Development of a Construction Injury Predictive Model

A Final Report

Submitted by
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TO

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Centers for Disease Control and Prevention

National Institute for Occupational Safety and Health (NIOSH)
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LIST OF ABBREVIATIONS AND DEFINITIONS

Commercial construction   Type of construction projects that include office buildings, shopping centers, hotels, sports facilities[1] that are generally for commercial uses.

Double-Breasted   A contractor who employs both union and non-union workers.

ENP   (Effective Number of Projects) This is a measure of the concentration of labor in a construction project. A small ENP means a large number of workers concentrated in a few projects, while a large ENP indicates the spread of a large number of workers over many projects.

Fast Track   Also known as Phased Construction, Fast Track is a construction delivery method which features simultaneous design and physical construction.

Injury Rate   Number of injuries per worker-year.

Naive Z   The difference in two (2) injury rates divided by its standard error. Assumes that similar contractors (contractors whose characteristics are alike or who undertake similar projects) will have similar injury rates.

Partnering   Can be defined as a concept where the often adversarial relationships between owner, design professional, contractor, subcontractors, is replaced by working relationships and agreements designed to create cooperation among all parties.

Reportable injuries   Injuries that require the attention of a licensed medical care-giver.

Robust Z   Assumes that there can be consistent differences in injury rates between similar contractors or similar projects.

Total Quality Management (TQM)   A concept for improving the quality of construction projects with customer satisfaction as the main focus.[2]

Worker-year   The total number of hours of labor (man-hours) divided by 200 (200 = 40 hour-week x 50 weeks per year).

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SIGNIFICANT FINDINGS

1. The very large variation in injury rates between contractors was well beyond that expected by chance.

2. Injury rates tend to be higher for new construction than for renovation work.

3. Injury rates per worker-year tend to increase with financial size (contract amounts) of projects when adjustments are made for other factors. Rates, however, decreased sharply with an increase in the number of Superintendents and Project managers.

4. Overall, overexertion was the most common type of injury (accounted for 30% of all injuries) as well as requiring the most hospitalization (accounted for 36% of all hospitalization).

5. While falls were not the most common type of injury (accounted for 12% of all injuries), they were especially likely to result in hospitalization (accounted for 24% of all hospitalizations).

6. Drywall installers had a high hospitalization rate. Although Injuries to drywall installers were not common, they are more likely to be hospitalized when injured.

7. Carpenters were the most frequently injured trade among all trades represented.

8. Overall, pre-cast concrete structures had the highest rate of injury when compared to steel, cast-in-place, masonry and wood structures.

9. Among the larger projects, steel and combination of steel and concrete structures tended to have low risk of injury, while wood and pre-cast concrete structures tended to have higher risk.

10. Among large projects parking garages seem to have higher injury rates, while church and entertainment facilities seem to have lower injury rates.

11. Projects constructed using the Fast Track method seem to have lower injury rates when compared to other contract-delivery methods.

12. 10% of all injuries reported required hospitalization.

13. For a commercial construction project with a contract amount over \$250,000, the predicted injury rate per worker-year can be written as follows:

$$P = \exp(-5.31 - 1.03X_1 + 0.54X_2 - 2.78X_3 - 2.13X_4)$$

Where
P = predicted injury rate per worker-year
X_1 = zero for new construction and (1) for renovations
X_2 = the natural logarithm of the contract amount
X_3 = one if there is a project manager and zero if not
X_4 = zero if there is one or no superintendent and 1 if there are multiple (more than one) superintendents

Importance to Occupational Safety and Health

The results of analysis of injury data has been used to prevent injuries in the manufacturing and transportation industries. The National Safety Council[3] indicates that job safety analyses have proven time and time again to be an accident and occupational illness tool in many industries over the past years. Therefore the ability to predict the rate of injuries can:

- help the construction industry (general contractors, subcontractors, owners, safety engineers/coordinators, etc.) to minimize or prevent injuries by developing safety programs that are tailored specifically for each type of project and each contractor.

- lead to lower injury rates by enabling contractors with safety programs to evaluate the effectiveness of their programs and improve safety practices.

In particular, efforts to reduce overexertion injuries and falls would likely have the most impact on hospitalizations, and hence on costs. The predictive model should be of use in evaluating the risk of projects that differ in size, amount of supervision and scope of work.

The results of this study can provide the construction safety research community, contractors, insurance companies, risk managers and OSHA a tool that can help in directing specific safety efforts. The appropriate balance between a contractor's record, relative to the project-specific hazards, and the inherent hazard of newly planned projects is an appropriate topic for further work that may be of use to the insurance industry.

Finally, the results of this study can greatly expand available knowledge on construction-related injuries, lead to lower injury rates and serve as the basis for future research on developing injury predictive models for the remaining categories of construction such as residential, industrial, and heavy and highway construction.

Abstract

The construction industry experiences a high rate of injuries in general, and a high rate of fatal and disabling injuries in particular. The ability to predict injuries can help control and prevent them. However, because of the dynamic nature of the industry and the unique nature of each contractor and project, traditional methods of prediction, such as historical averages, can provide inaccurate and misleading information.

The primary goal of this study is to develop knowledge that can be used in preventing traumatic injuries at commercial construction sites. The main outcome of interest was the rate of traumatic injuries occurring at commercial construction sites that require medical treatment by a licensed caregiver. The injuries studied were the same as those that are required to be reported by OSHA.

All general contractors in the state of Washington who perform commercial types of construction projects were contacted in order to obtain information on construction site injuries between 1991 and 1993. A total of 730 commercial construction projects were sampled. The overall rate of injury was 23 injuries per 100 worker years. The variation of injury rate between contractors was far in excess of that expected due to chance alone, but the variation could not be explained by ascertainable general features of the contractor's business. The more detailed information on individual projects revealed several strong associations. Renovations tended to have a lower rate of injury than new construction. In addition, the injury rate was strongly related to the balance between project size and the number of supervisory personnel. A log-linear model, fit by generalized estimating equation methods, suggests that the rate of injuries increases with the financial size of a project, but decreases as the number of supervisory personnel are increased from absent to moderate levels. The use of more supervision on larger projects appears to balance the increase in hazard, resulting in a flat or even declining injury rate as financial size increases. Several specific safety practices were in such common and uniform use that no real evaluation of their association with injuries was possible. The data cast some doubt on the value of financial incentives and disincentives, but this is qualified by the strong association of their use with other features of projects that are relevant to safety. Tabulation of injuries by type, trade, and activity revealed that overexertion was the most common cause of all injuries to employees of general contractors, and the most common cause of hospitalizations. Injuries involving cuts, blows, objects in the eye, and falls were also large contributors to both total injuries and hospitalizations, with falls accounted for a disproportionate number of hospitalizations. Injuries during interior work, and injuries to drywall installers in particular, were not common but especially likely to require hospitalization.

Report

<u>Methodology</u>

Safety should be one of the most important concerns of occupational health and safety professions in general, and engineers and construction industry managers in particular because, even though the construction industry employs only an estimated 6% of the industrial workforce in the United States, it accounts for an estimated 20% of all occupational fatalities each year. In spite of efforts being made, such as safety manuals and new or tougher legislation, the industry continues to be plagued with one of the highest rates of injuries among all other industries. The results of a pilot study previously conducted indicated that risk factors related to contractors, projects and workers could influence the rate of injuries.[4] Therefore, the focus of this study will be on specific characteristics of general contractors, projects and workers.

<u>Objectives</u>

The primary goal of this project is to develop knowledge that can be used in preventing traumatic injuries at commercial construction sites. The objectives are:

1. To investigate and identify the most significant risk factors that can influence the occurrence of injuries at commercial construction sites.
2. To analyze the characteristics of any risk factors identified in order to understand their relationship (if any) to the rate of traumatic injuries which occur at commercial construction sites and require medical treatment by a licensed caregiver.
3. To utilize these factors in a parsimonious empirical model that will have good capabilities of predicting the incidence of traumatic injuries requiring medical care among construction workers employed by general contractors on commercial construction sites.

