Safety vs. productivity and other factors in US underground coal mines

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Abstract

Based on the relationships between severity measure vs. productivity and other factors, this paper presents a comprehensive analysis of US underground coal mine injuries in 1996 by mine size. From the 1996 data, it was concluded that, generally, the larger the mine, the more productive it is (in tons per employee-hour) but the more severe is its injury experience (r = 0.65). However, within very large, large and medium mines, the more productive the mine, the less severe is its injury experience (r = -0.43, -0.36 and -0.26, respectively). For small and very small mines, a deeply nested analysis would be required to understand relationships. Other interesting relationships and comparisons are presented.

Introduction

The elevated fatality rates and, at times, the elevated serious injury rates in small mines (fewer than 50 employees but more than 19) and very small mines (less than 20 employees) have been documented in past studies (National Academy of Sciences, 1983; Tisdale, 1993; Peters and Fotta, 1994; Grayson, 1999). This paper presents a followup study of the 1996 West Virginia underground coal mine accident experience, extending it to all US underground coal mines with a focus on examining differences in both safety and productivity performances by mine size.

Grayson (1999) challenged the conventional belief that the most productive mines are also the safest. Based on 1993 and 1996 West Virginia mine-accident data, it was shown that this relationship generally holds in very large, large and medium-size mines (1996 data only), but the relationship does not hold for small and very small mines. This study further examines the relationship between productivity and safety measures nationwide by mine size using the most current, final US Mine Safety and Health Administration (MSHA) accident data available at the time work began on this paper (1996). General summaries of data analyses are presented, as well as results of statistical tests for significant relationships.

Description of database and data-reduction procedures

The 1996 Mine Safety and Health Administration accident database was downloaded off the MSHA Web site, as was the 1996 coal-production and employee-hour database.

Mines with no tons mined or no employee-hours worked were removed, along with their associated accident records. In addition, accident records with missing ages for miners and illogical experience-related relationships were also removed. It was believed that these inconsistencies yielded unreliable information for those records.

Summary of selected safety measures by mine size

Table 1 presents a summary of selected safety measures and employee hours worked by mine size. The largest number of fatalities occurred in the largest and smallest mines. Very small mines had the highest fatality incident rate at 0.261 fatalities per 100 miners working for one year.

The next highest rate occurred in medium mines, but this rate was lower than the rate for very small mines by a factor of three. Similar results are seen for the statutory severity measure.

A serious injury is one in which a miner incurs at least 20 lost and/or restricted workdays. The serious injury rate was highest for very large mines, and the rate dropped consistently by mine size. A similar trend was observed for the serious injury severity measure.

The lost-time injury rate was highest for very small mines. And it was very nearly the same for all other mine-size categories. However, the severity measure was highest for very large mines and dropped consistently in magnitude by diminishing mine size, with the lowest rate occurring for very small mines. A similar trend was seen for the average severity across mine size categories.

Table 2 gives the number of mines in parenthesis for each mine-size category, as well as the productivity, severity measure and average severity for each. It is seen that productivity generally decreased by mine size, except for very large mines. The severity measure decreases consistently from very large mines to very small mines, as does the average severity. Later, the overall relationship between severity measure and productivity will be analyzed for significance, but a general relationship for this data can be stated. Generally, the larger the mine, the more productive it is. But the larger the mine, the more severe its injury experience, as evidenced by the severity measure. The overall correlation between severity measure and productivity across mine size was $r = +0.065$. This indicates that, as productivity increases, so does the severity measure. A different picture is obtained, however, when examining the relationship between productivity and severity measure within a mine-size category, as will be shown later.

TABLE 1

Summary of selected safety measures and employee hours by mine size.

	Mine size				
	Very large	**Large**	**Medium**	**Small**	**Very small**
Number of fatalities	8	3	5	4	6
Fatal incident rate (IR)	0.050	0.028	0.084	0.058	0.261
Statutory days	55,870	36,138	41,220	33,960	47,010
Statutory severity measure (SM)	352.0	337.3	690.8	488.7	2,046.7
No. serious injuries	482	291	145	167	54
Serious injury IR	3.04	2.72	2.43	2.40	2.35
No. serious injury days lost	27,254	15,989	7,854	8,386	2,468
Serious injury SM	171.7	149.2	131.6	120.7	107.5
No. lost-time incidents	1,105	760	443	476	226
Lost-time IR	6.96	7.09	7.42	6.85	9.84
No. days lost	31,766	18,994	9,614	10,175	3,318
Lost-time SM	200.1	177.3	161.1	146.4	144.5
Average severity (AS)	28.7	25.0	21.8	21.4	14.7
Employee hours (millions)	31.745	21.430	11.934	13.901	4.594

