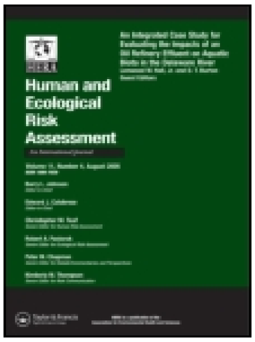

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A Graphical Analysis of Mortality Rates and Years of Potential Life Lost

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ABSTRACT

One challenge in assessing occupational fatal injuries is choosing a summary measure of the impact of these injuries. Each metric emphasizes different aspects of health risk, and fatal injury reports often focus on only one summary measure at a time. Deaths from the National Traumatic Occupational Fatality database were combined into external cause of death (e-code) groups. Graphs comparing average years of potential life lost (YPLL), mortality rate, and their product, "YPLL-rate", are presented for e-code groups overall, industries and occupations, and e-code groups within selected industries and occupations. This integrated analysis of fatal injury characteristics allows identification of the portion of the workforce at highest risk. Homicides and electrocutions (e-code groups) had high mortality rates, average YPLL, and YPLL-rates, both overall, and within several of the industries and occupations examined. The industry and occupation of Agriculture, Forestry, and Fishing experienced a very high mortality rate and the lowest average YPLL for both industries and occupations. Laborer was the most hazardous occupation for young workers with an average YPLL near 40, and a mortality rate greater than 15 deaths per 100,000 worker-years.

Key Words: external causes of deaths, occupational injury risk assessment, death certificate registries, rate-ypll contour plot, actuarially adjusted life expectancy.

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INTRODUCTION

Quantifying the impact of fatal occupational injuries allows for the identification of the workers who are most at risk and establishes priorities for intervention. Previous studies have used several different measures as a means for describing impact. Typically, one summary measure is chosen and examined for differing levels of other descriptive variables. As an example, the National Institute for Occupational Safety and Health (NIOSH) released reports detailing the mortality rates for different types of injuries (*e.g.,* NIOSH 1993). These reports show mortality rates for industries and occupations both overall and within different demographic groups. The trends among these rates over time have also been statistically modeled and examined to highlight industries and occupations in which risks are increasing and decreasing (Bailer *et al.* 1998).

Alternatively, others have used years of potential life lost (YPLL) as an impact measure of premature death. The Mortality and Morbidity Weekly Report (MMWR), published by the Centers for Disease Control (CDC), commonly uses YPLL to describe the overall effect of certain causes of death (*e.g.,* CDC 1993). YPLL has also been used to show how age of death varies over industries, occupations, and time (Gilbert *et al.* 1998). Recently, related measures such as disability-adjusted-life-years (DALYs) and quality-adjusted-life-years (QALYs) have surfaced as impact measures for chronic diseases (Murray 1996).

The goal of this paper is the integration of two measures of impact, mortality rates and YPLL, in an effort to better illustrate the risks evident in industries and occupations. By plotting mortality rate versus average YPLL, insight into both the quantity of occupational fatal injuries and the amount of life lost when such a fatality occurs may be gained. By making these rate-YPLL comparisons, differences between industries and occupations may be observed. Further, the creation and plotting of external cause of death (e-code) groups can illustrate dissimilarities in the causes of occupational fatal injuries as well.

In the next section, the data used in this analysis is detailed and the construction of the rate and YPLL summaries is described. Combining these summaries into contours of "YPLL-rate" impact follows. These contour analyses are then graphically evaluated in the remaining sections. Plots of e-code groups overall, and separate plots for both industries and occupations, give a general description of risks for the population. Finally, by looking at the mortality rate and average YPLL for specific e-code groups within an industry or occupation, the risks faced by selected sectors of the workforce are described.

METHODS

Data

Occupational fatal injury data for this analysis came from NIOSH's National Traumatic Occupational Fatality (NTOF) database (NIOSH 1993), a death-certificate-based registry of occupational fatal injuries in the United States. The information includes age, gender, race, industrial code (Standard Industrial Classification, Office of Management and Budget 1987), occupation code (Standard Occupation Classification, U.S. Department of Commerce 1982), and external cause of death classification (ICD-9, U.S. Department of Health and Human Services 1991). External cause of death codes in the NTOF database describe the type of event, and in some instances the circumstances of the event, for workers who are at least 16 years old. Deaths included in this analysis occurred in the years 1983 to 1994. External causes of death describing similar events were combined, forming 25 e-code groups (Table 1) that were used for the figures.

Summary Measures for Assessing the Impact of Fatal Injuries

The two primary measures used for this study were mortality rate and average years of potential life lost. The overall mortality rate due to a particular injury is the total number of deaths due to that cause in the database, divided by the total number of years worked during the study (worker-years) by all workers. Worker-years were computed using employment data provided to NIOSH by the Bureau of Labor Statistics (BLS), and are based upon the current population survey (US Bureau of the Census 1978). To find the mortality rate within a specific industry or

Table 1. Classification method and Graph representation key for external causes of death.

