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THE ECONOMIC BURDEN OF FATAL OCCUPATIONAL INJURIES TO MINERS IN THE UNITED STATES – FATALITIES COST IN MINING

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ABSTRACT

To better understand the burden imposed by fatal accidents in the mining industry, it is necessary to develop measures of the economic component of loss to complement existing surveillance research efforts. The Fatalities Cost in Mining web application, developed by the NIOSH Mining Program, uses an adapted version of a well-known cost of illness methodology to estimate the societal cost of an individual fatality based on key characteristics of the fatally injured miner. The user can select fatality characteristics (demographics, incident, employer, etc.) and reporting year (2010–2017 currently available) to generate a report and view the average societal cost per fatality as well as the total cost for all fatalities matching the criteria. For example, from 2010 through 2017 there were 316 fatal accidents with a median cost of $1.48 million per fatality with a total societal cost of $445.42 million. Researchers, occupational health professionals, workplace safety organizations, and labor unions have proven to be willing and avid users of past NIOSH estimates. This manuscript reviews the Fatalities Cost in Mining web app, including its development and how it can be used to estimate the economic burden of fatal mining injuries.

INTRODUCTION

It is commonly recognized that there are costs involved with fatal injury to workers. These costs generally address the overall costs to victims, families, employers, organizations, and to society as a whole. This wide-ranging national burden imposed by occupational fatalities consists of numerous areas of personal and public life that can include social costs, organizational costs, and even intangible personal costs which can include suffering and grief. It affects personal well-being, family, and relationships with coworkers, communities, companies, and governments.

This burden also includes an economic component of loss. Surveillance data is vitally important for understanding the occupational safety and health of mine workers, and analyzing this data helps in identifying accident trends over time, the magnitude of occupational injuries, identifying risk factors, and setting priorities for prevention research. However, there is a need to better understand the burden levied by fatal occupational injuries and to continue to develop measures of the economic component of loss. The work described in this paper adds an economic dimension to existing mining fatal injury research. The focus is on monetary costs of fatal occupational injury, which largely consist of lost wages and benefits, but also includes the direct costs of medical care and the indirect costs of the decedent's household production.

This work represents a continuation of previous research by the National Institute for Occupational Safety and Health (NIOSH) that attempted to establish the economic consequences of workplace injury (NIOSH, 2009, 2011). It builds on existing research on the occupational injury economic burden as it focuses on the mining industry and uses specific data from MSHA datasets to make specific burden estimates for individual fatal injuries. And, some of the initial results are captivating. Over 2010–2017, the costs from 316 premature deaths exceeded $445 million, which can provide motivation to reduce the severe toll of occupational fatalities on our nation's workers, institutions, and communities. Researchers and concerned parties within the occupational and public health professions, academia, organizations focusing on workplace safety, labor unions, and the business community have all proven to be willing and avid users of this data and have used this research to continue their efforts, in concert with continuing NIOSH research efforts, to reduce the great toll that fatal injury imposes on our nation, workplaces, and workers (NIOSH, 2011).

METHODS

Identifying Fatal Occupational Injuries in Mining

In the United States, the Mine Safety and Health Administration (MSHA) requires all mines and their independent contractors who perform work on mine property to report all occupational injuries (not including first-aid), illnesses, and fatalities as required under the Code of Federal Regulations, Title 30 Part 50 (Notification, investigation, reports and records of accidents, injuries, illnesses, employment, and coal production in mines, 2014). The Accident/Injury/Illness data files and the Address/Employment data files are released annually to the public on the MSHA web site. These data are in the public domain and are provided in statistical analysis software format (SPSS) by the NIOSH Mining Program (NIOSH, 2018). These are the most comprehensive publicly available mining injury data available.

For this work, the Accident/Injury/Illness data files for 2010 through 2017 were combined and only fatal injuries were selected. This identified 316 fatal mining injuries for this time period. The mine IDs were matched to those in the Address/Employment data files, and they were merged into to one data file in order to get mine characteristic information for these fatal injuries.