Examination of data for underreporting of accidents in small mines

Anecdotally, it was hypothesized that underreporting of accidents according to 30 CFR Part 50 persists in small mines. Thus, it was judicious to examine this hypothesis. To gain insight into whether this is a possibility, the distribution of lost time for accidents within a mine-size category was examined. If significant underreporting did occur, then the percentage of low lost-time accidents that occurred in small and very small mines should be comparatively smaller than the percentage for other size mines. Figure 1 shows a plot of lost-time incidents by mine size for various classes of lost time. Upper limits of lost-time classes are plotted on the abscissa, while frequencies of classes are plotted on the ordinate. Examination of the plots by mine size reveals that percentages in the low lost-time incident classes are actually higher for small and very small mines, indicating that there does not appear to be significant underreporting of accidents in small and very small mines.

Correlation between severity measure and other variables

Entertaining the possibility that multiple regression analysis could be used to model the relationship between severity measure and other variables, the correlation between severity measure and other variables was calculated by mine size for scrutiny. Few relationships were apparent, as shown in Table 3. In some cases, a variable appeared to have a good correlation with severity measure, e.g., experience in the job for very large mines, but the relationship did not hold for other mine sizes. This general result held for all variables. In many cases, the apparent relationship changed. For example, experience in the job negatively correlated with severity measure for very large mines. Thus, as more experience was attained by miners, then a lower severity measure resulted. This is a logical expectation. However, the relationship was reversed for all other mine sizes, except for small mines where the correlation was negative but very low.

Correlation of severity measure and productivity by mine size

Although the general result exposed that larger mines have a more severe injury experience, it is not appropriate to compare larger mines to smaller ones because their cultures, capital resources, size of the workforce to support mine infrastructure, level of contract work, etc., are very different. Thus, the relationship between severity measure and productivity was examined within each mine-size category.

Correlations. The correlation between severity measure and productivity for the various mine-size categories was -0.432, -0.357, -0.262, +0.003 and +0.0001 for very large, large, medium-size, small and very small mines, respectively. To determine if each correlation was significant, Fisher's Z-transformation approximation was applied. The results are given below.

Statistical testing of correlations. For application of a one-tailed Fisher's Z-transformation approximation test, a level of significance of $\alpha = 2.5\%$ is used here, giving a test statistic of $t_{0.975} = -1.960$ for testing the null hypothesis (H_0: $\rho = 0$) vs. the alternative hypothesis (H_1: $\rho < 0$). A 95% confidence interval may also be developed around the correlation, which will be done in these cases. The results of testing for each mine size are as follow:

- *Very large mines:* With $r = -0.432$, a 95% confidence interval was calculated to be (-0.139, -0.656). H_0 was rejected because $t = -2.810 < t_{0.975} = -1.960$. Thus, the correlation was significant at $\alpha = 2.5\%$.
- *Large mines:* With $r = -0.357$, a 95% confidence interval was calculated to be (-0.117, -0.556). H_0 was rejected because $t = -2.865 < t_{0.975} = -1.960$. Thus, the correlation was again significant at $\alpha = 2.5\%$.
- *Medium size mines:* For medium-size mines, with $r = -0.262$, a 95% confidence interval was calculated to be (-0.032, -0.465). H_0 was rejected because $t = -2.226 < t_{0.975} = -1.960$. Thus, the correlation was again sig-

nificant at $\alpha = 2.5\%$.

- *Small and very small mines:* In testing the correlation for small and very small mines, H_0 was accepted. Therefore, neither correlation was *significantly* different from $\rho = 0$.

Examination of severity measures of high-productivity vs. low-productivity mines within mine size categories

The negative correlation between productivity and severity measure for very large, large and medium mines indicates that the more productive mines are also the safer ones. To further examine the validity of this statement, a more detailed analysis was made.

For each mine category, the set of mines was partitioned according to high- and low-productivity subsets. The average productivity was calculated for each subset for comparison purposes. The severity measure and standard deviation for it were calculated for each subset as well, so that testing via a one-tailed t-test could be done. The null hypothesis for each test is that the calculated severity measure for each subset is equal. Rejection of the null hypothesis would indicate that the severity measures are not equal, and the relationship between productivity and severity measure could then be described according to the data. Results of tests are as follows.

Very large mines. There were 40 very large mines with productivities averaging 4.60 tons/employee-hour with a standard deviation of 2.14 tons/employee-hour. Of these, 19 were mines with productivities less than 4.6 tons/employee-hour. These were classified as low-productivity mines and averaged 3.09 tons/employee-hour. They had a severity measure of 262.5 lost days/200,000 employee-hours, with a standard deviation of 175.36 lost days/200,000 employee-hours. Another 17 mines were classified as high-productivity mines with productivities greater than 4.8 tons/employee-hour. These averaged 6.61 tons/employee-hour. They had a severity measure of 120.5 lost days/200,000 employee-hours, with a standard deviation of 71.38 lost days/200,000 employee-hours.