Event Group Name	Graphical Symbol	External Causes of Death (ICD-9)
Air Transport Events	AIR	840-845
Drownings	DROWN	910
Electrocutions	ELEC	925
Explosions	EXPL	921,923
Fires	FIRE	890-899
Fall from a Building or Structure	FL BLD	882
Fall from a Ladder or Scaffolding	FL LAD	881
Other Falls	FL OTH	883-886
Fall on Stairs or Steps	FL ST	880
Unspecified Falls	FL UNSP	887-888
Homicides	HOMI	960-969
Machinery Incidents	MACH	919
Motor Vehicle Drivers	MV DR	810.0, 811.0, …, 819.0
Non-traffic Motor Vehicle Accidents	MV NTR	820-825
Motor Vehicle Passengers	MV PAS	810.1, 811.1, …, 819.1
Pedestrian – Motor Vehicle Accidents	MV PED	810.7, 811.7, …, 819.7
Unspecified – Motor Vehicle Accidents	MV UNSP	810.9, 811.9, …, 819.9
Nature or Environmental Events	NAT	900-909
Other Events	OTH	External causes of death not listed
Poisonings	POIS	850-869
Railway Accidents	RAIL	800-807
Struck by a Person or Object	STRUCK	916-918
Suffocations	SUFF	911-913
Suicides	SUIC	950-959
Water Transport Events	WATER	830-838

occupation, the same process was repeated accumulating the number of deaths and worker-years within each industry or occupation only. Mortality rates are expressed in terms of deaths per 100,000 worker-years. Direct age standardization (Lee 1992) was employed using, as reference, the overall age distribution of employment in all industries and occupations. This standardization is illustrated in Appendix A.

Years of potential life lost (YPLL) is the actuarially estimated conditional life expectancy for an individual based on the age at death. These life expectancies are based upon lifetables for a particular population (Lee 1992). YPLL calculations presented here are based on the U.S. vital statistics tables for males and females with all races combined (Anderson 1999). Since the vital statistics tables give life expectancy at the beginning of an age interval, and the exact age for members of this study was unknown, the YPLL reported is the average for the two age intervals bracketing the person's age at death. Thus, the YPLL for a male dying at age 55 would be the average of life expectancies for 55 and 56-year-old males presented in the life tables. Calculations of YPLL, average YPLL, and YPLL-rate per 100,000 worker-years are explained in further detail in Appendix A.

Graphical Methods

The analyses are presented as plots with average YPLL graphed on the horizontal axis and age-adjusted mortality rate per 100,000 worker-years, depicted with a logarithmic scale, on the vertical axis. The product of these two indices gives a third metric, YPLL per 100,000 worker-years (YPLL-rate), which is displayed as contour lines through the plots. In the graphs, the top "half" of the graph lists high mortality rate values, and the lower "half" has lower mortality rate occurrences. Data on the right hand side of the graph, with high average YPLL, represent occurrences for younger workers primarily while the left-hand side depicts lower average YPLL, and thus occurrences for relatively older workers. For YPLL rate, the values increase from the lower left-hand corner to the upper right-hand corner, indicating a higher burden in the upper right portion of the graph.

Graphs of fatal injuries by industry and occupation display points as circles whose areas represent a relative measure of the total number of fatalities within a given industry or occupation. For all other graphs, points are plotted with the same size because the number of people employed, and at risk for each e-code group, is similar for the groups being compared.

RESULTS

For all workers, regardless of injury, occupation, or industry, the mortality rate was 5.05 deaths per 100,000 worker-years, and the average YPLL was 35.95 for the years 1983 to 1994. Based upon Figure 1, most fatal occupational injury e-code groups had mortality rates between 0.1 and 0.5 per 100,000 worker-years and average YPLL between 35 and 40. Homicides, machinery incidents, and fatalities to motor vehicle drivers had the highest mortality rate and YPLL-rate. Electrocutions and air transport accidents were incidents that affected young workers the most. Machinery incidents and falls were e-code groups that occurred generally to older workers. In particular, falls from stairs affected the oldest workers among the event groups studied. Falls from stairs also affected the fewest workers, with a mortality

