of Labor Statistics, 1920). The authors felt there was a need for a uniform system for assigning lost work time to disabling injuries and deaths. The results included, for example, a statutory charge of 6,000 lost workdays for a fatal injury and for certain non-fatal but permanently disabling injuries such as loss of both eyes. Other impairments were assigned statutory days lost based on a percentage of permanent total disabilities. The Z16 Committee was formed in 1926 to revise the standard, and adopted the Bulletin's table and chart referring to scheduled charges or statutory days lost for specific bodily impairments. The Bulletin also details the rationale for assigning the values found in the table. Later revisions of the American National Standards Institute (ANSI) Z16 standards through Z16.1-1967 maintained the same table and chart (United States of America Standards Institute, 1968), which are now used by the U.S. Department of Labor Mine Safety and Health Administration (MSHA, 1986).

Researchers in mining safety and health have examined lost workdays in a variety of studies in mining. Coal miners with impaired respiratory health were hypothesized to experience greater numbers of disability days due to job injury, but the analysis did not support the hypothesis (Ames & Trent, 1985). Five mines in northeast England were studied for days lost due to skin disorders over a 6-year period. Summary measures (means, medians, and incidence rates) were reported, showing that foot dermatitis in coal mines accounted for some of the longest lost day mea-

sures (Puttick, 1990). Small mines with high incidence rates of transport injuries have a greater share of fatal and permanently disabling injuries, while larger mines have a greater share of injuries involving no lost time (Hunting & Weeks, 1993). Lost workdays have also been used to develop risk indices for specific mining tasks. Using detailed microanalysis of task components, injuries incurred, injury severity, and time spent per component, risk analysis can pinpoint the specific task component with the highest risk of injury and the highest risk of loss of worktime (Grayson, Layne, Althouse, & Klishis, 1992). Grayson et al. later updated and expanded their microanalysis approach to produce an index number for ranking job titles by priority of intervention (Grayson, Althouse, Winn & Klishis, 1998), which relies on MSHA's lost workday statistics.

Research in other high-risk industries has also studied lost workdays, primarily as severity indices. Construction injuries that occurred during the construction of the Denver International Airport in Denver, Colorado, between 1990 and 1994 were analyzed and data presented on lost-work-time claims, their incidence and median days lost. Specific types of work were tabulated by median number of days lost, among other measures. The authors concluded that lost workday estimates reported by BLS are likely to underestimate those derived from workers' compensation insurance data (Lowery et al., 2000). Construction industry injuries in the Australian state of Victoria during 1996–1998 were analyzed to determine occupations, tasks, and activities in terms of priorities for intervention and prevention. A four-part injury severity index, including indicators for days compensated, hospital days and costs, maiming (compensation for temporary or permanent impairment), and a fracture or amputation indicator, was developed for this purpose (Larsson & Field, 2002). These authors also point out that a summary measure, 'harm,' which is the number of claims multiplied by the injury severity, has been used in the transportation safety field.

Lost-worktime distributions were summarized in Mital, Pennathur, and Kansal (1999) using Bureau of Labor Statistics reports on OSHA-reportable cases by type of accident, source of injury, and part of body injured. These results demonstrate the utility of comparing selected groups of injuries by amount of time lost and enable identification of the type and nature of the accident and the parts of the body injured that account for the largest percentages of cases in which 21 or more days of work were lost. Unfortunately, cases with no lost workdays are not included in the table, making it difficult to understand the complete form of the distributions.

3. Methods

The following background on MSHA reporting requirements and practices are important for understanding this study. Underground and surface mining are part of the

extraction industries in the United States. The general categories of commodities mined are coal, metal, nonmetal, stone, and sand and gravel. The accident data for this study were collected by MSHA, part of the Department of Labor. MSHA has collected mine accident data for many years, providing public access to data from 1983 forward on its website. The mine must report an incident to MSHA if there is a work stoppage of 30 minutes or more or if there is an injury or fatality connected with the incident.

More severe injuries, including fatalities, are investigated by MSHA. The accident information is coded into a database for that particular calendar year at MSHA's office in Denver. There are 48 variables recorded in the accident-injury-illness database for each incident. MSHA also has other databases that include mine employment and address information, and narrative descriptions of each incident. Mine employers are classified according to whether they mine coal (anthracite or bituminous), metal, nonmetal, stone, or sand and gravel. The term "metal/nonmetal" is sometimes used to designate all non-coal mining (i.e., metal, nonmetal, stone, sand and gravel). Mines are further subdivided into surface and underground mining.

Lost time due to accidents is recorded in three categories: actual lost days from work, statutory days charged, and restricted activity workdays. The lost workday variable can have a value of zero if no time away from work occurred due to the accident, such as when a roof-fall stops work for 30 minutes or more but no injuries occur. It can also be zero if an injury occurs without death, days away, or restricted activity. In these cases, if the injured miner loses less than 1 day of work, the case is coded as having zero lost work-days. The lost time data attributed to an accident are not considered final until the injured worker returns to work or is permanently transferred or terminated. The employer updates each open case by submitting a final form with total days lost to MSHA. MSHA issues a closed or completed database for a particular year after May 15 of the following year, to record the final disposition of cases still open.