Theoretical Basis of Societal Cost Estimation

The cost to society of a fatal mining injury was approximated using the cost-of-illness method, which combines direct and indirect costs to calculate the total lifetime societal cost of a mining fatality. Direct costs measure the opportunity cost of resources used for medical treatment, while indirect cost measures the value of resources lost due to the premature occupational fatal injury (Segel, 2006). Medical expenses were used to estimate a one-time direct cost of the fatality. The indirect lifetime cost of a fatal mining injury is determined by using the human capital approach, which calculates the present value of lost future compensation (earnings and benefits) and household production. The indirect cost calculations were built on a model developed by Rice (1965), modified by Biddle (2004), and published by NIOSH (2009; 2011). Indirect costs are calculated for each fatality by accounting for: the victim's probability of survival to the next year, annual wages at time of death, benefits at time of death, expected wage growth after death, lost household production, and the real discount rate. The indirect cost is an annual series of costs starting at the decedent's age at death (a_d) and ending at a maximum age of 67 (a_{MAX}). All costs are initially calculated in dollars of the year of death (y_d) and then adjusted for inflation using the GDP deflator ($GDPd_x$). This adjustment allows the costs of multiple fatalities (which may have occurred in different years) to be reported in a selected common year's dollars.

The mathematical representation of indirect costs have been previously described by Biddle (2004) as:

$$\mathrm{PVF} = \sum_{n=y}^{67} P_{y,q,s}(n)\left[Y_{s,j}(n) + Y_s^h(n)\right] * (1+g)^{n-y} / (1+r)^{n-y}$$

Where:

PVF = present discounted value of loss per individual due to a fatal occupational injury
$P_{y,q,s}$ (n) = probability that an individual of age *y*, race *q*, and sex *s* will survive to age *n*
q = race of the individual (all races used)
s = sex of the individual
n = age if the individual had survived
$Y_{s,j}(n)$ = median annual compensation of an employed person of sex *s*, specific occupation at death *j*, and age *n* (includes wages and benefits by detailed industry and wage growth adjustments)
j = specific occupation of individual at death
$Y_s^h(n)$ = mean annual imputed value of home production (*h*) of a person of sex *s* and age *n*
g = earnings growth rate attributable to overall productivity
y = age of the individual at death
r = real discount rate (3%)

This is easier to understand if the total cost calculation is broken down into three parts: the direct cost, the sum of the indirect costs (from age of death to age 67), and adjusting for inflation.

$$total\ societal\ cost = \left\{direct\ cost + \sum_{a_i=a_d}^{a_{max}} (indirect\ cost)_{a_i}\right\} \times \frac{GDPd_{y_\$}}{GDPd_{y_d}}$$

Direct Cost. The direct cost has one component: the medical expense adjusted by medical care consumer price index (CPI). Medical expenses were only included in the first year calculations because over 90% of fatalities occurred within one day of the accident (MSHA, 2018).

NIOSH-sponsored, preliminary unpublished estimates assessed the average medical cost of a fatal occupational mining injury in 2013 at approximately $70,000. Therefore, the medical expense associated with each fatality is estimated at $70,000 in y_{ME} = 2013 dollars. This is adjusted using the medical care CPI ($mcCPI_x$) to determine what the medical expense would have been if it had occurred in y_d rather than in y_{ME}.

$$Direct\ Cost = Medical\ Expense \times \frac{\mathrm{mcCPI}_{y_d}}{\mathrm{mcCPI}_{y_{ME}}}$$

Medical Expense = $70,000

$mcCPI_x$ = average medical care consumer price index for year *x* (BLS, 2018a)
y_d = year of death
y_{ME} = year of medical expense = 2013 dollars

For this model, $\mathrm{mcCPI}_{y_{ME}} = 425.134$.

Indirect Cost. The indirect costs of the fatal mining injuries are derived by calculating the present value of lost household production and future compensation of the miner until the decedent would have reached the estimated retirement age of 67 years, also accounting for the probability of survival. For those who died at or over 67 years of age, only a single year of indirect cost is included in the indirect cost calculation.