Applying a one-tailed t-test (0.05 level of significance) in comparing the two distributions gave $t = 3.027$, which exceeded $t_{0.95} = 1.30$. Thus, the two severity measures were significantly different. In this case, this implied that the higher productivity mines were safer than the lower-productivity mines.

Large mines. There were 62 large mines with productivities averaging 5.15 tons/employee-hour with a standard deviation of 2.74 tons/employee-hour. Of these, 25 were mines with productivities less than 4.2 tons/employee-hour. These were classified as low-productivity mines and averaged 3.22 tons/employee-hour. They had a severity measure of 261.4 lost days/200,000 employee-hours, with a standard deviation of 171.02 lost days/200,000 employee-hours.

Another 21 mines were classified as high-productivity mines with productivities greater than 4.8 tons/employee-hour. These averaged 7.80 tons/employee-hour. They had a severity measure of 98.3 lost days/200,000 employee-hours, with a standard deviation of 87.21 lost days/200,000 employee-hours.

TABLE 2

Productivity, lost-time severity measure, and average severity by mine size.

Mine size	Productivity, (tons per employee hour)	Lost-time severity measure	Average severity
Very large (40)	4.60	200.1	28.7
Large (62)	5.15	177.3	25.0
Medium (72)	4.47	161.1	21.8
Small (200)	4.32	146.4	21.4
Very small (199)	3.59	144.5	14.7

Applying a one-tailed t-test (0.05 level of significance) in comparing the two distributions gave $t = 3.87$, which exceeded $t_{0.95} = 1.30$. Thus, the two severity measures were significantly different, implying, again in this case, that the higher productivity mines were safer than the lower-productivity mines.

Medium mines. There were 72 medium mines with productivities averaging 4.33 tons/employee-hour with a standard deviation of 2.02 tons/employee-hour. Of these, 29 were mines with productivities less than 3.5 tons/employee-hour. These were classified as low-productivity mines and averaged 2.78 tons/employee-hour. They had a severity measure of 203.1 lost days/200,000 employee-hours, with a standard deviation of 192.68 lost days/200,000 employee-hours.

Another 21 mines were classified as high-productivity mines with productivities greater than 5.0 tons/employee-hour. These mines averaged 6.69 tons/employee-hour. They had a severity measure of 97.70 lost days/200,000 employee-hours, with a standard deviation of 93.34 lost days/200,000 employee-hours.

Applying a one-tailed t-test (0.05 level of significance) in comparing the two distributions gave $t = 2.27$ which exceeded $t_{0.95} = 1.30$. Thus, the two severity mea-

FIGURE 1

Frequency plot of lost-time incidents by mine size.

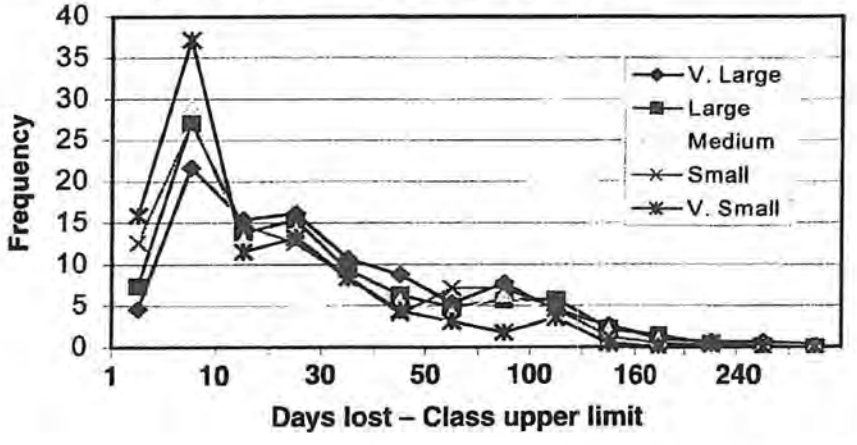

TABLE 3

Correlation between severity measure and various other variables.

	Mine size				
Variable	**Very large**	**large**	**Medium**	**Small**	**Very small**
Seam height	-0.177	-0.299	-0.070	-0.001	+0.094
Average employment	+0.209	-0.161	-0.073	+0.002	-0.075
Age of miner	+0.015	+0.184	+0.122	-0.015	+0.014
Experience in job	-0.422	+0.062	+0.222	-0.004	+0.090
Experience in mine	-0.145	+0.023	+0.141	+0.072	-0.085
Total mining experience	-0.267	+0.210	+0.185	-0.109	+0.016

sures were significantly different, implying, again in this case, that the higher productivity mines were safer than the lower-productivity mines.