While days lost from work and days with restricted work activity depend on healing times, the nature of the work being done, and other factors, the statutory days charged are more a reflection of attempts to quantify the "future loss of productive time brought about by an employee's permanent loss of a body member or permanent impairment of function" (MSHA, 1986). MSHA publishes the tables and charts used to determine statutory days lost on their website. The origin of the estimates in these tables and charts is the 1920 bulletin mentioned above (BLS, 1920), and they may also be found in the ANSI Method of Recording and Measuring Work Injury Experience Z16.1 (ANSI, 1967). The decision to include this measure along with the other two was guided by a desire for a measure that reflected the full range of injury outcomes from minor injuries to fatalities.

For this study, the reported measures for each case were summed to arrive at a total time-lost measure.

To find the distributions of the days lost by sector, standard distributions, such as the beta, gamma, Weibull, lognormal, exponential, and Pareto, were examined (Hogg & Klugman, 1983). Because the distribution of lost workdays by case has a large proportion with zero days lost on the low end and a significant proportion of cases with 6,000 days lost corresponding to fatal injuries on the high end, the beta distribution was selected because of its flexibility in modeling the U-shape of the histogram. The beta distribution is also defined on a closed interval, which matches the MSHA data in having lost workday outcomes of 0 to 6,000 days. Least-squares techniques were used to develop the fitted distributions, and to test goodness-of-fit, the Kolmogorov-Smirnov D-statistic test (K-S D-statistic) was used (Conover, 1980).

Statistical and related programs used for this study included Excel (Microsoft Office Excel 2003, Redmond, WA), SPSS Ver. 11.5 (SPSS Inc., Chicago, IL), Mathematica Ver. 5.1 (Wolfram Research, Inc., Chicago, IL), and The SAS System for Windows, Ver. 9.00 (SAS Institute, Cary, NC).

4. Results

4.1. Summary of lost workday trends

For the period 1983 through 2004, MSHA received 321,011 case reports of nonfatal injuries with lost workdays. A total of 2,215 fatal injuries was also reported in this period. The sum of lost workdays, statutory days lost, and days of restricted work activity for all of these cases was 31,515,368 over 22 years, or the equivalent of more than 5,700 person-years lost annually.

For consistency with MSHA's convention, and for comparison with its published data, the overall loss data were separated into four groups: coal mine operators, coal mine contractors, metal/nonmetal mine operators, and metal/nonmetal contractors. From 1989 to the present, coal mine and metal/nonmetal mine operators, and metal/nonmetal contractors, have reduced the incidence rates of lost workday cases (Fig. 1), some more than others. Coal mine contractors reported increases about as often as decreases from year to year, reaching their lowest rates in 2003–2004. The ratio of incidence rates for lost workday cases for coal mine operators to the average incidence rates for the other three sectors was consistently 1.5 to 2.0 during the period and was at its highest from 1987 through 1998. While three of the four groups demonstrated long-term reductions in lost workday case incidence rates it should be noted that the large increase in incidence rates for coal mine operators in 1986 through 1988 may be a reporting artifact resulting from an MSHA initiative. In December of 1986, MSHA released a program circular titled "Report on 30 CFR Part 50" to clarify and increase enforcement of the reporting regulations (MSHA, 1986; Fig. 1). The remaining groups demonstrate less dramatic increases during or after the same period, in apparent response to the initiative.
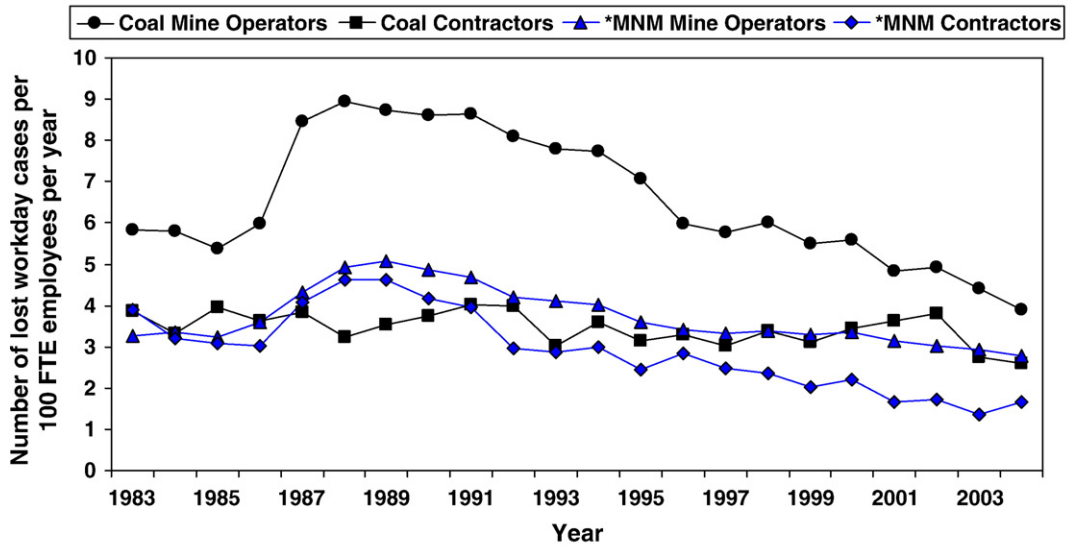
Fig. 1. U.S. Mining Nonfatal Lost Workday Case, Incidence Rates, 1983 - 2004.

Figs. 2–5 (see Appendix A for actual data) illustrate the trends in lost workdays associated with each of the four groups. For coal mine operators, the total number of lost days steadily decreased until the last 2 years, when the number increased slightly (Fig. 2). The figures for coal mine contractors show greater variability, but overall the pattern has been relatively steady (Fig. 3). Metal/nonmetal operators showed a modest reduction in total days lost over the period, while metal/nonmetal contractors showed a long-term trend toward a higher number of total days lost, also with increasing variability.