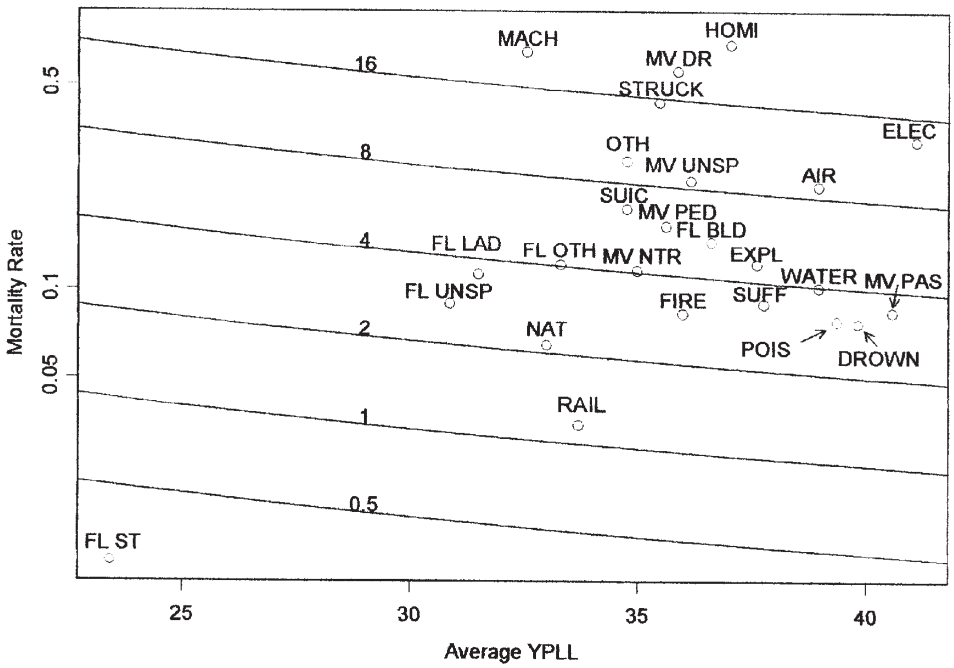


Figure 1. Plot of directly standardized mortality rate per 100,000 worker-years versus average years of potential life lost (YPLL) overall, by INJURY, with contour lines included that represent the YPLL per 100,000 worker-years. Mortality rates are displayed on a common logarithmic scale. Labels appear directly above the plotted points except where marked by an arrow.

rate that was much lower than the e-code group with the next fewest fatalities, railway accidents.

Examining industry and occupation plots gives an indication of the types of employment where high frequencies of injuries occur, and which age groups are most affected. Among industries (Figure 2), Mining had the highest mortality rate, but relatively fewer total fatalities. The average YPLL for Mining was also very high, second only to Public Administration. Construction, Transportation, and Manufacturing were the industries where the most fatalities occurred (biggest plotting symbols), while Finance, Insurance, and Real Estate and Wholesale Trade had the fewest total deaths (small plotting symbols). Agriculture, Forestry, and Fishing was the most dangerous industry for older workers, with an average YPLL distinctly lower than other industries.

Among the occupations in Figure 3, the Laborer occupation was the most dangerous for younger workers, with a very high rate and average YPLL. Those holding Transportation jobs had the highest mortality rate and the second highest total number of fatalities, next to the Precision Production, Crafts, and Repair occupation (labeled "Crafts"). The occupation where older workers generally experienced the highest mortality rate and YPLL-rate was Farming, Forestry, and Fishing. Clerical and Administrative Support was the safest occupation, both in terms of number of fatalities and mortality rate, but was relatively high in average YPLL.

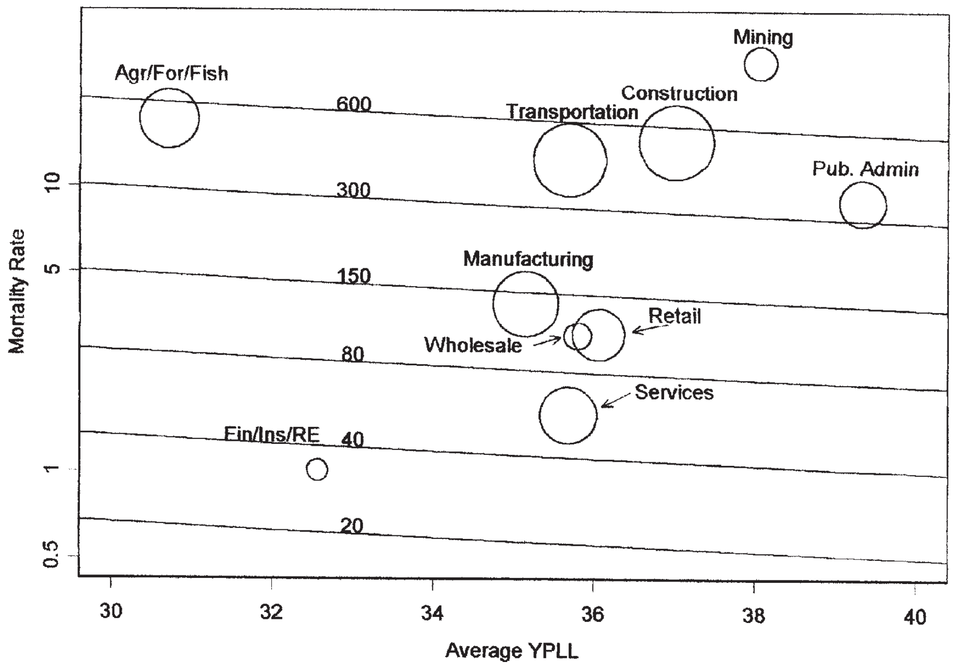


Figure 2. Plot of directly standardized mortality rate per 100,000 worker-years versus average years of potential life lost overall, by INDUSTRY, with contour lines representing YPLL per 100,000 worker-years. Mortality rates are displayed on a common logarithmic scale. The circle area represents a relative measure of the number of fatalities within each industry. Labels appear directly above the plotted points except where marked by an arrow.

More detailed analyses of e-code groupings also were conducted within several industries and occupations. A subset of industries from Figure 2 is further explored in Figure 4 to illustrate industry specific tendencies for different e-code groups. In the Agriculture, Forestry and Fishing industry, machinery incidents were the most frequent, while water-related fatalities (drowning and water transport accidents), deaths to motor vehicle passengers, and electrocutions were the most dangerous for younger workers. In Construction, most e-code groups had elevated mortality rates and average YPLL relative to other industries, indicating their dramatic effect on young workers. The electrocution e-code group was especially noteworthy, with both the highest mortality rate and the highest average YPLL in Construction. In Retail Trade, intentional acts (homicide and suicide) exhibited a higher frequency in both mortality rate and YPLL-rate relative to other events. Air transport accidents affected the youngest workers at a very high rate in Public Administration. Motor vehicle accidents and intentional acts were frequent occurrences in this industry group.