Employee compensation is broken down into wage value and benefit value, and therefore, the indirect cost has three components: the wage value, the benefit value, and the household production value. For each year in which the indirect cost is calculated (between a_d and a_{max}), these three values are summed and then adjusted for the time value of money using the real discount rate. This adjustment is required because the indirect cost represents a future value relative to y_d. Sixty-seven years was selected as the maximum work age since it is the full retirement age to collect Social Security (SSA, 2018). Indirect cost calculations can be represented as:

$$\sum_{a_i=a_d}^{a_{max}} (indirect\ cost)_{a_i}$$

a_{max} = 67
a_d = Age of death
a_i = age iteration if decedent did not die

$$(indirect\ cost)_{a_i} = (survival\ probability)_{a_i \to a_i+1} \times \left[\frac{(wage\ value)_{a_i} + (benefit\ value)_{a_i} + (household\ production\ value)_{a_i}}{[1 + (real\ discount\ rate)]^{a_i - a_d}}\right]$$

The survival probability represents the chance that the decedent would have survived an additional year (a_i to a_{i+1}) if he or she had not died at a_d (Arias et al., 2017). Since MSHA does not report a decedent's race, the survival probability for "all" races is used.

Wages. The wage value estimates the annual income of the decedent if he or she had not died. The model assumes that the decedent had worked full-time in the same occupation until retirement age. The wage value is estimated from base earnings, economy-wide productivity growth, and life-cycle wage growth. The wage value estimate is based on the Bureau of Labor Statistics' (BLS) Occupational Employment Statistics (BLS, 2018b) annual median wage of individuals sharing the decedent's occupation based on Standard Occupational Classification codes in y_d. The decedent's age and gender are used to account for deviation from the median BLS wage value as follows:

$$Adjusted\ wage = (annual\ wage_{Occ,\ State})_{y_d} \times (wage\ adjustor)_{a_d,\ sex,\ y_d}$$

Annual wage is the median annual gross earnings (before taxes and other deductions), based on occupation by state. This is multiplied by a wage adjustor to account for deviations from the median value based on age and sex.

$(annual\ wage_{Occ,\ State})_{y_d}$ = Median annual wage for a given occupation by state for the year of death

$(wage\ adjustor)_{a_d\ sex,\ y_d}$ = Adjustment to median earnings by age and sex of decedent

The published median earnings from the BLS Current Population Survey (CPS) for a particular age group was assigned to the median age of that age group (BLS, 2018c). To derive an earnings value for each age, the difference between sequential age groups was calculated as:

$$Earnings_{x+1} - Earnings_x$$

Earnings = CPS published age group earnings

This difference was evenly distributed within the age group by dividing by the number of ages in that age category. Using this quotient, subtract from median income for ages below median, and add to median income for ages above it for each age category. This now creates median incomes for each age. Then the proportion of the median age earnings for each age was determined by dividing by the median income for the entire year to get a proportion of median earnings. The process was repeated for both males and females and for each year of earnings data.

In order to model annual changes in wage, two more adjustments are made to the adjusted wage. First, Employment Cost Index (ECI) accounts for changes due to economy-wide productivity growth. ECI is an indicator of employee costs to businesses and is prepared by the BLS. The employment cost index for wages (ECIW) estimates economy-wide productivity growth, or how much earnings would rise jointly with the growth of the entire U.S. economy (BLS, 2018d). It measures the change in cost of labor and includes changes in wages.

The ECI uses a current-cost approach, where annual costs are calculated based on the current price of benefits. Because this model has the potential to forecast decedent wages for up to 50 years, it uses a long-term productivity growth rate, the average of the percent changes in ECI from 1976–2017 for wages and 1980–2017 for benefits. This inflation-free change in wages and benefits represents an annual proxy for a change in productivity (NIOSH 2011).

$ECIW_x$ = the employment cost index for wage rate for year x. This is the 12-month proportional change in ECI for wages and salaries ending in December of the specified year.

$\langle ECIW \rangle$= the average ECIW for goods-producing industries reported over 1976–2017. For this model, it is 0.0930.

Second, the life cycle wage growth rate accounts for changes in wages due to employee experience. This rate was based on mean wages from the historical income tables of the Current Population Survey (CPS) for the years 2010 through 2017 (BLS, 2018c). Mean wages were presented in constant dollars by sex and BLS age group for each year. The rate of change for mean wages was determined for each sex and race within a specific age group. Wages for the initial age group (x) were subtracted from the wages of the next age group (x+1) and divided by the initial age group wage: (x+1)-x/x. This process was repeated for male and female. In this model, it was assumed that the salary growth rate is constant within age groups–in equal increments for each year of age within that age group.