For both coal groups, the use of restrictions on work activity for those recovering from injury appears to be low, that is, the number of days spent on restricted work activities averages 1% to 2% of total lost days over the period. By contrast, more metal/nonmetal mine operators assigned recovering workers to restricted work activity; restricted-activity days averaged 2% to 8% of total lost workdays. As a percentage of total days lost, restricted-activity days increased for the metal/nonmetal mining trades (trends significant at $p < 0.0001$).
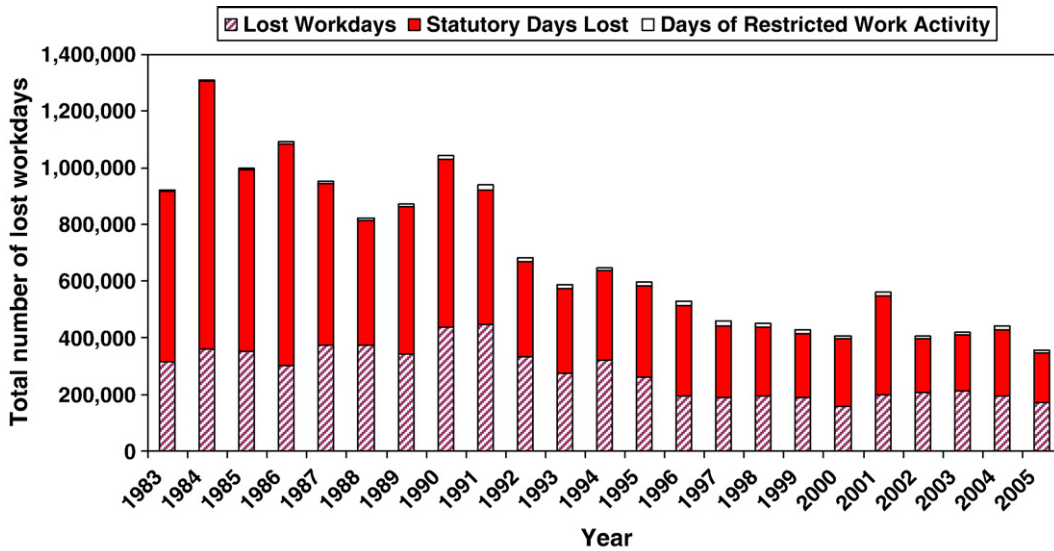
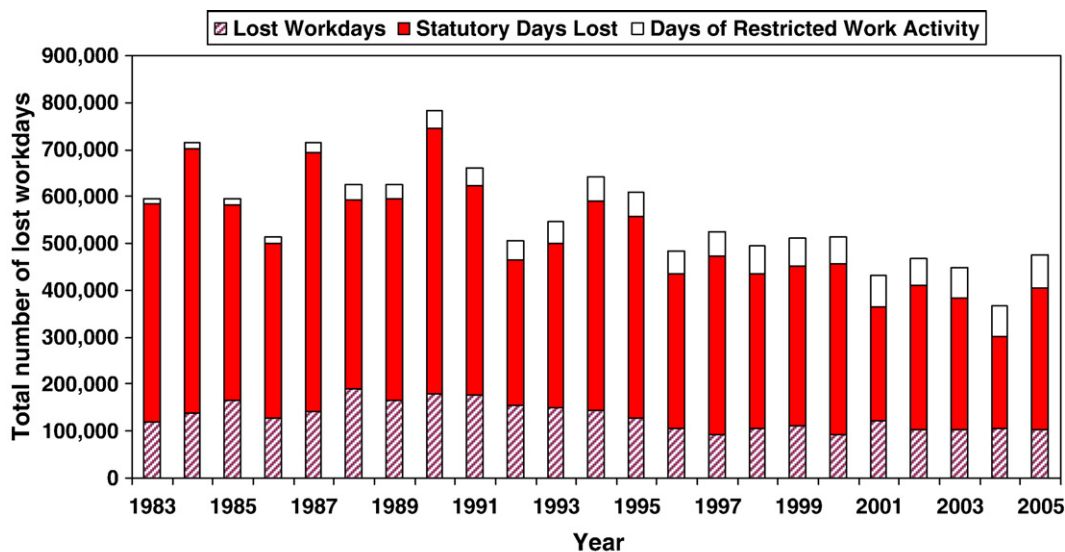Fig. 2. Lost Workdays for Nonfatal Injuries - Coal Mine Operators.
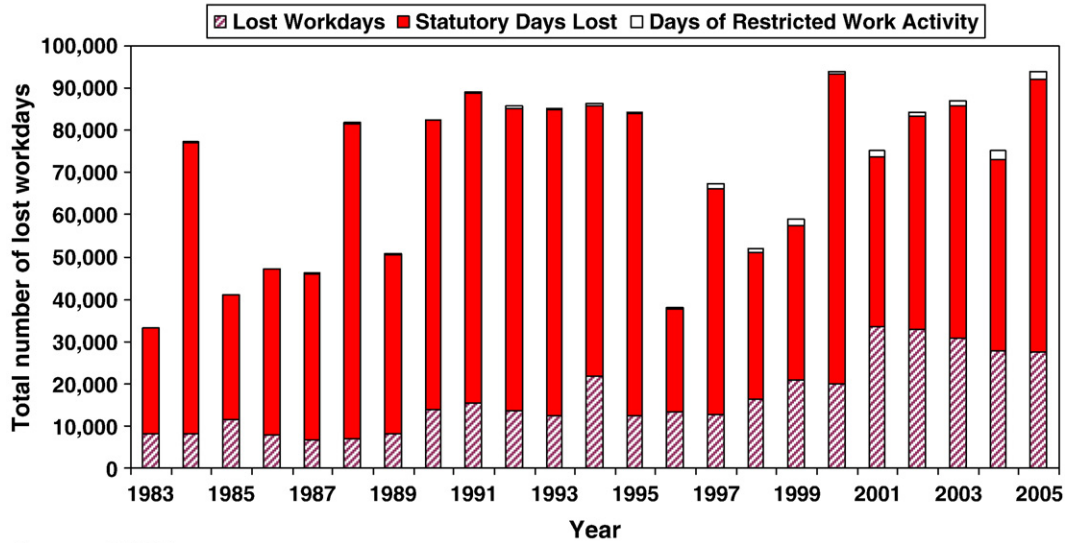
Fig. 3. Lost Workdays for Nonfatal Injuries - Coal Mine Contractors.