Finally, four occupations from Figure 3 are explored in more detail in Figure 5. Not surprisingly, motor vehicle accidents were the most frequent among transportation workers. However, homicide, water transport events, and electrocutions also had a high mortality rate for younger workers, while the e-code groups of *machinery incidents* and *being struck by a person or object* had high mortality rates and occurred to

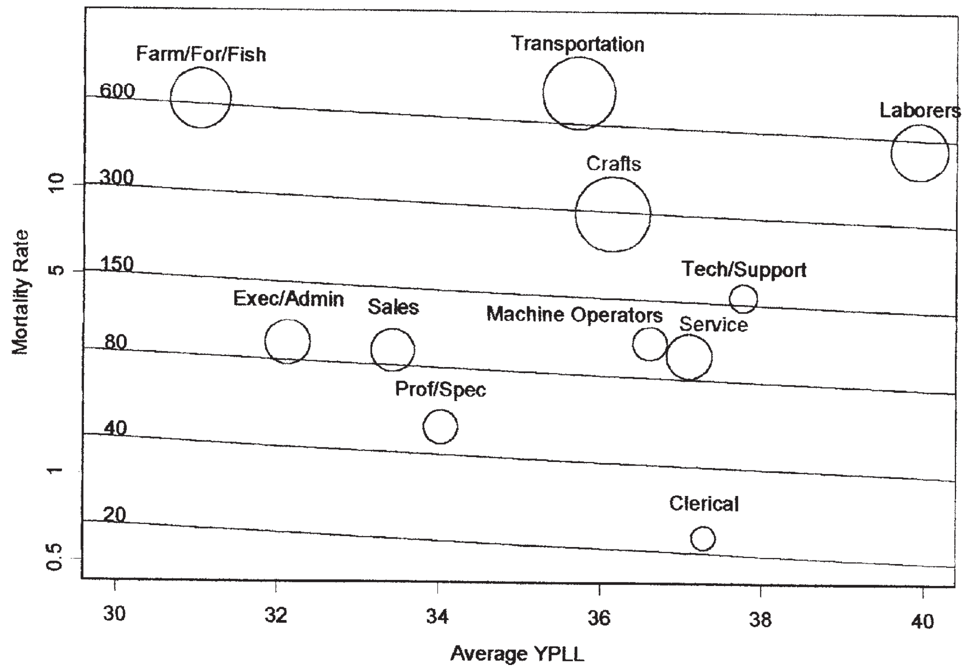
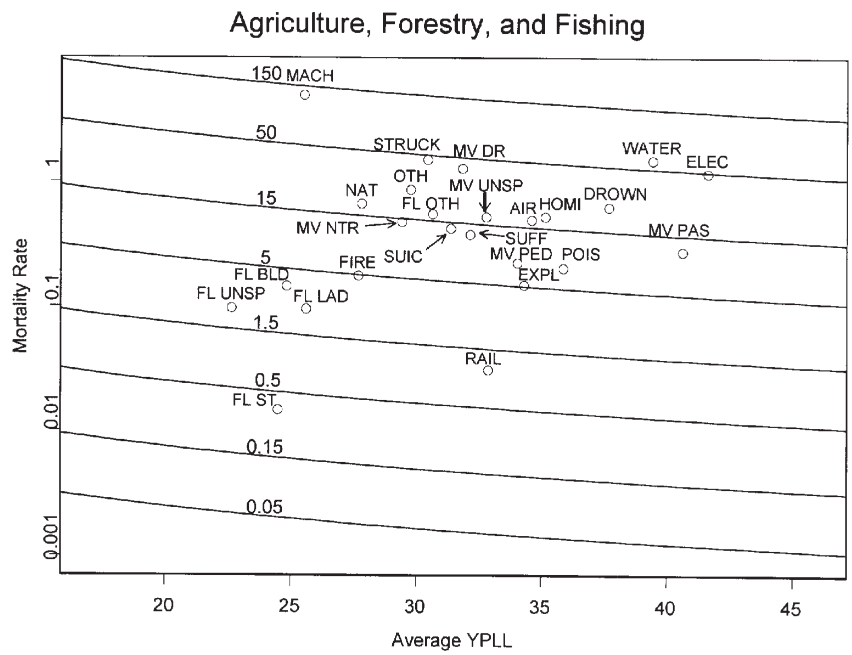


Figure 3. Plot of directly standardized mortality rate per 100,000 worker-years versus average years of potential life lost overall, by OCCUPATION, with contour lines representing YPLL per 100,000 worker-years. Mortality rates are displayed on a common logarithmic scale. The circle area represents a relative measure of the number of fatalities within each occupation. Labels appear directly above the plotted points.

somewhat older Transportation workers. All falls took place at higher rates and to younger workers among Laborers, and motor vehicle accidents were less frequent. For the most part, all e-code groups within the Labor occupation had higher average YPLL and YPLL-rate than they did in other occupations, as only two e-codes groups, air transport events and falls from stairs had YPLL-rates of less than 5. Intentional acts again appeared at higher rates relative to other injuries within the occupation for Executives, Administration, and Managers, and Clerical and Administrative Support. The motor vehicle driver e-code group had a high mortality rate in these occupations as well.