$life\_cycle\ wage\ growth\ rate$ = Salary growth due to experience of individual workers

In order to account for fluctuations in economic conditions over time, the average ECIW for the years, 1976–2017 is used. For the first year, it is assumed that the death occurred in the middle of the year, so only calculate for half of a year:

$$(Wage\ value)_{a_i=a_d} =$$
$$(adjusted\ wage) \times \left(1 + \frac{1}{2}\langle ECIW \rangle\right) \times \left[1 + \frac{1}{2}(life\_cycle\ wage\ growth\ rate)_{a_i}\right]$$

For the subsequent years, the first-year wage value is used. The ECI wage rate and life cycle growth rate are compounded as follows:

$$(Wage\ value)_{a_i>a_d} =$$
$$(Wage\ value)_{a_i=a_d} \times (1 + \langle ECIW \rangle)^{a_i-a_d} \times \prod_{a_j=a_d+1}^{a_i} 1 + (life\_cycle\ wage\ growth\ rate)_{a_j}$$

Benefit Value. To get an accurate representation of the market value for compensation, the value of employee benefits is added to indirect cost. These benefits include the employers' share of insurance (life, health, and disability), retirement and savings contributions, and legally required payments (Social Security, Medicare, Unemployment, and Workers' Compensation). Employer Costs for Employee Compensation (ECEC) measures the average cost to employers for benefits per employee hour worked (BLS, 2018e). Benefits are estimated from the adjusted wage.

As previously mentioned, the Employment Cost Index (ECI) accounts for changes due to economy-wide productivity growth. The employment cost index for benefits (ECIB) estimates how much benefits would change jointly with the growth of the entire U.S. economy (BLS 2018f). It measures the change in employee benefit costs. In order to account for fluctuations in economic conditions over time, the average ECIB for the years, 1980–2017 is used. The first-year benefit value is calculated as:

$$(benefit\ value)_{a_i=a_d} =$$
$$(adjusted\ wage) \times \frac{ECECB_{y_d}}{1 - ECECB_{y_d}} \times \left(1 + \frac{1}{2}\langle ECIB \rangle\right)$$

For subsequent years, the first-year value is reused. The ECIB (ECI benefit rate) is compounded as follows:

$$(benefit\ value)_{a_i>a_d} = (benefit\ value)_{a_i=a_d} \times (1 + \langle ECIB \rangle)^{a_i-a_d}$$

ECEC = Employer costs for employee compensation

$ECECB_x$ = the ECEC benefit rate for year x. This is the ECEC for benefits, expressed as a proportion of total compensation. These include insurance plans, retirement, and legally required benefits.

$ECIB_x$ = the Employment Cost Index for benefits for year x. It is the 12-month proportional change in ECI for benefits, ending in December of the specified year. It estimates economy-wide productivity growth. It measures the change in cost of labor and includes changes in wages as well as employee benefit costs.

<*ECIB*> = the average ECIB from 1980–2017 for private industry. For this calculator, it is 1.147%.

Household Production Value. The value of household production losses associated with a fatally injured miner were derived from time diary data captured in the National Human Activity Pattern Survey (NHAPS), a study sponsored by the U.S. Environmental Protection Agency and conducted from 1992–1994. The survey inquired about daily activities completed over a 24-hour period (Klepeis et al., 2001). Activities were grouped into five large categories: household production, providing care, hygiene and personal care, leisure, and employment and education (Expectancy Data, 2000). Household production is defined as activities that could produce benefit for all members of the household and includes cooking, housework, cleanup, chores, plant and animal care, home and auto maintenance, and purchasing goods and services. Providing care includes childcare, playing with children, transporting children, and providing care to others. The market replacement value for this time is reported in 1998 dollars and based on total compensation (hourly wages plus the employer's legally required benefit costs). For this mining fatality cost model, household production and providing care activities were calculated by each age and sex category and multiplied by 365 to obtain annual values. Dollar values are adjusted by the ECI wage rate for all industries (BLS, 2018g).

$$(Household\ production\ value)_{a_i} = (Household\ production)_{a_i} \times ECIHP_{y_d}$$

$Household\ production$ = market replacement value of household production and providing care. Household production is reported in y_{HP} = 1998 dollars. It is adjusted to y_d using the ECI wage rate ($ECIW_x$).