Notice also that the possible reporting artifact identified in Fig. 1 is less evident in the total lost workday trends of Figs. 2–5.

4.2. Distributions of lost work days

The average values of lost workdays are useful measures of overall safety performance in a mine, since they can reflect factors such as the use of personal protective equipment, the effective use of first aid and rapid access to medical care,

or company policies concerning return-to-work practices. To study the empirical distributions of lost work time, reported cases with no lost time (degree=6) were incorporated. Fig. 6a–b illustrate the distribution of cases by lost workdays for the underground coal and metal/nonmetal sectors during 2000–2004. The figure shows only the initial and final segments of the graph; the large segment in the middle has low frequencies for each sector. Graphing both coal and metal/nonmetal on opposite y-axes emphasizes the noticeable similarity between the two sectors' lost workday patterns.
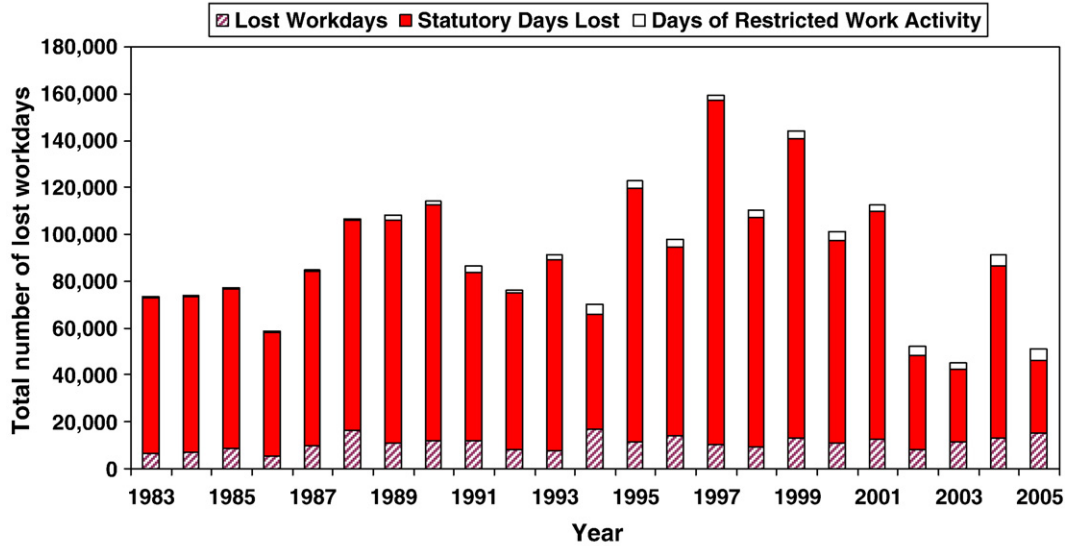
Fig. 4. Lost Workdays for Nonfatal Injuries - Metal/Nonmetal* Mine Operators.

Fig. 5. Lost Workdays for Nonfatal Injuries - Metal/Nonmetal* Mine Contractors.

For coal, 24.3% of the cases reported no days lost, while decreasing percentages make up the heavy tail. While the 97 severe cases (94 fatalities, 3 permanent total disabilities) in this period constituted 5% of the cases, the losses for the severe cases accounted for 41% of the total lost workdays.

The metal/nonmetal sector had a larger percentage of zero lost workday cases (36%). The 22 fatal cases with assigned statutory days lost accounted for 0.8% of the total case count and 65% of the total lost workdays.

The beta distribution has the probability density function

$$f(x, \alpha, \beta) = \frac{\Gamma(\alpha + \beta)}{\Gamma(\alpha)\Gamma(\beta)} \; x^{\alpha - 1} \; (1 - x)^{\beta - 1}$$

where alpha and beta are shape parameters. The beta was fitted to both the underground metal/nonmetal and underground coal sectors. To facilitate the fitting, values on the lost workday axis were divided by 6,000, resulting in a range of 0 to 1 for the transformed values. Table 1 shows the estimated parameter values for each group of injuries.

Graphically the fitted beta curves are close to the observed data, but the K-S D-statistic for the underground coal data suggests a possibly poor fit, while the metal/nonmetal fitting can be considered acceptable (Table 1). The discussion section below includes comments on this.