DISCUSSION

By looking at injuries along multiple metrics, a more integrated picture of occupational fatal risk emerges. Examination of average YPLLs reveals the age dependence of injury fatality rates within specific populations. The Construction industry and closely related Labor occupation had the highest risk of injuries among younger workers. Within these fields and many other areas as well, electrocutions occurred frequently and afflicted young workers. Homicides and accidents affecting motor vehicle passengers were events that were high in both mortality rate and



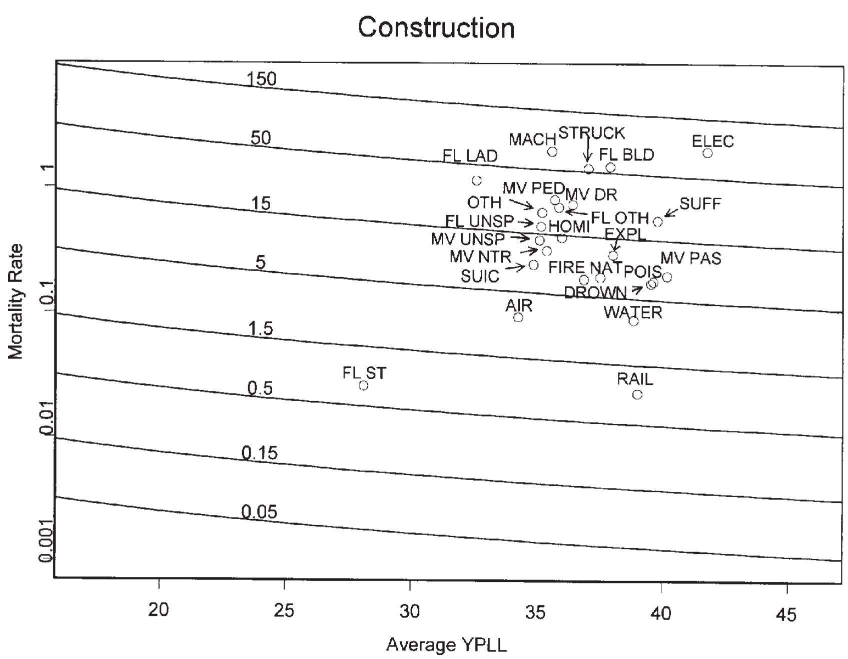
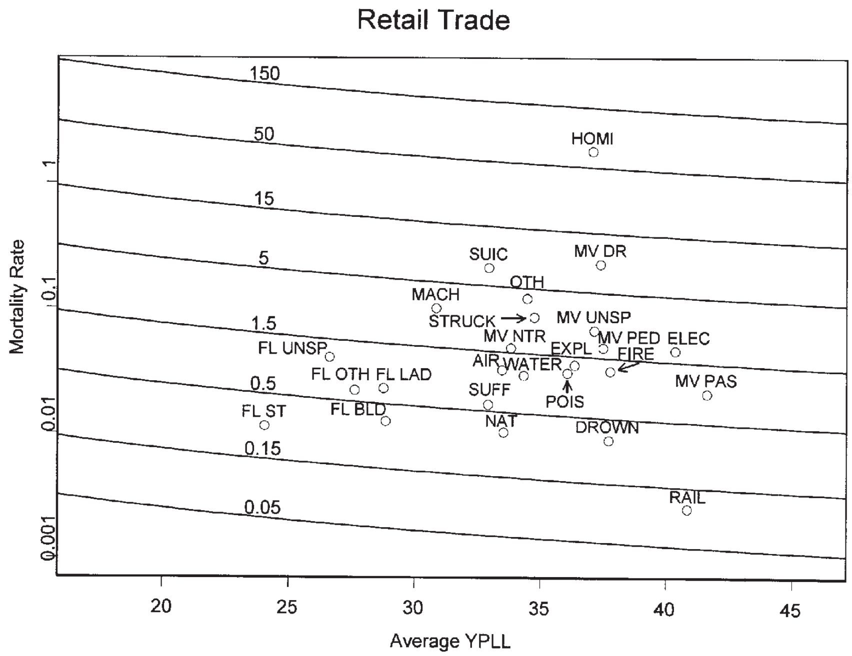


Figure 4a. Plots of directly standardized mortality rate per 100,000 worker-years versus average years of potential life lost for selected industries, by INJURY. Contour lines representing YPLL per 100,000 worker-years are provided to facilitate comparison between industries. Mortality rates are displayed on a common logarithmic scale. Labels appear directly above the plotted points except where marked by an arrow.