$ECIHP_{y_d}$ $= \prod_{y_j=y_{HP}}^{y_d} 1 + ECIW_{y_j}$

$ECIHP_{y_d}$ = Employment cost index for household production.

$ECIW_x$ = the ECI wage rate for all industries in year x. Previously in this model, it was only from goods-producing industries.

Adjusting for Inflation and Discounting. Gross domestic product (GDP) is the value of the goods and services produced in the United States. The GDP deflator measures the level of price inflation with respect to a base dollar year. To adjust for inflation, the sum of the direct and indirect costs are multiplied by the quotient of the GDP deflator of the year of death divided by the GDP deflator of the dollar year used to measure the societal cost. This is represented as:

$$\frac{GDPd_{y_\$}}{GDPd_{y_d}}$$

$GDPd_x$ = GDP deflator for year x (BEA, 2018)

y_d = year of death

$y_\$$ = dollar year

The social discount rate is used for public health evaluations, and it is a rate at which society is willing to exchange present costs for future benefits. The discount rate appropriate for use in economic analyses of health-care interventions is 3% (Neumann et al., 2016). The discount rate already accounts for inflation, so there is no need for further adjustment. The work in this paper uses the three percent discount rate; however, it is recommended to recalculate cost estimates using alternative discount rates to demonstrate the effect of initial assumptions regarding appropriate societal rate. It is appropriate to use a rate between zero and ten percent in a sensitivity analysis.

The overall lifetime societal costs of fatal occupational injury in mining is calculated by combining the present discounted value of loss per individual (indirect costs) with the medical expenditures related to the fatal injury (direct costs).

The cost model explained above was written into a computer program that uses key variables from the fatal injuries sorted from the MSHA accident/injury/illness files (including occupation, state, year, gender, age, etc.) to make the cost estimates. Reports can be run using many of the MSHA mine-specific variables such as state, number of employees working at the mine, subunit, commodity, and accident/injury/illness specific variables (including accident classification, source of injury, and the decedent's occupation, mining experience, and age).

RESULTS

All cost estimates are in 2017 dollars and are discounted at 3%. Median and mean costs are included to help show cost distribution. The median provides a good estimate for a single fatal injury. However, the mean can shed light on the high cost of fatal injuries. For example, if the mean is much higher than the median, then there is at least one cost outlier or a very high-cost estimate that is driving up the mean cost.

Table 1 displays the annual counts and median, mean, and total cost estimates for fatal mining injuries from 2010–2017 for all mining commodities. Counts, average costs, and total costs have been on a downward trend since 2014; however, 2017 has the highest median cost and second highest mean cost during the time period.

Table 1. Number and lifetime societal costs (represented in millions of U.S. dollars) of fatal mining injuries by year, 2010–2017, for all mining commodities.

Year	Count	Median	Mean	Total
2010	72	$1.500	$1.468	$105.695
2011	37	1.483	1.511	55.903
2012	36	1.487	1.422	51.180
2013	42	1.457	1.304	54.756
2014	47	1.546	1.402	65.876
2015	29	1.367	1.302	37.747
2016	25	1.274	1.304	32.588
2017	28	1.641	1.488	41.677
Total	**316**	**$1.481**	**$1.410**	**$445.422**

The 11 states with the highest number of fatal occupational mining injuries and the estimated lifetime societal costs are shown in Table 2. West Virginia led all states by far with 71 fatal injuries with an estimated total cost of $104.877 million. Kentucky had the second highest number of fatal injuries with 36 during the 2010–2017 time period and the second highest total cost with an estimated $57.374 million. Illinois had the highest median cost at $1.832 million per fatal injury, and Alabama had the highest mean cost with $1.655 million per fatal injury.