To assess the risk values associated with each sector and estimate the difference in risk, the cumulative form of the fitted curve F(x, α, β) was first calculated. For convenience in representing the probability of a loss exceeding a given value, the form 1-F(x, α, β) was used for plotting (Fig. 7). For each curve, the value plotted for a given magnitude of loss represents the probability of a case having more lost

workdays than the given magnitude. For example, for the metal/nonmetal sector for the period studied, the probability of a case exceeding 10 lost workdays is 0.35, while for the underground coal sector, the probability is 0.52.

As a summary measure, which we termed "normalized risk," the integral of the function 1-F(x, α, β) over the interval (0,1) was calculated. For any cumulative distribution function defined on the interval (0,1), the value of this integral lies between 0 and 1. The area under this function is analogous to average risk for the group of cases modeled. Fig. 7 demonstrates clearly that the metal/nonmetal sector experience corresponds to the safer sector, since for each loss on the horizontal axis, the probability of a greater loss is higher for coal than for metal/nonmetal. The normalized risks, obtained for each sector by integrating the corresponding function, show that "smaller" area corresponds to a "safer" sector, condition, or population. Confidence intervals for the normalized risks were obtained by integrating "confidence curves" banding the observed and fitted curves using the associated Kolmogorov-Smirnov tabled value (Massey, 1951).

Table 2 compares the traditional measures of safety for the underground coal and underground metal/nonmetal sectors.

As Table 2 demonstrates, the sectors are disparate in size, number of cases, and lost workday totals. The two measures using denominators – fatal and nonfatal case incidence rates – show that coal has slightly higher rates. The lost workday distribution comparisons, however, suggest graphically and without denominators that the risks associated with coal mining exceed those for the metal/nonmetal sector across a significant portion of the lost workday range (Fig. 7).
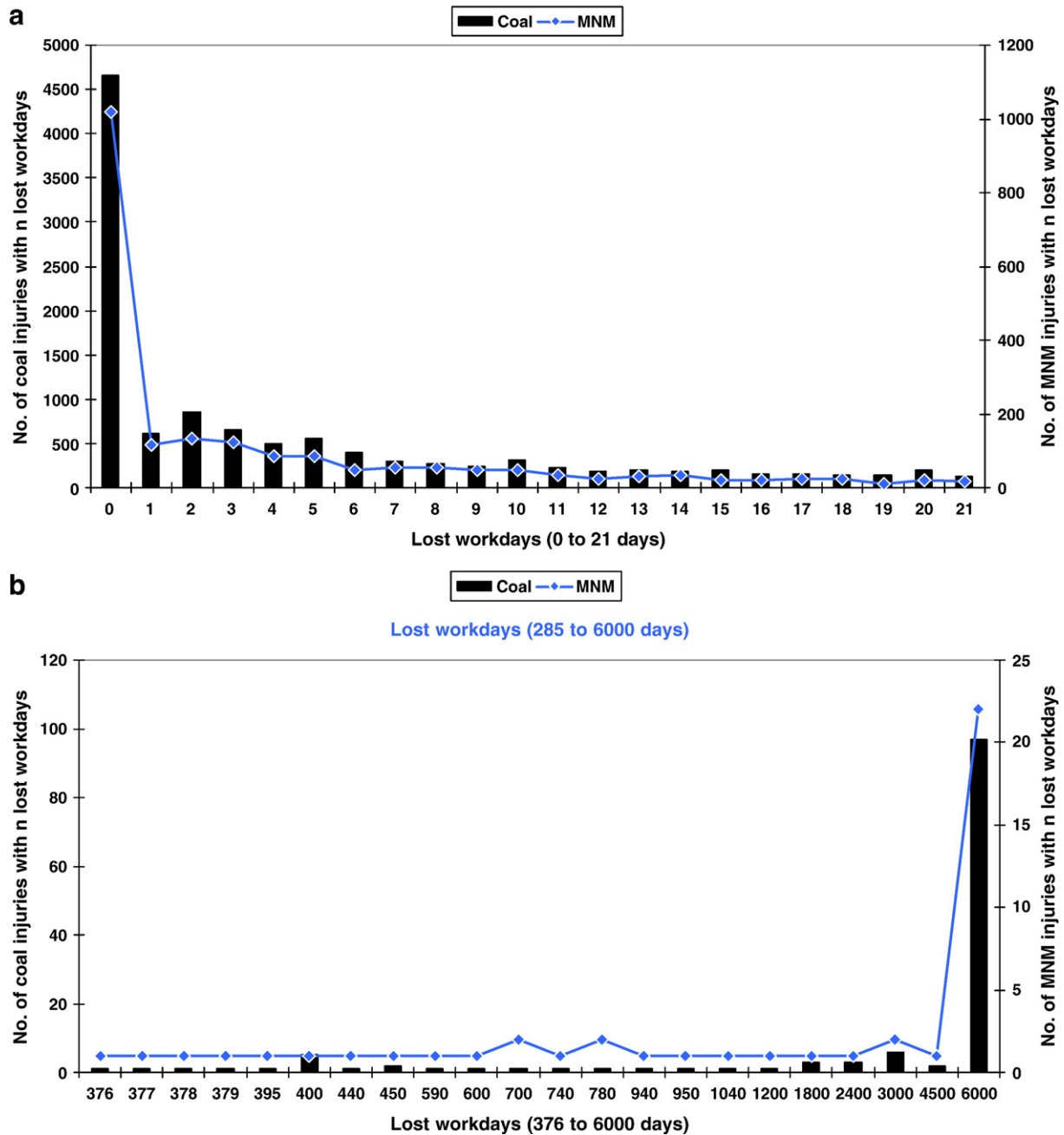
Fig. 6. a. U.S. underground coal and metal/nonmetal injury lost workday distributions, 2000 - 2004, b. U.S. underground coal and metal/nonmetal injury lost workday distributions, 2000 - 2004.