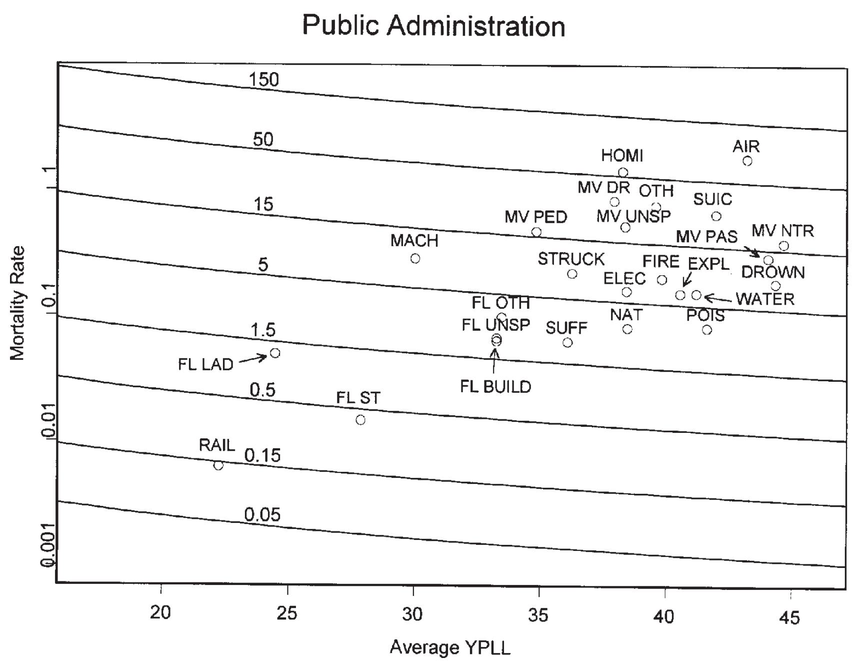
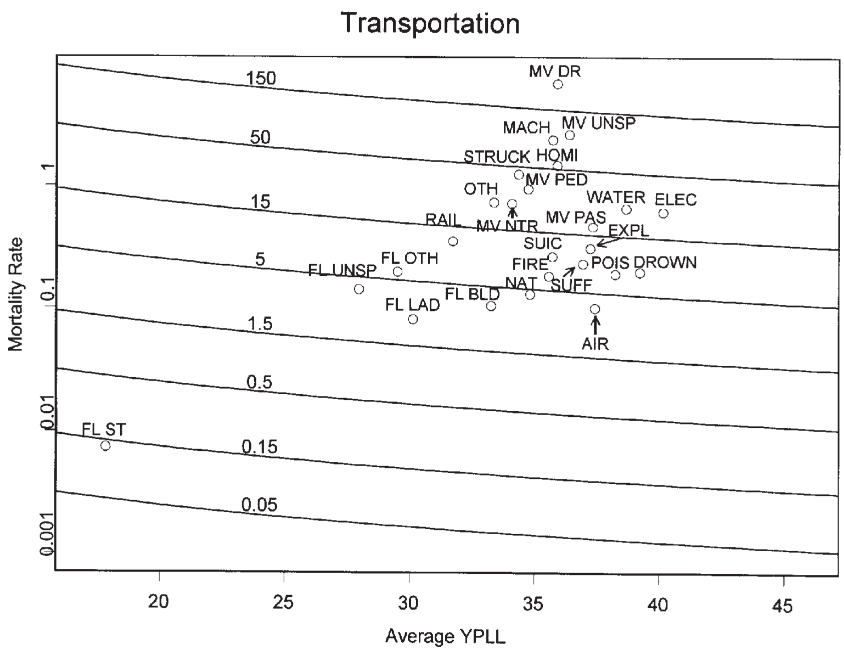


Figure 4b. Plots of directly standardized mortality rate per 100,000 worker-years versus average years of potential life lost for selected industries, by INJURY. Contour lines representing YPLL per 100,000 worker-years are provided to facilitate comparison between industries. Mortality rates are displayed on a common logarithmic scale. Labels appear directly above the plotted points except where marked by an arrow.



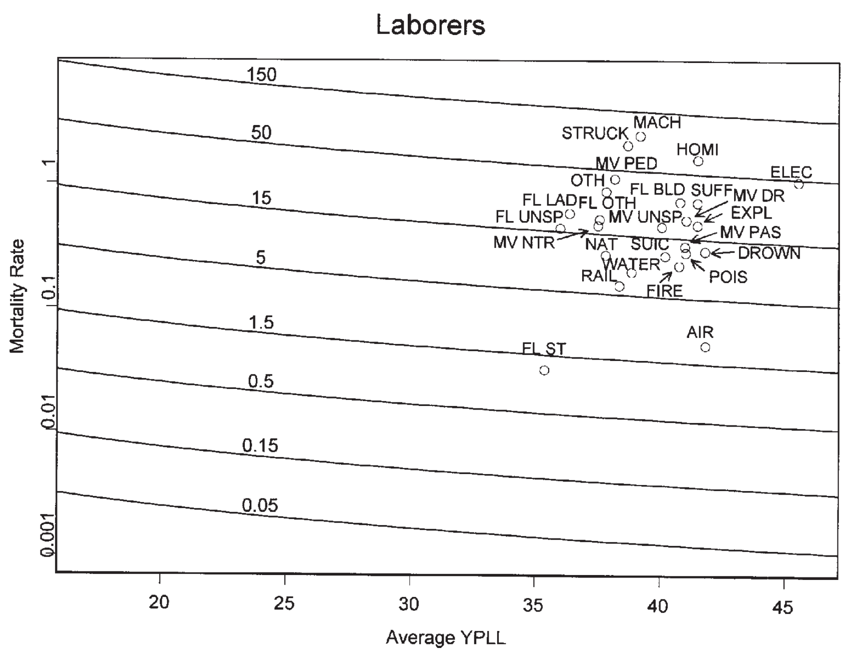


Figure 5a. Plots of directly standardized mortality rate per 100,000 worker-years versus average years of potential life lost for selected occupations, by INJURY. Contour lines representing YPLL per 100,000 worker-years are provided to facilitate comparison between occupations. Mortality rates are displayed on a common logarithmic scale. Labels appear directly above the plotted points except where marked by an arrow.