Table 2. Number and lifetime societal costs (represented in millions of U.S. dollars) of fatal mining injuries for states with the highest fatal injury counts, 2010–2017, for all mining commodities.

State	Count	Median	Mean	Total
West Virginia	71	$1.435	$1.477	$104.877
Kentucky	36	1.765	1.594	$57.374
Nevada	15	1.511	1.466	21.991
Illinois	14	1.832	1.571	21.996
Alabama	13	1.640	1.655	21.511
Texas	12	1.689	1.527	18.322
Pennsylvania	11	1.754	1.366	15.031
New York	9	1.268	1.348	12.136
Virginia	9	1.718	1.592	14.332
Arizona	8	1.551	1.410	11.281
Ohio	8	1.478	1.381	11.048

Fatal injury counts and associated lifetime societal costs by MSHA canvass are shown in Table 3. Bituminous coal mining had the most fatal injuries from 2010–2017 with 159 fatal injuries and the highest societal cost totaling over $240 million. Coal mining made up over half of the fatal injuries and half of the total societal costs for the entire mining industry during this time period. Stone mining was a distant second with 66 fatal injuries and total societal costs just over $82 million.

Table 3. Number and lifetime societal costs (represented in millions of U.S. dollars) of fatal mining injuries, 2010–2017, by MSHA Canvass or product class.

MSHA Canvass	Count	Median	Mean	Total
Coal – Bituminous	159	$1.562	$1.513	$240.550
Stone	66	1.265	1.243	82.007
Metal	35	1.619	1.570	54.961
Sand and Gravel	34	1.180	1.092	37.127
Nonmetal	21	1.101	1.369	28.741
Coal – Anthracite	1	2.038	2.038	2.038

The MSHA subunit indicates the location at a mine where the fatal injury occurred. Table 4 shows that 138 fatal injuries occurred underground with a total societal cost estimate of $218.670 million. Strip and open pit mining had the second highest counts and total costs with 125 fatal injuries at a cost of $158.018 million.

Table 4. Number and lifetime societal costs (represented in millions of U.S. dollars) of fatal mining injuries, 2010–2017, by MSHA subunit or work location of fatally injured miner.

MSHA Subunit	Count	Median	Mean	Total
Underground operations	138	$1.687	$1.585	$218.670
Strip or open pit	125	1.257	1.224	153.018
Mill or preparation plant	30	1.727	1.524	45.714
Surface operations at underground mine	13	0.979	0.963	12.517
Dredge	5	1.583	1.570	7.849
Office	2	1.429	1.429	2.859
Auger	1	1.820	1.820	1.820
Culm bank	1	2.038	2.038	2.038
Independent shops and yards	1	0.938	0.938	0.938

Societal costs can also be evaluated according to the size of the mine. MSHA provides the average number of employees in their address/employment data set. The average number of employees employed per year can be used as a surrogate for mine size. Table 5 shows the number of fatal injuries and their associated societal costs by average number of employees working at the mine. While the distribution seems even, as the smallest three employee categories (generally considered "small" mines) has similar values to the largest employee category, mines that employed an average of 250 or more employees per year had the most fatal injuries, 73, and the highest societal cost at over $112 million.

Table 5. Number and lifetime societal costs (represented in millions of U.S. dollars) of fatal mining injuries, 2010–2017, by average number of employees working at mine.

Number of Employees at Mine	Count	Median	Mean	Total
Less than 5	15	$1.113	$1.171	$17.570
5-9	25	1.179	1.072	26.796
10-19	28	1.290	1.314	36.790
20-34	29	1.740	1.516	43.970
35-49	16	1.317	1.393	22.283
50-99	66	1.456	1.455	96.007
100-149	31	1.423	1.367	42.362
150-249	32	1.465	1.470	47.026
250 or more	73	1.619	1.535	112.087

Besides mine-specific information, costs can be reported by accident-specific details. Table 6 shows the most common mine worker activity that the decedent was performing when the fatal accident occurred. Forty-seven fatal injuries occurred during machine maintenance and repair, the most common mine worker activity associated with a fatality, with a total societal cost of over $69 million. It is worth noting that the second highest mine worker activity is "unknown," which means that it is not clear what the fatally injured miner was doing when the injury occurred. These unknown activities contributed to over $52.5 million in societal cost.