A final example compares the lost time of miners killed and injured in accidents associated with the operation of continuous mining machines, which are used primarily in

Table 1
Beta distribution curve parameters for lost workdays, underground mines, 2000 - 2004

Shape parameter	Coal	Metal/nonmetal
A	0.307419	0.2162522
B	40.00770373	54.96983
N	19,236	2,864
Goodness-of-fit (K-S D-statistic)	0.049	0.029
Critical value for p 0.05	0.009	0.024

underground coal operations. Note that machine-specific incidence rates cannot be computed, since hours worked are not specific to time spent working with or near a particular mining machine. The total losses of cases associated with continuous miners in 2001–2002 were compared to those reported in 2003–2004. After fitting beta curves (Table 3) to the loss distributions of these cases for the two periods, the assessment showed that cases occurring in 2003–2004 had a larger total loss. In this example, the Kolmogorov–Smirnov test statistics show good fits for each period.

Table 4 summarizes the available traditional measures as well as the distribution-based measures. The ratio of average
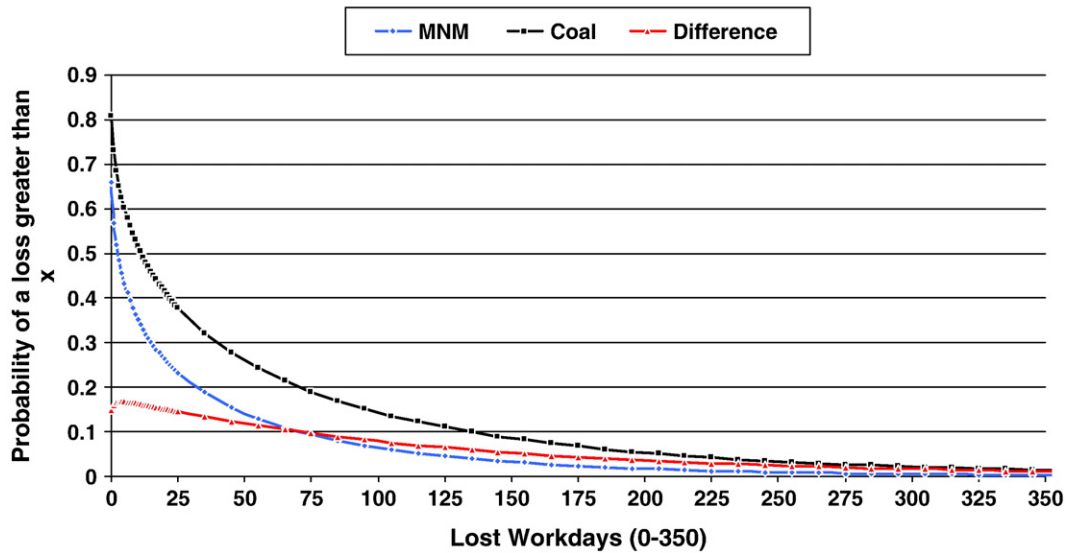
Fig. 7. Lost Workday Fitted Distributions for Underground Coal and Underground Metal/Nonmetal Mining, 2000 - 2004.

losses for 2001–2002 to those of 2003–2004 was 0.925, suggesting that recent continuous miner operations are less safe than earlier ones (Fig. 8). Because the confidence intervals for normalized risk overlap, the difference is not statistically significant, however.

Table 2

Safety measures comparing two underground mining industry sectors, 2000 2004

Measure	Coal	Metal/nonmetal
Average number of employees per year	46,011	13,167
Number of employee hours	379,939,113	93,462,088
Number of injuries (degrees 1 6)	19,236	2,864
Number of fatalities (degree 1)	94	22
Number of permanent disabilities (degree 2)	187	24
Actual days lost from work	764,330	43,296
Days of restricted work activity	31,770	21,023
Statutory days lost	646,940	138,660
Total days lost	1,443,040	202,979
Fatal case incidence rate (no./100,000/year)	49.48	47.08
Nonfatal case incidence rate (no./100/year)	10.08	6.08

Table 3

Beta distribution curve parameters for lost workdays, continuous mining machines, 2001 2002, 2003 2004

Shape parameter	2001 - 2002	2003 - 2004
A	0.26221	0.300873
B	22.2116	23.5436
N	429	337
Goodness-of-fit (K-S D statistic)	0.028	0.059
Critical value for p 0.05	0.066	0.074

5. Discussion

It's well known that surveillance data of occupational injuries and illnesses for U.S. industries in general have significant limitations. 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. Public health practitioners are constantly faced with decisions that require prioritizing activities and interventions in the face of incomplete and less-than-ideal information, and the collection of surveillance data is no exception.