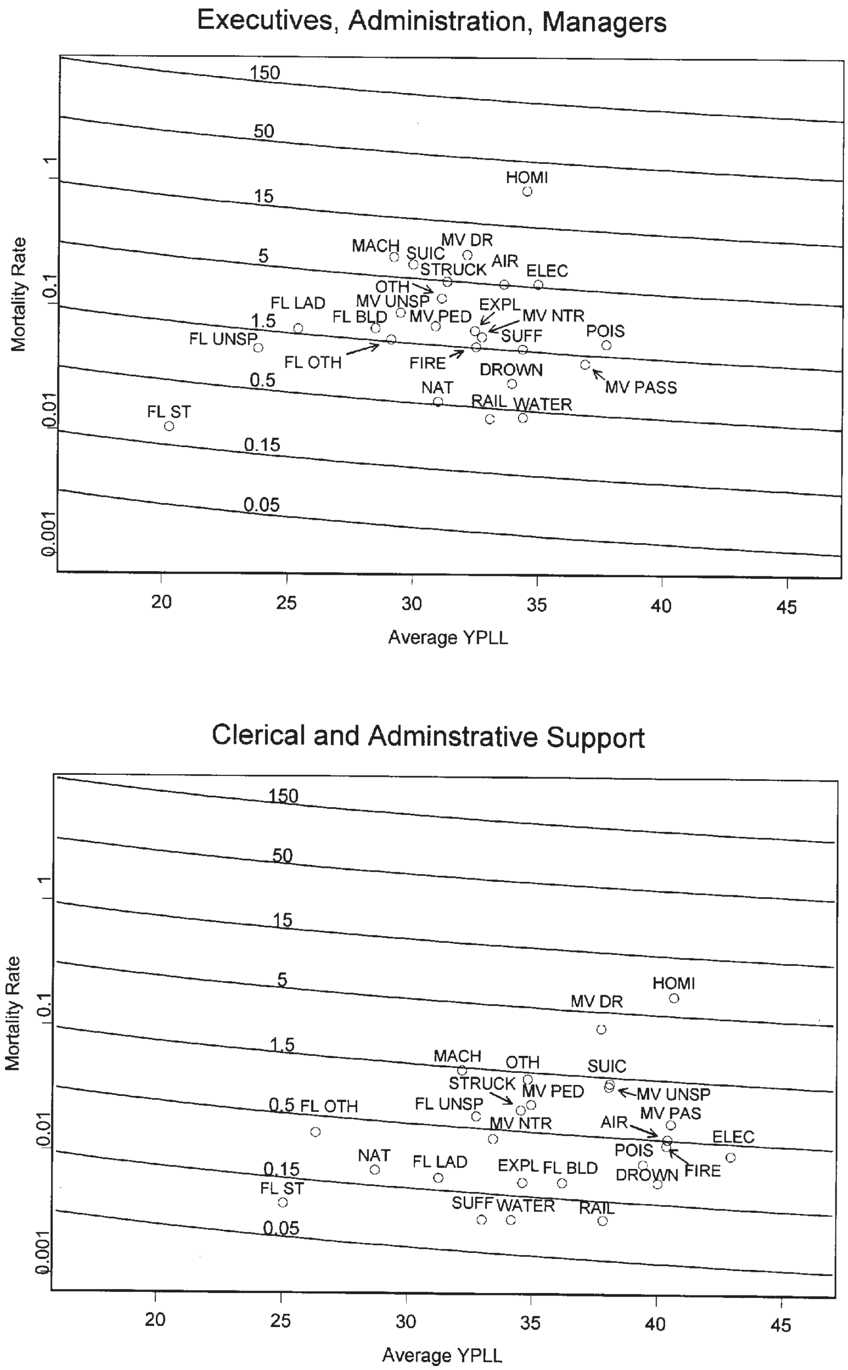


Figure 5b. **Plots of directly standardized mortality rate per 100,000 worker-years versus average years of potential life lost for selected occupations, by INJURY.** Contour lines representing YPLL per 100,000 worker-years are provided to facilitate comparison between occupations. Mortality rates are displayed on a common logarithmic scale. Labels appear directly above the plotted points except where marked by an arrow.

average YPLL in almost all occupations and industries studied. Drowning and poisoning were also e-code groups that most often occurred to younger workers. Machinery deaths, which affected older workers most often, occurred at high rates in most areas studied. The Agriculture, Forestry, and Fishing industry and occupation had one of the highest mortality rates among industries and occupations, and the lowest average YPLL.

The interpretation of age dependence of risks is problematic, however, because exposure to specific injury hazards may also have age dependence. For example, skilled trades workers encounter special risks, and tend to be older than the workforce in general. Note also that use of a logarithmic scale for age-adjusted mortality rates in the graphs obscures the fact that e-code groups differ over a greater range in mortality rate than in average YPLL. Due to these differences in range, the YPLL-rate contours reflect the differences in mortality rate more than those in average YPLL. However, the visual perception of the graphs balances the effect of both average YPLL and mortality rate (on the log scale) in the plot.