<u>Sampling</u>

The study population was comprised of all 125 general contractors who were active in commercial construction in the state of Washington between 1991 and 1993. The contractors were all assigned random numbers, contacted and asked to provide information on injuries, projects, safety practices, and the nature and size of their business. Sixty-one general contractors responded and agreed to participate in the study. A member of the study team visited each of the 61 contractors and collected data using the forms included in the appendix. The target population consisted of projects in Washington that were worth more than $250,000, and all such projects were sampled from the 61 general contractors. In addition, data was collected on all projects that had an injury, as well as a sample of projects in Washington worth less than $250,000. Analyses restricted

to the target population are reported separately, to allow exclusion of the ascertainment bias in the retrospective sampling of the smaller projects. Injuries and worker-hours from out-of-state projects were included in the contractor-level analysis, but project and injury forms were only collected for projects in the state of Washington. Reportable injuries were counted for only employees of the general contractor. Subcontractors were not surveyed.

Data Collection and Analysis

The data collection forms in the appendix list the information collected on each contractor, each sampled project, and each injury on projects in the state of Washington. Data were collected on color-coded forms, entered into computer files, using double-entry verification and analyzed. Computing was done using Statistic Analysis System (SAS Release 6.09, SAS Institute Inc., Cary, NC) for data management and Splus (Version 3.3 Release 1 for Sun SPARC, SunOS 5.3, 1995 MathSoft, Inc.) for statistical computing. The analysis addresses the impact of both contractor and project attributes on the risk of injury. The number of worker-years for hourly employees (re-scaled from worker-months on the contractor forms) was used as a denominator, measuring risk exposure for each contractor. Injuries and worker-hours at risk were both obtained for individual projects, allowing a similar analysis of injury rates at the project level. Allowance was made for the correlation between projects of the same contractor. The injury forms contained details about injured workers and the circumstances surrounding each injury. However, no similar level of detail about the composition and activities of the uninjured workforce was available, so at the most detailed level, the data are informative about typical numbers and severity of injuries of various types, but not about rates per worker-year or relative risk. Injury counts, total direct costs and total days lost for each project were tabulated from injury report forms by computer, so all injuries and costs at the project level are documented in the injury reports. The detailed information from individual injury reports is summarized, but formal inferential methods are not used because appropriate denominators are not available. This merely reflects that fact that more detailed information is obtained for injuries than in normal circumstances.

Inferences about the association between contractor characteristics and injury rates were made by fitting log-linear models (using the glm function in Splus) with a Poisson error function, and an adjustment for over-dispersion[5]. The rate of injuries per worker-year was modeled by including the logarithm of worker-years as a known term, or offset, in a log-linear model for the injury count. The effects of project characteristics on injury rates were modeled using a generalized estimating equation approach [8] that allows a log-linear model, over-dispersed Poisson error structure, and denominators, but provides valid inferences despite the possible correlation between the projects of a single contractor. Models were fit using the gee function for Splus (V. Carey and A. McDermott, Channing Laboratory, Harvard Medical School, archived at statlib, Carnegie Mellon University,). The working correlation matrix was based on independence, as the resulting weights yield consistent inferences for effects that apply to the typical worker on the job, despite the presence of informative denominators[7].

Findings

Characteristics of Contractors

The characteristics of the contractors who participated in the study are summarized in tables 1 to 8.

Table 1: Age and size of business

	experience (years)	gross revenue (million $)	projects (per year)
Min.	3	0.16	3.7
1st Qu.	10	1.8	7.8
Median	17	3.8	16
Mean	26	55	22
3rd Qu.	33	19	26
Max.	109	1610	142
Not Avail.		1	2

Table 2: Size of workforce

	Average Annual Worker Years				
	salaried	hourly (field)			
	(home office)	total	permanent	temporary	W2 forms
Min.	0.8	2.7	0.0	0.0	4
1st Qu.	2.1	7.9	2.0	4.3	21
Median	4.8	16.3	4.4	13.6	42
Mean	10.2	55.1	5.1	50.0	102
3rd Qu.	14.6	64.3	6.7	58.0	126
Max.	89.4	392.0	18.9	380.0	723
Not Avail.					1

The firms had been in business from just under three to over 100 years, with sizes varying across two orders of magnitude in terms of number of employees and across four orders of magnitude in terms of revenue. About half of the contractors perform some kind of construction in addition to commercial construction, and just over half are unionized. Most of the contractors report having a formal safety program and a dedicated company safety director, although usually at a modest percent effort. One in four companies uses mandatory drug testing. The prevalence of union affiliation, safety programs, directors and drug testing increases with gross revenue. Both number of projects and involvement in projects besides commercial construction are positively, but weakly associated with financial size. In particular, several contractors with high revenue have relatively few projects, and several with revenue under 4 million per year have a relatively large number of projects.

Table 3: Employee Affiliation

Non-Union	26
DoubleBreasted	4
Union	31

Table 4: Noncommercial construction

None	28
Industrial	17
Underground-util	3
Other	4
Unknown	9

Table 5: Safety related programs

	No	Yes	percent
Formal Safety Program	7	54	89%
Company Safety Director	15	46	75%
Mandatory Drug Testing	46	15	25%

Table 6: Safety Director

Safety Director % FTE	N
0	11
0+ thru 25	31
25+ thru 50	8
50+ thru 99	6
100	4

Table 7: Safety programs and size

	Gross revenue (millions)		
	0.16 thru 4	4+ thru 20	2+ thru 1610
Safety program			
No	6	1	0
Yes	24	14	15
Percent yes	80%	93%	100%
Safety Director			
No	12	3	0
Yes	18	12	15
Percent yes	60%	80%	100%
Drug testing			
No	26	11	8
Yes	4	4	7
Percent yes	13%	27%	47%

Table 8: Other attributes by size

	Gross revenue (millions)		
	0.16 thru 4	4+ thru 20	2+ thru 1610
Affiliation			
Non-union	20	2	3
D-Breasted	2	2	0
Union	8	11	12
Percent Union	27%	73%	80%
Projects per year			
0+ thru 10	13	4	3
10+ thru 25	8	9	6
25+ thru 150	7	2	6
Noncommercial			
None	16	5	6
Industrial	6	5	6
Undergr-util	2	1	0
Other	3	0	1
Unknown	3	4	2

Reportable Injuries

All 61 contractors provided data summary which included the numbers of injuries requiring professional medical attention during 1991, 1992, and 1993, as well as person-months of labor during the same period. In addition, 46 contractors provided detailed information on specific projects and injuries. From the summarized data, there were 1772 injuries during a total 10,092 worker years reported by the 61 contractors. This represents a gross rate of 18 injuries per 100 worker-years. Among the 46 contractors contributing detailed information, there were 1688 injuries documented by injury report forms. Of these 1688 injuries, 1135 occurred on projects with valid worker-hours information, totaling 4877 worker years, for a second estimated gross rate of 23 injuries per 100 worker-years. Fifteen of the 61 contractors reported no injuries in the three year period, but three contractors reported over 100, and six contractors accounted for over half of the total injuries. Of the 1668 documented injuries, 176 required hospitalization. Total direct costs and days lost were tallied for each contractor, but nearly half of the contractors had missing cost data. Both measures of cost of injuries are highly skewed, with a large majority of contractors having costs less than average, and only four contractors accounting for more than half of the lost days.