Small mines. There were 200 small mines with productivities averaging 4.24 tons/employee-hour with a standard deviation of 2.02 tons/employee-hour. Of these, 20 were mines with productivities less than 2.22 tons/employee-hour. These were classified as low-productivity mines and averaged 1.72 tons/employee-hour. They had a severity measure of 67.1 lost days/200,000 employee-hours, with a standard deviation of 110.52 lost days/200,000 employee-hours.

Another 27 mines were classified as high-productivity mines with productivities greater than 6.26 tons/employee-hour, and averaging 8.24 tons/employee-hour. They had a severity measure of 120.3 lost days/200,000 employee-hours, with a standard deviation of 147.13 lost days/200,000 employee-hours.

Applying a one-tailed t-test (0.05 level of significance) in comparing the two distributions gave $t = -1.33$, which exceeded $t_{0.95} = -1.30$. Thus, the two severity measures were significantly different, implying, differently in this case, that the higher-productivity mines were less safe than the lower-productivity mines.

Very small mines. There were 199 very small mines with productivities averaging 3.47 tons/employee-hour with a standard deviation of 1.89 tons/employee-hour. Of these, 17 were mines with productivities less than 1.58 tons/employee-hour. These were classified as low-productivity mines and averaged 1.02 tons/employee-hour. They had a severity measure of 53.9 lost days/200,000 employee-hours, with a standard deviation of 100.91 lost days/200,000 employee-hours.

Another 25 mines were classified as high-productivity mines with productivities greater than 5.36 tons/employee-hour. These mines averaged 7.36 tons/employee-hour. They had a severity measure of 155.5 lost days/200,000 employee-hours, with a standard deviation of 250.80 lost days/200,000 employee-hours.

Applying a one-tailed t-test (0.05 level of significance) in comparing the two distributions gave $t = -1.55$, which exceeded $t_{0.95} = -1.30$. Thus, the two severity measures were significantly different, implying, again differently in this case, that the higher productivity mines were less safe than the lower-productivity mines.

Conclusions

In the analysis of 1996 mine-accident and production-employment data, productivity (tons/employee-hour) was found generally to decrease by mine size, except for very large mines. The severity measure decreased consistently from very large mines to very small mines, as did the average severity. The correlation between productivity and severity measure across mine-size categories was $r = 0.65$. This indicated that, as productivity increased, so did the severity measure. However, this relationship does not give a true picture of the relationship between productivity and severity measure, as revealed by further analysis.

Relationships between severity measure and other variables, such as seam height, average employment, age of miner, experience in the job, experience in the mine and total mining experience, were nonexistent across mine-size categories. A substantial correlation was found within a mine-size category in isolated cases. Plots of frequency distributions for classes of lost time revealed that there is apparently no underreporting of accidents in small and very small mines now.

Examination of the relationship between productivity and severity measure within mine-size categories revealed a significant negative correlation for very large, large and medium mines (-0.43, -0.36, and -0.26, respectively). Thus, within these mine-size categories, higher-productivity mines are safer than lower-productivity mines. Correlation analysis revealed no relationship across all mines in the small and very small mine-size categories. Further analyses focused on statistical testing of severity-measure distributions for high- and low-productivity mines within each mine-size category. Statistical testing (one-tailed t-tests) confirmed the general relationship determined in the correlation analysis for very large, large and medium-size mines, i.e., the more productive mines are also the safer ones. The opposite relationship was found for small and very small mines, i.e., higher-productivity mines are less safe than lower-productivity mines. ■

References

Grayson, R., 1999, "Challenging conventional wisdom and setting new priorities concerning West Virginia mine safety performances," *Transactions SME*, Vol. 306, pp. 42-48.

National Academy of Sciences, 1983, "Fatalities in small underground coal mines," Open File Report 124-83 on Contract No. J0100145, US Bureau of Mines, Washington, DC, 20 pp.

Peters, R., and Fotta, B., 1994, "Statistical profile of accidents at small underground coal mines," *Proceeding*, Bureau of Mines Technology Transfer Seminar, *SP-18-94*, US Bureau of Mines, Washington, DC, 10 pp.

Tisdale, J., 1993, "Meeting the challenge of serious safety problems at small coal mines," *Proceedings*, 24th Annual Institute on Mining Health, Safety, and Research, Virginia Polytechnic Institute and State University, Blacksburg, VA, 15 pp.