This study suffers from the limitations that affect any study based upon a death certificate registry. Misclassification of the cause of death and the underreporting of certain types of causes are two of many problems that could arise, and are discussed elsewhere (*e.g.*, Russell and Conroy 1991). A specific drawback to the NTOF database is the inclusion of occupational fatalities only for workers age 16 and older, which restricts the upper limit of YPLL. This becomes an issue for comparing average YPLL, as industries and occupations with a substantial workforce under 16 may have a higher true average YPLL than reported here. Using median YPLL as an alternative to average YPLL reduces the effect of outlying observations, but does not impact the results greatly.

The methods used here offer insight into the sectors of the workforce that are most at risk for certain types of fatal injuries. These risks may not be apparent if each of the measures were studied separately. If only mortality rate was studied, homicides, machinery incidents, and motor vehicle drivers would be the e-code groups that would be highlighted for their danger. Public Administration, Mining, and Agriculture, Forestry and Fishing would be viewed as industries with similar risks because of their high mortality rate. Meanwhile, if attention was restricted to only average YPLL, Laborers and Farming Forestry, and Fishing would gain attention as the occupations that affect relatively younger and older workers, respectively. The Transportation and Service occupations would be viewed similarly in this measure. Electrocution, drowning, and motor vehicle passenger e-code groups would appear to be the greatest threats for younger workers. Similarly, machinery incidents and falls would be of equal concern for older workers.

The integration of these two measures reveals information on both the quantity and age of workers who are workers most at risk. The presentation of these risks graphically is an easy way to evaluate both metrics simultaneously. The impact of electrocutions and air transport on younger workers is apparent from the graphs, as is the fact that machinery incidents arise as a greater cause of fatalities for older workers than falls. The average YPLL discrepancy between the industries of Public Administration and Agriculture, Forestry, and Fishing indicate that although they share similar overall rates of fatal injury, the workers impacted may differ significantly.

The diversity in risks faced within different industries and occupations limits the specificity of recommendations that are appropriate. However, based upon the levels of certain e-code groups in both YPLL and mortality rate, some global insights can be made. For example, the fact that electrocutions occur frequently and across diverse sectors, and appear to affect especially younger workers, indicates a great need for improved emphasis on electrical safety in basic design, installation and utilization of equipment. Enhanced training for design, supervisory and hourly employees is needed to eliminate these avoidable injuries. Other major e-code groups accounting for a high burden of fatal injury include machinery, motor vehicle, and homicide-related events, indicating that safety issues in design, management and training, appropriate for the type of workers who suffer these tragic events, should receive top priority.

ACKNOWLEDGMENTS

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APPENDIX A: CALCULATION OF SUMMARY MEASURES

Calculation of Age Adjusted Mortality Rate:

The age-adjusted mortality rates were computed using direct standardization (Lee 1992). The crude mortality rate for a specific age group in an industry or occupation was multiplied by the proportion of total employment in all industries and occupations for that age group. This yields the age standardized mortality rate. The age-adjusted mortality rate is the sum of the age- standardized mortality rate for all age groups.

Example: The following table shows the calculation of age-adjusted mortality rate for the Mining industry.

(a)	(b)	(c)	(d)	(e)	(f)
Age Group	**Deaths**	**Employment In Mining**	**Age-Specific Mortality Rate per 100,000 (b / c) *100000**	**Proportion of Employment (All Industries)**	**Age-Standardized Mortality Rate per 100,000 (d * e)**
16-19	44	120289	36.5786	0.0552	2.0191
20-24	295	710372	41.5275	0.1155	4.7964
25-29	396	1386246	28.5664	0.1395	3.9850
30-34	433	1735053	24.9560	0.1444	3.6036
35-39	367	1563940	23.4664	0.1340	3.1445
40-44	251	1272289	19.7282	0.1158	2.2845
45-49	199	914201	21.7676	0.0927	2.0179
50-54	183	736988	24.8308	0.0743	1.8449
55-59	135	561087	24.0604	0.0605	1.4557
60-64	89	322518	27.5954	0.0397	1.0955
65 +	84	143356	58.5954	0.0284	1.6641
Total	**2476**	**9466339**	**26.1558**	**1.0000**	**27.9112**

RATE = Age-adjusted mortality rate per 100,000 worker-years = 27.9112.

Calculation of YPLL for an Individual:

YPLL is computed by averaging the life expectancies for the age intervals surrounding the age of death for an individual because life expectancy is given as at the beginning of the age interval.

Example: For a 55 year old male,

$$YPLL = [(LE_{55\text{-}56} + LE_{56\text{-}57}) / 2] = [(23.3 + 22.5) / 2] = 22.9,$$

where $LE_{55\text{-}56}$ is the years of life expected to be remaining for someone at the beginning of their 55^{th} year of life, while $LE_{56\text{-}57}$ is the same measure at the beginning of the 56^{th} year of life.

Calculation of Average YPLL:

The average YPLL is the sum of all YPLL for a group divided by the total number of fatalities within that group.

Example: For the industry of Mining,

AVG.YPLL = (sum of YPLL in Mining / number of deaths in mining)
= (94315.95 / 2476) = 38.09

Calculation of YPLL-rate per 100,000 worker-years:

The YPLL-rate per 100,000 worker years is the product of average YPLL and the age-adjusted mortality rate.

Example: For the Mining industry,

$$\text{YPLL-rate} = \text{RATE} * \text{AVG.YPLL} = 27.9112 * 38.09 = 1063.138.$$