Table 6. Number and lifetime costs (represented in millions of U.S. dollars) of fatal mining injuries, 2010–2017, by most common mine worker activity of fatally injured miner.

Mine Worker Activity	Count	Median	Mean	Total
Machine maintenance/repair	47	$1.661	$1.470	$69.080
Unknown	34	1.653	1.544	52.509
Operate haulage truck	23	1.395	1.273	29.287
Operate continuous miner	20	1.913	1.756	35.113
Walking/running	15	1.143	1.122	16.824
Operate bulldozer	11	1.138	1.127	12.399
Operate utility truck	10	1.529	1.492	14.916
Get on or off equipment, machines, etc.	9	0.806	1.042	9.379
Handling supplies or material, load and unload	8	1.667	1.645	13.156
Welding and cutting	8	1.711	1.529	12.232

Accident classifications of fatal injuries are displayed in Table 7. Powered haulage is a category that covers the haulage of materials and personnel, and includes haul trucks and conveyor belts. Powered haulage was involved in 88 fatal accidents and accrued a total societal cost of $117.867 million. Machinery was involved in 61 fatal accidents with a total societal cost of approximately $83.499 million. Falling material is separated into three different classifications, but when combined, they are responsible for 74 fatal injuries and total almost $106 million in societal costs.

Table 7. Accident classification, number and lifetime costs (represented in millions of U.S. dollars) of fatal mining injuries, 2010–2017, for all mining commodities.

Accident Classification	Count	Median	Mean	Total
Powered haulage	88	$ 1.352	$1.339	$117.837
Machinery	61	1.640	1.369	83.499
Ignition or explosion of gas or dust	32	1.543	1.544	49.399
Falling, rolling, or sliding rock or material of any kind	30	1.474	1.340	40.210
Fall of face, rib, pillar, side, or high wall (from in place)	29	1.820	1.718	49.809
Slip or fall of person (from an elevation or on the same level)	26	1.353	1.242	32.292
Fall of roof, back, or brow (from in place)	15	1.468	1.338	20.067
Electrical	9	1.817	1.762	15.855

Societal costs can also be estimated based on characteristics of the deceased miner. Table 8 shows the number of fatal injuries and the associated estimated societal costs by categories of years of total mining experience. The category of four to nine years of total mining experience had the most fatal injuries, with 77, and the highest societal costs, with over $125 million. The second most fatal injuries occurred in the 27–49 years of mining experience category. This category had 58 fatal injuries and total societal costs of approximately $58 million. Even though this category had the second highest number of fatal injuries, the total costs were much lower than the lower categories of mining experience. This is likely due to the correlation of higher experience with older age. On average, miners with this much work experience are going to be older than miners with much less mining experience and the societal costs in this model stop calculating at age 67, which is the estimated age of retirement.

Table 8. Years of total mining experience of fatally injured miner, number and lifetime costs (represented in millions of U.S. dollars) of fatal mining injuries, 2010-2017 for all mining commodities.

Years of Experience	Count	Median	Mean	Total
Less than 1	40	$1.803	$1.806	$72.245
1-3	42	1.704	1.641	68.924
4-9	77	1.759	1.632	125.683
10-17	53	1.479	1.359	72.020
18-26	40	1.141	1.097	43.899
27-49	58	1.022	1.000	57.998
50 or more	1	0.075	0.075	0.075
Unknown	5	0.806	0.916	4.580

DISCUSSION

The cost-of-illness method for measuring economic burden of fatal mining injuries estimates the potential costs that could be saved if the fatal injury did not occur. Knowledge of these costs can help policy makers decide which mining commodities or accident causes need to be addressed first through prevention efforts or increased health and safety research.

The Upper Big Branch mine disaster occurred in April 2010 and resulted in twenty-nine fatal injuries. This would have an impact on West Virginia, the coal commodity, the ignition/explosion accident classification, and the 2010 fatal injury count and cost data. The web application allows the display of costs by mine ID, and therefore the societal costs of mine disasters can be calculated. The Upper Big Branch Mine-South has a mine ID of 46-08436, and the twenty-nine fatal injuries from the April 2010 explosion had an estimated total societal cost of $45.491 million and a median cost of $1.591 million per deceased miner.