Mining in the United States has an advantage over other industries in that the long-term development of safety and health regulations, including injury and illness reporting

Table 4

Safety measures comparing continuous mining machine injuries in two periods, 2001 2002 and 2003 2004

| Measure	2001 - 2002	2003 - 2004
Number of fatalities (degree 1)	12	7
Number of permanent disabilities (degree 2)	2	6
Number of non-fatal injuries (degrees 3 6)	415	324
Total days lost	99,146	63,363
Actual days lost from work	20,001	18,373
Days of restricted work activity	995	654
Statutory days lost	78,150	44,535
Percentage of total losses for the two periods	61%	39%
Comparison of distributions (normalized risk)	0.012	0.013
95% confidence intervals for normalized risks	(0.007, 0.018)	(0.008, 0.019)
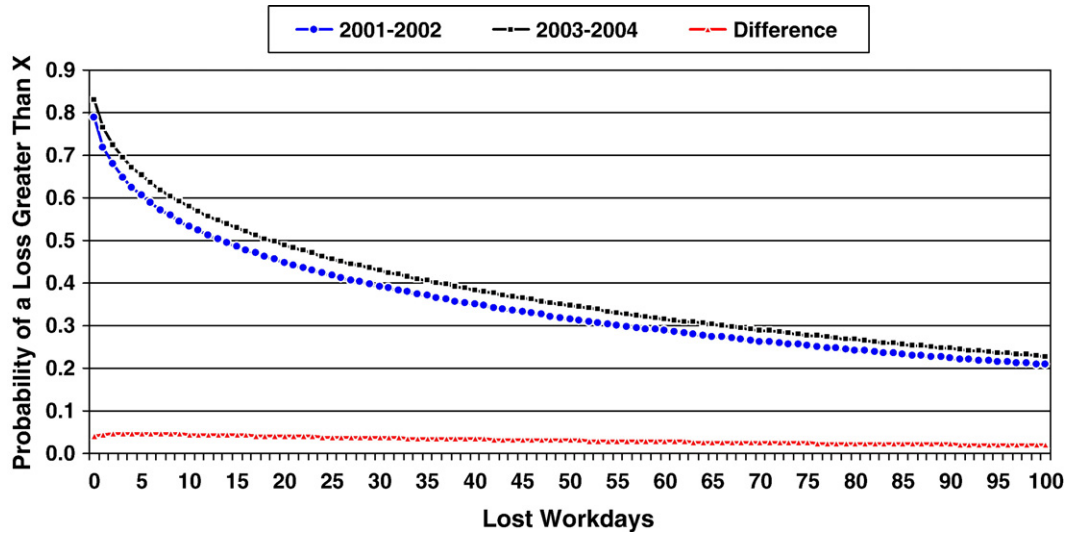
Fig. 8. Lost Workday Fitted Distributions for Continuous Coal Mining Machines in 2001 - 2002 vs. 2003 - 2004.

requirements, has resulted in a very detailed, relatively consistent case series. The risks faced by miners have historically been such that the mining industry has generally complied with stringent reporting requirements, and the industry, research, and regulatory agencies have benefited. Combined with hours-worked reports, the MSHA accident-injury-illness database can be analyzed to determine high-priority research needs as well as trends that help in evaluating intervention effectiveness.

This study suggests that methods of analysis can be extended to include comparisons based on differences in accident outcomes such as lost workdays. These methods allow comparisons of disparate operations for almost any grouping of categories in the MSHA database.

The curve-fitting process is one that deserves further exploration. In the first example above, the beta curve fitted to the underground coal losses had a K-S D-statistic of 0.049, which exceeded the tabled values for both the 0.05 and 0.01 p-levels. We chose to use the fitted curve despite this for two reasons: (a) graphically the beta appeared to fit the observed data well; and (b) the unusually large sample size for the underground losses (19,236 cases over the 5-year period 2000–2004) produced a very low cutoff value for the D-statistic. Additional work is planned for this and related questions.

6. Data and methodology limitations

The limitations of the MSHA data deserve some discussion. Specifically, the use of statutory days as a measure of injury severity raises several questions. Are the assignments of statutory days charged based on scientific methodology? Does MSHA arbitrarily assign such values to each applicable case? In practice, the tables and charts that explain the assignment of lost workday equivalents to specific impairments of body parts are based on medical histories and the opinions of medical professionals. MSHA includes instructions that require the physician treating the case to estimate the loss of use of an amputated member, or an enucleated eye, for example.

While the origin of the tables adopted by MSHA is not specifically addressed in the ANSI Z16 standards, modern developments of the methodology have focused on more comprehensively assessing and rating an individual's permanent impairment (Cocchiarella & Andersson, 2005). A person's disability, or activity limitations, is often related to an impairment, but in a nonlinear fashion. More information, including the person's skills, education, job history, adaptability, age, and environmental requirements, is needed to assess disability level. To the extent that the ANSI standard reflects a cumulative history based on population averages, the statutory days charged can be a meaningful index of lost work time. One advantage of the MSHA data is that statutory days are consistently defined over the period of data collection, and therefore serve as a useful surrogate measure of diminished working lifetimes.

Long-term trends in injury incidence and in lost time measures are subject to reporting practices and rules. Injury data for the period 1984–1986 show a possible artifact of reporting due to MSHA initiating an effort to clarify the reporting process and increase enforcement of the reporting regulations in December 1986 with the release of the "Yellow Jacket" Report on 30 CFR Part 50. Although no clear cause and effect conclusions can be proven, there was a coincident 20–40% increase in reports of lost-time injuries.

Given that coal mine operators may have contributed to the artifact mentioned earlier, with the apparent increase in incidence rates of almost 50% for 1986 through 1988, the relatively steady decline in rates for 1989 through 2004 is likely to represent a true reduction in risk over the period. An alternative explanation is that the decline represents a progressive return to under-reporting. This is less likely,

since the fatal incidence rate for coal mine operators has also trended downward quite dramatically over the period 1966 through 2004.