The contractors with the largest numbers of injuries were also among the contractors with the most worker-years of risk exposure. The eight contractors that accounted for just over half of the worker-years of hourly labor also accounted for just over half of the, injuries. However, the risk exposure as measured by hourly labor does not explain all of the variation of injury rates between contractors. If the risk of injury was proportional to the number of worker-years, the injury counts would follow independent Poisson distributions, with means proportional to worker-years. The lack of fit of such a model can be measured by the deviance statistic, defined as-2 times the log-likelihood, which would follow a chi-square distribution if injury rates were homogeneous. For the 61 contractors, the deviance is 1262 on 60 degrees of freedom. There is only a 1 in 1,000,000 chance of observing a deviance as high as 127 due to random fluctuations, thus the observed deviance represents overwhelming evidence of variation in risk between contractors, over and above what can be reasonably explained by random variation and differences in hourly labor. The ability of the contractor characteristics to explain this large variation was examined. Summarizing the injury rates by contractor characteristics produces some interesting patterns, but none are statistically significant, due to the large over-dispersion, or unexplained variation between contractors. In the tables below, two summary rates are given.

Table 9: Injuries and severity

	Per year for each contractor			
	Injuries	Hospitalization	Direct Cost	Lost Days
Min.	0.00	0.00	0	0
1st Qu.	0.33	0.00	0	0
Median	3.33	0.00	65	5
Mean	9.69	0.96	24900	75
3rd Qu.	10.00	1.00	1680	42
Max.	102.00	15.30	366000	1030
Not Avail.			30	1

Table 10: Injuries per contractor

Total Injuries (In 3 years)	N
0	15
0.0+ thru 10	19
10.0+ thru 100	24
100.0+ thru 305	3

The overall injury rate is obtained by dividing the contractors into categories, and dividing the total number of injuries for each category by the total worker-years for that category. The average of rates is obtained by first computing an injury rate for each contractor, and then computing the arithmetic mean (and standard deviation) of these rates for the contractors in each category. The overall rate weights the contractors according to their number of worker-years, while the average of rates gives each contractor equal weight.

Because the injury rates are extremely variable, particularly among the smaller contractors, the equally weighted average of rates is subject to erratic variations. The equally weighted averages are included because they illustrate the variability due to contractors. The statistical tests were done using Poisson regression methods that weight the data according to the number of worker-years, but adjust the test statistics to allow for over-dispersion [6,5].The generic model used for testing can be described as follows. If y is the number of injuries, n the number of worker-years of exposure, and x the covariate of interest, possibly a vector, then the expected value of y can be modeled as:

$$E(y) = \mu = n\rho$$

where

$$\Rightarrow \quad \log \rho = X\beta$$

or equivalently

$$\Rightarrow \quad \log \mu = \log(n) + X\beta$$

This was fit using a generalized linear model with a log link, Poisson error structure, and a log n offset. The extra-Poisson variance component is estimated as described by Breslow [5], assuming the over-dispersion is homogeneous on the log scale, but rather than using this component of variance to update the iterative weights, a post-fit adjustment to standard errors was made, which preserves worker-years weighting, hence consistent estimation when the denominators are informative [10].

Table 11: Injury rates by size, nature and size of firm

	Firms	Injuries	Wrk-Yrs	Injury Rate/Wrkr-Yr		
				Overall	Ave	S.D.
Affiliation						
Non-union	26	309	1596	0.19	0.12	0.12
D-Breasted	4	48	415	0.12	0.15	0.17
Union	31	1416	8082	0.18	0.37	0.89
Noncommercial construction						
None	28	768	3914	0.20	0.30	0.89
Industrial	17	805	4343	0.19	0.18	0.13
Undergr-util	3	12	161	0.07	0.07	0.06
Other	4	59	126	0.47	0.51	0.88
Unknown	9	129	1549	0.08	0.15	0.21
Revenue						
0.2+ thru 4	28	123	1171	0.1	0.1	0.11
4.0+ thru 16	15	316	1971	0.2	0.5	1.20
16+ thru 64	10	584	3789	0.2	0.3	0.53
64.0+ thru 1610	4	730	2750	0.3	0.3	0.07
Projects						
4+ thru 8	14	73	1016	0.072	0.076	0.11
8+ thru 16	14	503	2334	0.216	0.610	1.29
16+ thru 32	20	618	3639	0.170	0.167	0.17
32+ thru 142	9	559	2811	0.199	0.235	0.12
W2 forms/yr						
4+ thru 25	17	37	391	0.09	0.06	0.09
25+ thru 50	16	121	830	0.15	0.18	0.18
50+ thru 150	13	362	1856	0.20	0.33	0.47
150+ thru 723	13	948	6085	0.16	0.51	1.29

Table 12: Injury rates by labor measures

	Firms	Injuries	Wkr-Yrs	Injury Rate/Wrkr-Yr		
				Overall	Ave	S.D.
Hourly labor (Worker-yrs/yr)						
2.7+ thru 16	30	216	740	0.29	0.35	0.91
16.0+ thru 64	15	230	1640	0.14	0.14	0.12
64.0+ thru 392	16	1327	7712	0.17	0.17	0.11
Salaried labor (Worker-yrs/yr)						
8+ thru 50	28	165	1046	0.16	0.25	0.896
50+ thru 250	24	601	4606	0.13	0.26	0.375
250+ thru 1070	8	702	3556	0.20	0.19	0.091
Hourly/salaried						
0.24+ thru 1	4	58	75	0.78	0.555	0.867
1.00+ thru 4	23	528	2419	0.22	0.158	0.177
4.00+ thru 8	22	607	2723	0.22	0.368	0.997
8.00+ thru 16	8	460	2890	0.16	0.122	0.099
16.00+ thru 28	4	120	1986	0.06	0.068	0.044
Perm.field (wk-yr/yr)						
0+ thru 50	28	447	1604	0.28	0.28	0.896
50+ thru 100	22	464	3245	0.14	0.25	0.389
100+ thru 227	11	862	5242	0.16	0.18	0.085
Temp/Perm (field)						
0+ thru 1	8	71	134	0.53	0.36	0.64
1+ thru 5	23	184	1058	0.17	0.14	0.11
5+ thru 10	15	357	2298	0.16	0.13	0.13
10+ thru 1000	15	1161	6601	0.18	0.48	1.20
Salaried/Gross						
0.3+ thru 15	8	658	3671	0.18	0.74	1.64
15.0+ thru 30	20	883	4728	0.19	0.26	0.40
30.0+ thru 60	19	181	970	0.19	0.17	0.13
60.0+ thru 450	13	51	714	0.07	0.05	0.08

Table 13: Injury rates by safety practices

	Firms	Injuries	Wkr-Yrs	Injury Rate/Wrkr-Yr. Overall	Ave	S.D.
Drug testing						
No	46	779	5044	0.15	0.17	0.29
Yes	15	994	5048	0.20	0.49	1.20
Safety program						
No	7	7	126	0.055	0.05	0.13
Yes	54	1766	9966	0.177	0.27	0.68
Safety director						
No	15	84	794	0.11	0.11	0.12
Yes	46	1689	9298	0.18	0.29	0.74
Safety director FTE						
0+ thru 10	39	295	2326	0.13	0.17	0.31
10+ thru 50	11	531	3075	0.17	0.57	1.41
50+ thru 100	10	941	4630	0.20	0.22	0.13

Projects

Of the 61 contractors providing data, 45 were able to provide worker-hours per project on a total of 730 sampled projects. These included 425 projects each with a contract amount of more than $250,000 and 305 projects each of which had a value of less than $250,000. The result is a complete sampling of large projects and a complete sample of projects with injuries, among the 45 contractors with adequate records.