These are the only current mining-specific fatal injury burden estimates for the U.S. that the author has been able to identify. Much of the mining-related burden estimates are from twenty-five-year-old data that combines mining with oil and gas, and gives one aggregate cost for a ten-year period (NIOSH 2009, 2011). It is difficult to compare these current estimates to previous cost estimates; however, the mean and median total costs are in line with the previous NIOSH estimates after adjusting for inflation.

The Bureau of Mines sponsored the development of the Accident Cost Indicator Model (ACIM) in the late 1970s. The ACIM (DiCanio and Nakata, 1976) provides cost estimates for underground coal mines based on publicly available data on wages, workers' compensation claims, medical payments, investigation costs, and other direct and indirect costs. It was designed to provide a useful guideline on the magnitude of costs suffered by individuals, mining industry, and society. The last known published results from this model were from Randolph and Boldt's (1997) work on haulage accidents where the six haul truck related fatal injuries had an estimated total cost of $2.58 million.

This current model will be maintained on the NIOSH Mining web page as a web application called *Fatalities Cost in Mining.* Users will be able to select characteristics of the fatal injury (occupational, mine, incident, and employer), select a dollar year and discount rate for calculations, then generate a cost report based on victim, mine, and/or accident related variables. A few examples of these reports are shown in the Results section. This model is expected to be updated annually and maintained for years to come.

LIMITATIONS

In light of the many advantages of the method, the cost-of-illness methodology has some limitations. It can show which kinds of fatal injuries may require increased prevention resources. This methodology does not measure benefits, but provides the framework and important cost information when conducting cost-effectiveness or cost-benefit analyses, which can determine the best course of action for prevention.

As previously mentioned, the entire burden of a fatal mining injury is not captured by this model, as intangible losses of premature death are not included. The more extended nature of the degree of the fatal occupational injury problem includes the cost of suffering and role loss. These subjective and personal components are difficult to measure and are not considered in these calculations.

The method used for developing these estimates produces a conservative estimate for the lifetime economic costs of fatal mining injuries. The estimates are based on many factors and are subject to the limitations of the model used as well as the limitations associated with the level of detail of the some of the data in the calculations. The wage data is not specific to the mining industry as the data are from state averages by occupation. The mining-specific wage data acquired by NIOSH was not robust enough to use for specific mining occupations throughout the United States. Additionally, specific benefits data by industry and occupation would improve burden cost estimates.

Despite the acknowledged limits of the burden estimates, they do offer important applied value. The cost estimates provide information to policy and decision makers on relevant costs of fatal mining occupational injuries in relation to costs and selection of prevention programs. These cost outcomes represent income that is not received and medical expenses incurred because of a fatal injury and, therefore, have direct impact on state, regional, and national economic measures of goods and services production, such as GDP and other national income measures. The estimates can be used to plan, enhance, and prioritize mining injury prevention and control programs, policy analysis, evaluations of health and safety interventions, and promotion for a safer work environment.

CONCLUSION

The cost model and data sources used in the *Fatalities Cost in Mining* methodology in this research combine to form an effective tool for determining the societal cost of fatal mining injuries. These cost estimates can be used to determine the specific burden of injury to particular demographic groups, as well as the circumstances of injury. This can be extremely useful in determining the cost to various constituencies—to the country, states, and geographical regions, and to mining commodities and occupations. In addition, this work provides the frequency of fatal mining events to indicate the extent of the occupational fatal injury problem. The contribution of this societal cost estimation data, in identifying the financial cost of fatal mining occupational injuries, constitutes a major component in defining the scope of these fatal injuries. The use of economic losses, such as those calculated using the *Fatalities Cost in Mining* model described in this paper, provides an additional measure to existing societal measures of frequency and rate of injury to assist in defining the overall dimensions of traumatic workplace fatalities in the mining industry.

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DISCLAIMER

The findings and conclusions in this paper are those of the author and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention. Mention of any company or product does not constitute endorsement by NIOSH.

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