While the downward trends are encouraging, this study did not explore the factors responsible for the downtrends. We can assume with some confidence that improvements in evolving mining technology have played major roles. Based on the assessments of an expert consultant, the following factors were identified:

- An ongoing increase in the level of mining mechanization
- An increase in health and safety emphasis by mining companies
- Work once done by contractors is increasingly done by salaried workers
- Consolidation of mines by bigger companies – smaller, more hazardous operations are fewer in number
- Improvements in mining systems and designs

Improvements in underground mining technology specifically include a shift from jackleg drills to drill jumbos, coupled with improvements in roof control mechanizations. Ore removal (mucking) operations done with load-haul-dump vehicles are replacing older, more hazardous techniques (using slushers, overshot muckers), especially in small operations (personal communication, William Hustrulid, Ph D., April 6, 2007).

7. Summary

This study was motivated by the search for a wider set of indicators for the effectiveness of safety program performance in mines. MSHA maintains a very thorough and detailed database of job injuries and illnesses reported by mining companies and contractors. However, denominators in the form of hours worked are not sufficiently detailed by category to allow traditional estimates of risk to be calculated for a variety of variables. Without denominators and the incidence rate calculations they allow, it is difficult to state with any certainty that machine A is safer to work with than machine B, or that one period of years for a given group of mines was safer than another period.

The lost workday outcomes from mining injuries are valuable indicators of a number of aspects of job safety programs. While traditional measures of preventive program performance are still needed, including total case counts and incidence rates, lost time measures offer the possibility of comparing important aspects of safety program performance among various sectors and time periods without relying on denominators. In particular, the distribution of lost workdays can be modeled statistically and the models can be used to quantify losses for more effective tracking of what works and what doesn't.

8. Impact on Industry

As in the use of balanced score cards in business management (Kaplan & Norton, 1996), a wider variety of measures can help to ensure that programs are performing as intended. In mining, as well as in other industries, job injuries are not only lagging indicators, but are often too infrequent to be used as day-to-day indices of program performance. While lost time measures do not provide more frequent indications, they can help the mining industry improve important aspects of their safety programming, including attention to personal protective equipment, timeliness of rescue efforts, and in general, management of the post-injury phase (Haddon, 1968).

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Appendix A
Lost time data for Figs. 2.–5

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Coal Mine Operators																							
Lost Workdays	314679	359,184	353,287	303,175	375,635	374,043	342,491	438,779	446,454	334,097	277,432	318,667	264,028	195,722	190,952	195,897	189,019	158,516	200,954	206,001	211,800	192,179	173,425
Statutory Days Lost	603,719	947,140	640,798	782,131	567,284	437,855	519,457	592,880	476,196	336,412	297,102	316,164	317,498	317,502	252,713	240,878	225,996	237,340	347,171	189,975	200,491	238,401	172,603
Days of Restricted Work Activity	3,819	4,202	5,172	5,793	9,076	9,055	8,149	10,877	14,516	10,816	11,383	13,038	15,334	13,149	16,441	15,248	12,440	9,576	12,554	9,458	9,941	11,111	10,339
Coal Mine Contractors																							
Lost Workdays	8,284	8,107	11,487	8,001	6,638	6,856	8,198	13,862	15,389	13,587	12,396	21,822	12,307	13,374	12,573	16,230	20,765	19,832	33,436	32,830	30,684	27,653	27,643
Statutory Days Lost	24,800	69,050	29,560	38,985	39,425	74,695	42,345	68,560	73,385	71,695	72,495	64,000	71,690	24,310	53,680	34,850	36,685	73,575	40,315	50,620	55,160	45,445	64,505
Days of Restricted Work Activity	83	318	51	105	74	193	197	149	228	542	436	609	355	498	970	940	1,330	518	1,353	936	1,152	2,021	1,844
Metal/Nonmetal Mine Operators																							
Lost Workdays	119,283	138,299	165,104	127,043	141,957	190,468	166,915	180,405	176,664	153,650	148,921	145,380	126,579	105,824	93,640	107,050	111,737	93,650	122,080	102,608	104,450	104,719	102,619
Statutory Days Lost	465,338	563,984	416,715	374,556	551,959	401,920	428,179	565,101	444,888	310,893	351,374	445,523	432,135	330,045	380,173	328,760	339,230	364,265	242,120	307,635	279,250	197,410	302,080
Days of Restricted Work Activity	10,975	13,083	14,305	12,407	19,840	31,646	28,956	38,920	39,336	41,504	46,051	50,605	51,282	48,414	51,704	58,079	59,016	56,451	69,452	57,130	63,969	64,533	70,553
Metal/Nonmetal Mine Contractors																							
Lost Workdays	6,513	6,916	8,853	5,296	9,835	16,364	10,863	11,932	12,152	8,417	7,412	16,895	11,392	14,205	10,583	9,088	12,961	10,753	12,320	7,957	11,322	13,153	14,985
Statutory Days Lost	66,110	66,630	67,995	53,036	74,580	89,450	95,220	100,850	71,761	66,610	82,040	48,960	108,085	80,495	146,790	98,180	127,875	86,365	97,475	40,220	31,225	73,365	31,140
Days of Restricted Work Activity	542	222	467	277	209	857	1,917	1,227	2,562	1,324	1,819	4,262	3,631	3,346	2,213	3,048	3,305	3,831	2,936	4,034	2,728	4,639	5,176