Because the sampling of small projects was influenced by the occurrence of injuries, separate tabulation of injury rates for large and small projects is provided, and adjustment or stratification for project size is used in the fitted models. The injury rates for large projects reflect the risk of such projects, being biased only by the selection of contractors with adequate recording of labor expenditures by project. The apparent risk for smaller projects will be biased upward, due to the retrospective enrichment of injuries in the sample, but the small studies provide valid information about the relative risks of project attributes, as in a pure case-control design. Stratification or adjustment for project size is necessary when the whole sample issued, to control for biases due to collinearity of project size with other factors. Unadjusted summaries of injury rates broken down by single factors are given here, but always together with separate summaries for large and small projects. Tables 14 through 32 give summaries of injury rates by individual project characteristics. The numbers of projects, total worker-years and number of injuries are given in columns 1, 3, and 4 for each category of projects. The injury rate is the ratio of injuries to worker-years. The second column gives the effective number of projects (ENP), which reflects the degree to which the total labor is concentrated in a small number of large projects. More precisely, the index is the ratio of the squared sum to the sum of squares of worker-years, which can be

interpreted as the number of projects with equal worker-years that would result in the same Gini/Simpson index (the same probability that two workers are on the same job if chosen at random with probability proportional to time on the job). This is included only to flag categories dominated by small numbers of projects. The last two columns give z-statistics comparing each category to the first (often the category with the most labor). An absolute value of 2 corresponds to a two-sided t-test significant at the 0.05 level. The naive-z is based on an assumed Poisson distribution, which would be the case if the risk per worker associated with a project depended only on the factors being investigated. The robust-z is adjusted to reflect the variation in underlying injury rates between different projects with the same or similar characteristics. The large number of categories that exhibit significant differences by the naive-z but not by the robust-z reflect variation between contractors and individual projects. One would not expect such results to necessarily generalize to other contractors in other states, for example, while findings that are significant by the robust-z probably reflect general relationships between project attributes and the risk of injury.

The large labor variations between projects create difficulties in defining an appropriate injury rate. There were 1135 injuries among all 730 analyzable projects . Dividing by the 4877 total worker-years yields an overall rate of 23 injuries per 100 worker-years. However, the average of the individual injury rates from each project is 116 injuries per 100 worker-years. Limiting attention to the 425 projects worth more than $250,000 leaves the overall rate essentially unchanged (22.7 as opposed to 23.3) but reduces the average of individual rates to 45 injuries per 100 worker-years. The averages of project-specific rates are extremely erratic, being heavily influenced by injuries that occur in small projects. In addition to being better behaved, overall rates yield valid inferences to the population of workers on the job even when injury rates are related to project size, giving them a sensible interpretation with respect to public health and financial implications. Table 14 summarizes the injury rates by the scope of the project. New construction resulted in nearly twice the injury rate of renovation projects, but due to the large variation between projects, the result is only marginally significant, with a one-sided p-value of 0.05 for the large projects and a two-sided p of 0.05 for the small projects.

Table 14: Scope of Project

Scope	Projects	ENP	Worker-years	Injuries	Rate	Naive Z	Robust Z
All projects							
New	234	26.9	2922	797	0.27		
Renov	450	6.8	1702	250	0.15	-8.5	-1.7
Unknown	46	19.2	2746	88	0.35	2.2	0.7
Over 250K							
New	198	23.9	2746	725	0.26		
Renov	201	4.9	1447	193	0.13	-8.4	-1.6
Unknown	26	13.8	176	74	0.42	3.8	1.3
Under 250K							
New	36	10.9	176	72	0.41		
Renov	249	47.9	255	57	0.22	-3.4	-2.0
Unknown	20	5.4	76	14	0.18	-2.7	-1.6

Table 15 gives the summary by type of project. Offices and institutions accounted for just under half of the total numbers of projects and worker-years. Offices, churches and entertainment facilities had low injury rates. Only garages and non-building projects had significantly higher rates than offices among the target group of large projects. The pattern was somewhat different among small projects, but is based on smaller numbers of projects and worker-years.

Table 15: Type of Project

Type of Project	Projects	ENP	Wkr-yrs	Injuries	Rate	Naive Z	Robust Z
All projects							
Office	120	3.8	1389	196	0.141		
Institution	227	77.3	1040	287	0.276	7.2	1.2
Factory	74	3.4	716	173	0.242	5.2	1.0
Medical	67	19.6	266	66	0.248	4.0	1.0
Retail	56	13.9	234	65	0.278	4.7	1.3
Church	10	1.8	184	18	0.098	-1.5	-0.5
Entertainment	14	8.2	43	6	0.141	0.0	0.0
Garage	6	4.8	37	28	0.761	8.3	1.9
Restaurant	18	13.0	31	7	0.226	1.2	0.8
Other Bldg.	104	15.3	788	206	0.261	6.2	0.9
Non-bldg.	34	8.0	148	83	0.560	10.5	2.5
Over 250K							
Office	53	3.4	1328	186	0.140		
Institution	132	56.8	788	228	0.289	7.3	1.2
Factory	33	3.0	667	169	0.253	5.6	1.1
Medical	46	17.3	236	61	0.259	4.2	1.0
Retail	40	12.1	217	57	0.262	4.1	1.2
Church	8	1.8	183	17	0.093	-1.6	-0.5
Entertainment	8	4.3	28	4	0.142	0.0	0.0
Garage	6	4.8	37	28	0.761	8.3	1.8
Restaurant	13	10.1	26	6	0.228	1.2	0.8
Other Bldg.	75	14.8	775	190	0.245	5.4	0.8
Non-bldg.	11	4.3	83	46	0.555	8.4	2.4
Under 250K							
Office	67	7.8	61	10	0.164		
Institution	95	20.7	52	59	0.234	1.0	0.6
Factory	41	24.8	49	4	0.082	-1.2	-1.3
Medical	21	2.3	31	5	0.163	0.0	0.0
Retail	16	7.2	17	8	0.479	2.3	2.6
Church	2	1.2	0	1	5.666	3.4	2.7
Entertainment	6	5.5	15	2	0.137	-0.2	-0.4
Garage	0						
Restaurant	5	3.8	5	1	0.212	0.2	0.3
Other Bldg.	9	17.3	13	16	1.201	4.9	3.4
Non-bldg.	23	3.7	66	37	0.565	3.5	3.1

Table 16: Type of Project by Scope

Type of Project	Projects	ENP	Wkr-yrs	Injuries	Rate	Naive Z	Robust Z
New Construction							
Office	30	3.2	549	158	0.288		
Institution	61	32.3	498	150	0.301	0.4	0.2
Factory	18	2.3	591	157	0.266	-0.7	-0.4
Medical	13	5.7	117	14	0.119	-3.2	-3.6
Retail	21	8.0	169	43	0.254	-0.7	-0.3
Church	5	1.3	153	17	0.111	-3.7	-2.1
Entertainment	6	4.0	28	3	0.108	-1.7	-2.0
Garage	5	4.4	35	28	0.803	5.0	1.5
Restaurant	7	4.9	13	4	0.301	0.1	0.1
Other Bldg.	56	11.1	649	165	0.254	-1.1	-0.3
Non-bldg.	12	5.3	119	58	0.489	3.4	1.7
Renovations							
Office	85	1.6	817	36	0.044		
Institution	140	34.3	367	72	0.196	7.3	2.7
Factory	53	17.4	118	15	0.127	3.5	1.5
Medical	53	18.3	147	52	0.353	9.6	3.9
Retail	3	10.5	61	22	0.363	7.8	5.7
Church	3	1.2	2	1	0.593	2.6	1.8
Entertainment	8	7.2	15	3	0.201	2.5	2.8
Garage	1	1.0	2	0	0.000		
Restaurant	11	8.2	18	3	0.169	2.2	2.3
Other Bldg.	46	6.7	138	41	0.298	8.4	3.2
Non-bldg.	17	3.9	18	5	0.279	3.9	2.5

Table 16 summarizes the data first by scope (new construction and renovations) and then by type of building. New construction projects show higher injury rates in comparison to renovations.

Table 17 summarizes the data by structure type. The categories are sorted by worker-years, except for other and unknown, the latter being a large category. It is interesting that sorting by decreasing labor nearly sorted the data in increasing order of hazard. Steel--concrete combination, steel and masonry structures had the smaller rates, with wood and cast-in-place structures having higher rates.

Table 17: Type of Structure

Type of Structure	Projects	ENP	Wrkr-yrs	Injuries	Rate	Naive Z	Robust Z
All projects							
steel+concrete	89	4.8	1471	189	0.13		
cast-in-place	53	6.0	858	240	0.28	8.0	1.4
steel	71	2.7	626	114	0.18	2.9	0.7
masonry	73	21.5	411	88	0.21	4.0	0.9
tilt-up	47	15.6	325	97	0.30	6.7	1.4
wood	128	52.6	264	83	0.31	6.8	1.7
pre-cast	9	1.9	21	12	0.57	5.0	2.4
other	31	6.4	149	75	0.51	10.0	3.5
unknown	229	77.9	752	237	0.32	9.2	1.6
Over 250K							
steel+concrete	65	4.4	1405	155	0.11		
cast-in-place	31	5.9	850	231	0.27	8.7	1.5
steel	34	2.3	579	108	0.19	4.2	1.0
masonry	52	20.4	400	85	0.21	4.9	1.1
tilt-up	37	15.2	321	95	0.30	7.6	1.7
wood	86	40.7	215	72	0.34	7.8	2.0
pre-cast	4	1.7	20	11	0.55	5.2	2.5
other	23	6.2	147	73	0.50	10.6	3.8
unknown	93	51.1	435	162	0.37	10.8	2.1
Under 250K							
steel+concrete	24	3.8	66	34	0.51		
cast-in-place	22	9.5	8	9	1.06	1.9	1.0
steel	37	6.2	47	6	0.13	-3.2	-2.2
masonry	21	11.5	11	3	0.27	-1.1	-0.9
tilt-up	10	6.9	4	2	0.45	-0.2	-0.1
wood	42	12.6	49	11	0.22	-2.4	-2.8
pre-cast	5	1.5	1	1	0.81	0.4	0.4
other	8	3.4	2	2	0.99	0.9	1.3
unknown	136	28.3	317	75	0.24	-3.8	-1.9

Table 18 summarizes the contract delivery methods commonly used. Competitive and negotiated lump sum contracts were by far the most commonly used. The others had a lower overall injury rate in the sample, but not significantly so. Collapsing the categories into lump sum contracts versus others did not detect a statistically significant difference.

Table 18: Contract Delivery System

Contract Type	Projects	ENP	Wrkr-yrs	Injuries	Rate	Naive Z	Robust Z
All projects							
Competitive	417	71.8	2423	609	0.25		
Negotiated	215	50.0	825	221	0.27	0.8	0.2
Time/materials	21	1.2	414	84	0.20	-1.8	-1.5
Design-build	19	3.8	54	10	0.18	-1.0	-0.9
Constr.Mgmt	1	1.0	0.4	0			
Other	39	2.5	1119	198	0.18	-4.3	-0.4
Unknown	18	6.9	43	13	0.31	0.7	0.8
Over 250K							
Competitive	260	54.8	2056	513	0.25		
Negotiated	115	40.9	733	189	0.26	0.4	0.1
Time/materials	9	1.2	411	83	0.20	-1.8	-1.3
Design-build	11	3.3	51	8	0.16	-1.3	-1.4
Constr.Mgm	0						
Other	24	2.4	1102	193	0.17	-4.2	-0.4
Unknown	6	2.8	16	6	0.37	0.9	1.2
Under 250K							
Competitive	157	29.0	367	96	0.26		
Negotiated	100	18.6	92	32	0.35	1.4	0.6
Time/materials	12	4.4	2	1	0.47	0.6	0.8
Design-build	8	6.1	3	2	0.62	1.2	1.1
Constr.Mgm	1	1.0	0.4	0			
Other	15	10.5	17	5	0.29	0.2	0.1
Unknown	12	4.2	26	7	0.27	0.0	0.1

Tables 19, 20 and 21 summarize the use of fast-track, partnering, and Total Quality Management's (TQM) concepts. Fast-track projects had significantly lower injury rates, with no significant difference for partnering, and TQM.

Table 19: Fast-track

Fast-track	Projects	ENP	Wrkr-yrs	Injuries	Rate	Naive Z	Robust Z
All projects							
No	643	23.1	3562	909	0.26		
Yes	83	8.5	1295	220	0.17	-5.4	-2.1
Over 250K							
No	361	17.6	3092	785	0.25		
Yes	62	8.2	1273	207	0.16	-5.7	-2.1
Under 250K							
No	282	43.6	470	124	0.26		
Yes	21	6.1	22	13	0.59	2.8	2.2

Table 20: Partnering Agreement

Partnering	Projects	ENP	Wrkr-yrs	Injuries	Rate	Naive Z	Robust Z
All projects							
No	660	46.9	3254	819	0.25		
Yes	67	4.9	1607	310	0.19	-4.0	-0.5
Over 250K							
No	362	34.6	2765	684	0.25		
Yes	62	4.9	1604	308	0.19	-3.7	-0.5
Under 250K							
No	298	46.5	489	135	0.28		
Yes	5	3.9	3	2	0.68	1.3	1.3

Table 21: TQM Concept Implement

TQM	Projects	ENP	Wrkr-yrs	Injuries	Rate	Naive Z	Robust Z
All projects							
No	596	17	2763	611	0.22		
Yes	131	15	2097	518	0.25	1.8	0.4
Over 250K							
No	303	12	2280	479	0.21		
Yes	121	15	2088	513	0.25	2.5	0.5
Under 250K							
No	293	46	483	132	0.27		
Yes	10	5	9	5	0.55	1.5	0.8

Tables 22, 23, and 24 concern safety programs. Only the rather rare use of disincentives was significantly associated with injury rates, with the projects that used disincentives having more than twice the normal injury rate. Safety incentives were used in about a third of the projects, and these also had higher observed injury rates, but not significantly so.

Nearly all projects reported employee safety training, and 68 of the 76 projects that reported no employee safety training did report a weekly safety meeting. Of 730 projects, 717 reported one safety meeting per week, 8 reported none, one reported two meetings per week, one reported 5 meetings per week, and 3 did not report for this item.

Table 22: Employee Safety Training

Training	Projects	ENP	Wrkr-yrs	Injuries	Rate	Naive Z	Robust Z
All projects							
No	76	36	31	12	0.39		
Yes	651	31	4829	1117	0.23	-1.8	-1.0
Over 250K							
No	17	15	17	4	0.24		
Yes	407	26	4352	988	0.23	-0.1	-0.1
Under 250K							
No	59	27	14	8	0.56		
Yes	244	44	478	129	0.27	-2.0	-1.6

Table 23: Safety Incentive Program

Incentives	Projects	ENP	Wrkr-yrs	Injuries	Rate	Naive Z	Robust Z
All projects							
No	476	8.8	1941	347	0.18		
Yes	251	26.6	2919	782	0.27	6.3	1.0
Over 250K							
No	237	6.1	1616	265	0.16		
Yes	187	23.9	2753	727	0.26	6.6	1.0
Under 250K							
No	239	42.5	326	82	0.25		
Yes	64	10.4	166	55	0.33	1.6	1.1

Table 24: Safety Disincentive Program

Disincentives	Projects	ENP	Wrkr-yrs	Injuries	Rate	Naive Z	Robust Z
All projects							
No	689	28.9	4640	1021	0.22		
Yes	39	19.2	235	114	0.48	8.0	3.3
Over 250K							
No	388	23.1	4134	882	0.21		
Yes	36	18.9	234	110	0.47	7.8	3.2
Under 250K							
No	301	48.4	506	139	0.28		
Yes	3	2.3	1	4	2.92	4.7	19.4

The number of project managers was similar to safety meetings, in that almost all (663 out of 730) projects had one manager. Table 25 shows the use of a manager among large and small projects. Projects without managers had higher injury rates. For large studies, the result is significant, but based on only six projects without managers. The method used for inflating the naive Poisson variance does not pool estimates of the over dispersion in saturated models, such as this [7,9] making the method somewhat less reliable when one of the cells is as small as this.

Table 25: Project size and use of manager

Manager/size	Projects	ENP	Wrkr-yrs	Injuries	Rate	Naive Z	Robust Z
Big.yes	418	25.6	4357	968	0.22		
Sm.yes	247	46.1	493	131	0.27	1.9	0.8
Big.no	6	5.1	7	4	0.60	2.0	2.2
Sm.no	58	25.7	14	12	0.83	4.6	2.2

Tables 26 and 27 describe the use of supervisory personnel. There is a significant drop in the injury rate as the number of superintendents is increased from 1 to 2. The trend appears to continue, but the small number of projects with more than 2 superintendents makes the evidence for the further trend somewhat tenuous.

Table 26: Superintendents on Large Projects

Superintendents	Projects	ENP	Wrkr-yrs	Injuries	Rate	Naive Z	Robust Z
1	373	152.8	1719	553	0.32		
2	41	25.4	820	169	0.21	-5.1	-2.3
3+	11	4.8	1830	270	0.15	-10.5	-1.5

Table 27: Engineers (Large Projects Only)

Engineers	Projects	ENP	Wrkr-yrs	Injuries	Rate	Naive Z	Robust Z
0	241	82.8	719	210	0.292		
1	138	71.0	1228	378	0.308	0.6	0.2
2	42	8.1	2409	403	0.167	-6.6	-1.4

Table 28: Contract Amount (if over $250,000)

Amount (Millions)	Projects	ENP	Wrkr-yrs	Injuries	Rate	Naive Z	Robust Z
.25 thru 1	209	146.5	353	107	0.303		
1+ thru 5	150	90.6	1114	304	0.273	-0.9	-0.6
Over 5	66	11.6	2902	581	0.200	-3.9	-1.4

The relationship of number of subcontractors to injury rates appeared to be flat overall, at least for the large projects, but there was some evidence of an increased injury rate for projects with modest to mid-range numbers of subcontractors. Treating number of contractors as a metric variable in a quadratic model did not reveal any significant relationship, whether the original or logarithmic scale was used.

Table 29: Number of Subcontractors

Subcontractors	Projects	ENP	Wrkr-yrs	Injuries	Rate	Naive Z	Robust Z
All projects							
0+ thru 8	183	29.5	207	50	0.24		
8+ thru 16	181	40.9	470	170	0.36	2.5	1.1
16+ thru 32	278	84.6	1902	415	0.22	-0.7	-0.3
32+ thru 145	83	7.5	2285	496	0.22	-0.7	-0.2
Over 250K							
0+ thru 8	53	15.3	145	24	0.17		
8+ thru 16	85	26.7	358	131	0.37	3.6	2.2
16+ thru 32	207	69.6	1678	365	0.22	1.3	1.1
32+ thru 145	76	6.8	2176	468	0.21	1.2	0.6
Under 250K							
0+ thru 8	130	47.7	62	26	0.42		
8+ thru 16	96	20.7	112	39	0.35	-0.7	-0.3
16+ thru 32	71	21.5	223	50	0.22	-2.6	-1.0
32+ thru 145	7	5.2	109	28	0.26	-1.8	-0.8

Table 30: Duration of Project

Months	Projects	ENP	Wrkr-yrs	Injuries	Rate	Naive Z	Robust Z
All projects							
1+ thru 6	339	96.3	416	104	0.25		
6+ thru 12	198	67.4	871	188	0.22	-1.2	-0.6
12+ thru 18	69	5.0	1475	261	0.18	-3.0	-0.7
Over 18	101	13.1	1979	556	0.28	1.1	0.5
Over 250K							
1+ thru 6	126	47.9	274	72	0.26		
6+ thru 12	148	51.5	721	158	0.22	-1.3	-0.7
12+ thru 18	62	4.5	1398	238	0.17	-3.2	-0.9
Over 18	75	11.7	1863	500	0.27	0.2	0.1
Under 250K							
1+ thru 6	213	88.0	142	32	0.23		
6+ thru 12	50	19.1	150	30	0.20	-0.5	-0.2
12+ thru 18	7	4.5	77	23	0.30	1.0	0.6
Over 18	26	5.6	117	56	0.48	3.4	1.9

Table 31: Number of Stories

Stories	Projects	ENP	Wrkr-yrs	Injuries	Rate	Naive Z	Robust Z
All projects							
0-1	278	36.3	1079	314	0.29		
2	158	5.0	1461	204	0.14	-8.2	-1.7
3+	163	11.8	1793	501	0.28	-0.6	-0.2
Over 250K							
0-1	190	30.3	977	272	0.28		
2	100	4.5	1380	185	0.13	-7.7	-1.6
3+	92	11.0	1728	490	0.28	0.2	0.1
Under 250K							
0-1	88	18.7	101	42	0.41		
2	58	11.8	81	19	0.23	-2.1	-1.6
3+	71	9.3	65	11	0.17	-2.6	-2.2
New							
0-1	122	19.7	748	196	0.262		
2	58	27.6	558	139	0.249	-0.5	-0.1
3+	35	6.8	1345	406	0.302	1.6	0.6
Renov							
0-1	135	22.6	280	92	0.328		
2	89	1.6	821	39	0.047	-10.1	-3.1
3+	121	24.3	378	71	0.188	-3.5	-2.1

Table 32: Finished Height

Height	Projects	ENP	Wrkr-yrs	Injuries	Rate	Naive Z	Robust Z
All projects							
0+ thru 12	29	5.6	123	22	0.18		
12+ thru 20	51	18.7	135	69	0.51	4.3	3.0
20+ thru 50	302	81.5	1585	414	0.26	1.7	1.7
50+ thru 100	76	6.2	1859	355	0.19	0.3	0.1
100+ thru 460	28	2.1	558	123	0.22	0.9	1.1
Over 250K							
0+ thru 12	21	4.5	106	18	0.17		
12+ thru 20	35	15.2	118	58	0.49	4.0	2.7
20+ thru 50	229	73.8	1489	374	0.25	1.6	1.8
50+ thru 100	60	6.1	1844	353	0.19	0.5	0.3
100+ thru 460	16	2.1	552	119	0.22	0.9	1.2
Under 250K							
0+ thru 12	8	1.3	17	4	0.23		
12+ thru 20	16	4.5	18	11	0.62	1.7	2.4
20+ thru 50	73	12.0	95	40	0.42	1.1	1.6
50+ thru 100	16	9.6	15	2	0.13	-0.6	-0.7
100+ thru 460	12	9.1	6	4	0.68	1.5	1.2

Injury Risk Model

The joint effects of project-specific risk factors were modeled using the generalized estimating equation approach. Inclusion of the logarithm of project worker-years as an offset results in a linear model for the logarithm of the probability of injury per worker year. An indicator variable was included so that the model would estimate rates separately for projects under and over the $250,000 threshold for complete sampling. For the larger projects the resulting rate estimates will not be biased by selection of projects with injuries. The estimation of covariate effects will be generally valid, but the combination of these with an intercept term to produce actual rate estimates will be biased for the smaller projects.

Models were constructed by adding terms to a base model consisting of the large/small indicator and scope (new construction versus renovation). These were kept in all models, despite sometimes modest significance levels. The number of stories was a significant term when added to the base model, but was highly correlated with the contract amount (on a log scale), which was highly significant, despite the fact that partial information about contract amount was captured by the large/small indicator variable. Note that the combination of these two results in parallel regression lines with a discontinuity due to sampling (and not in a piece wise linear model). Height and area were not significantly related to injury rate given the contract amount.

While the injury rate increased with the financial size of the project, the rates decreased sharply with the presence of a manager, with two or more superintendents, and with increasing numbers of engineers (simplified to zero, one, or more than one engineer). These factors are related in that engineers or multiple superintendents were only used on projects with managers. All three appeared to contribute additive terms to the reduction in risk, however.

Incentives and disincentives were somewhat confusing, in that they appeared to reduce the injury rate in the simpler models adjusted for project size, but they were associated with increased rates when the adjustment for project managers was made. As with multiple superintendents and engineers, both incentives and disincentives were only used on projects with managers, and were much more heavily used in large projects. In the simple tabulations, their association with large projects seems to lead to an apparent association with increased risk. When adjustment is made for project size, their association with managers seems to lead to an apparent beneficial effect, but when adjustment is made for managers, they appear again to be markers for increased risk.

The following model is the most extensive model found that includes only terms with RobustZ-statistics greater than 2 in magnitude, with the exception of unknown scope, which was included to avoid contaminating estimation for the other two groups.

THE FULL MODEL (fit to all data):

	Estimate	Naive S.E.	Naive Z	Robust S.E.	Robust Z
(Intercept)	-8.02	0.370	-21.7	1.99	-4.03
big proj	0.57	0.131	4.4	0.25	2.29
scope Renov	-0.88	0.093	-9.5	0.25	-3.47
scopeUnknown	-0.45	0.172	-2.6	0.49	-0.91
disincentives	0.90	0.140	6.4	0.40	2.27
incentives	0.79	0.084	9.4	0.34	2.28
log(amount)	0.64	0.021	30.1	0.14	4.57
manager.used	-2.25	0.160	-14.0	0.24	-9.49
twosupers	-1.35	0.205	-6.6	0.48	-2.80
eng.012	-1.38	0.082	-16.9	0.59	-2.34

As a check on the sensitivity of the estimation, the same model, except for the large/small indicator variable labeled "big proj," was fit to only the projects worth more than $250,000. The parameter estimates, standard errors, and test statistics are shown below. Except for the unknown scope, the parameter estimates are quite similar in both fits.

THE FULL MODEL (large projects only):

	Estimate	Naive S.E.	Naive Z	Robust S.E.	Robust Z
(Intercept)	-7.44	0.384	-19.35	2.31	-3.22
scopeRenov	-0.80	0.097	-8.24	0.26	-3.07
scopeUnknown	-0.15	0.185	-0.79	0.57	-0.26
disincentives	0.88	0.144	6.07	0.43	2.04
incentives	0.73	0.088	8.27	0.38	1.90
log(amount)	0.64	0.022	29.19	0.15	4.23
manager.used	-2.22	0.162	-13.71	0.25	-8.73
twosupers	-1.45	0.221	-6.57	0.50	-2.92
eng.012	-1.34	0.086	-15.60	0.67	-2.01

Simplifying the model by deleting the incentive and disincentive terms yields the following estimates.

A SIMPLIFIED MODEL (fit to all data):

	Estimate	Naive S.E.	Naive Z	Robust S.E.	Robust Z
(Intercept)	-7.26	0.348	-20.9	1.81	-4.01
scopeRenov	-1.07	0.090	-11.9	0.25	-4.21
scopeUnknown	-0.40	0.171	-2.3	0.46	-0.86
bigproj	0.81	0.128	6.3	0.31	2.57
log(amount)	0.62	0.020	31.2	0.14	4.58
manager.used	-2.34	0.159	-14.7	0.35	-6.76
twosupers	-0.91	0.197	-4.6	0.55	-1.65
eng.012	-1.11	0.075	-14.8	0.53	-2.08

Deleting either the term for superintendents or engineers increases the estimate and significance of the other term, as illustrated in this further simplification.

A FURTHER SIMPLIFICATION (fit to all data):

	Estimate	Naive S.E.	Naive Z	Robust S.E.	Robust Z
(Intercept)	-6.07	0.332	-18.3	0.865	-7.01
scopeRenov	-1.03	0.092	-11.2	0.284	-3.61
scopeUnknown	-0.34	0.176	-1.9	0.579	-0.58
bigproj	0.76	0.132	5.8	0.427	1.79
log(amount)	0.54	0.019	28.8	0.055	9.79
manager.used	-2.78	0.159	-17.5	0.441	-6.31
twosupers	-2.13	0.180	-11.9	0.287	-7.43

For a project over \$250,000, the predicted injury rate per worker-year can be written as follows:

$$\text{Log} \quad P = \exp(-5.31 - 1.03\, X_1 + 0.54\, X_2 - 2.78\, X_3 - 2.13\, X_4)$$

where X_1 is zero for new construction and 1 for renovations, X_2 is the natural logarithm of the contract amount, X_3 is 1 if there is a project manager and zero if not, and X_4 is 1 if there are multiple superintendents, and zero if there is one or no superintendent. Thus for a new construction project with the median contract amount of \$612,000, a project manager and one superintendent, the predicted rate is $\exp(-5.31 + 0.54 \log(612,000) - 2.78) = 0.41$ injuries per worker-year. At the mean amount of \$3,180,000 the rate increased to about 1 injury per year, but would be predicted to be only 0.12 per worker year if multiple superintendents are used. This simplified model attributes large effects to its few terms in order to explain the large variation in injury rates across projects and contractors. The full model attributes slightly more effect to the contract amount, but assigns smaller effect to the rest of the variables. It should be born in mind that there is a large variation around these predicted values, and that the usual Poisson or binomial formulas will grossly underestimate this variance.

Type and Severity of Injuries

There were 1688 Injury reports among the 61 contractors. In this section we report on the detailed information on the injured worker forms. Because only 1135 of these injuries can be linked to projects with a record of worker-hours, and none of these totals can be broken down into the detail on the injury reports, no attempt will be made to relate the injury details to numbers of workers at risk. The hospitalization rates presented here refer to the fraction of injuries that require hospitalization.

Table 33 shows injury counts and hospitalizations broken down by the scope of work. Although renovations had a lower rate on injuries per worker-year, the observed fraction of injuries requiring hospitalization was some what higher.

Table 33: Hospitalizations by Scope

Scope of Project	Total	Hospitalizations			
	Injured	Unknown	No	Yes	Percent
New	1175	9	1064	102	8.7
Renov	376	1	330	45	12.0
Unknown	137	0	108	29	21.2

Figures 1 through 9 give the total number of injuries, hospitalizations, and the percentages of injuries requiring hospitalization, broken down by the type of injury, trade of the injured worker, and the task the worker was engaged in when injured. Over exertion accounted for 30% of all injuries, and 36% of all hospitalizations. The two categories of falls, which together accounted for 12% of injuries, tended to require hospitalization more often than other types of injuries, accounting for 24% of all hospitalizations. High hospitalization rates were also observed for exposure to radiation or toxic or caustic material, and for contact with electricity, but both of these categories involved small numbers of injuries.

Carpenters were by far the most frequently injured trade, although this may merely reflect their relative numbers among the workforce employed by general contractors. Drywall installers had a high hospitalization rate, relative to their much lower ranking in frequency of injury. The majority of the injury reports did not record the task at the time of injury. However, the data document substantial numbers of injuries for workers involved in formwork, and somewhat lower numbers for concrete work and site work. The largest fraction of injuries requiring hospitalization was for interior work. However, any interpretation of such percentages must be cautious, because of the large amount of missing data.

Figure 1: Distribution of Injuries by Type
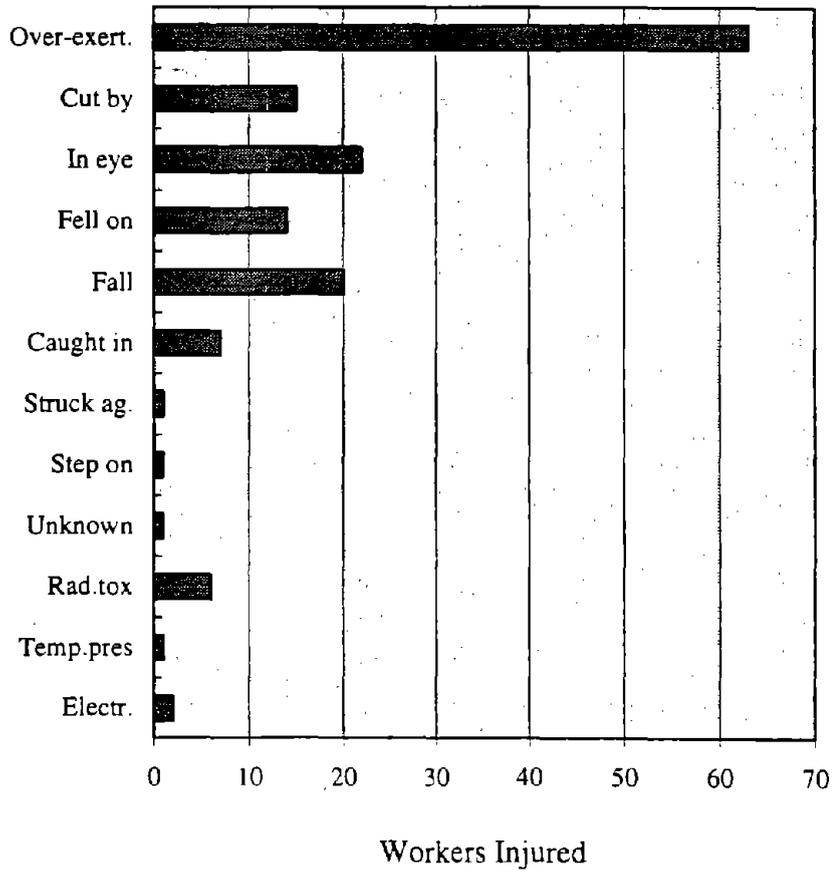(Total Number of Injuries = 1688)

Figure 2: Distribution of Hospitalization by Type of Injury
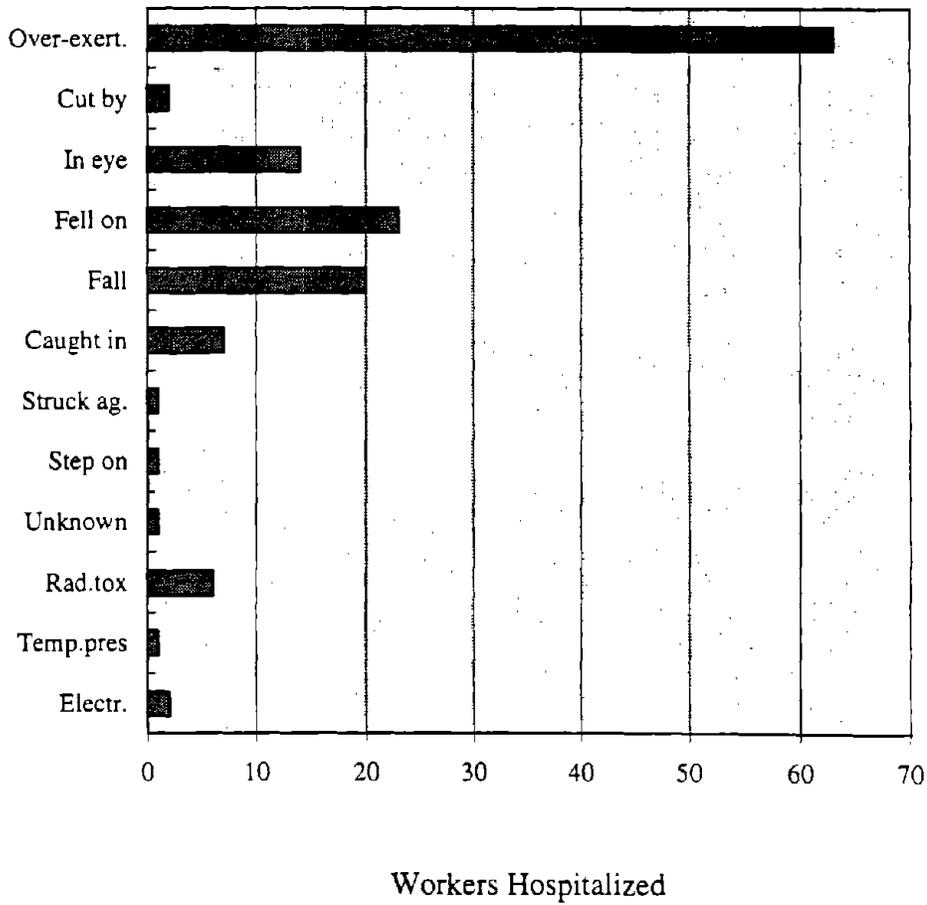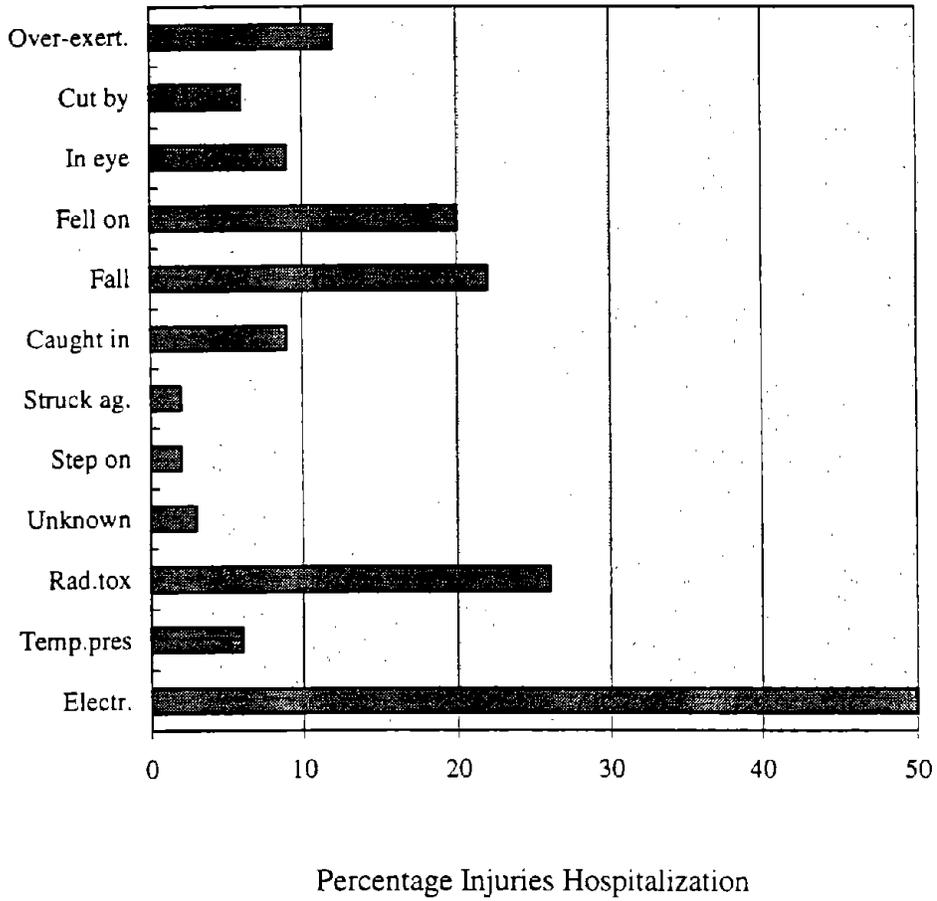(Total Number of Hospitalizations = 176)

Workers Hospitalized

Figure 3: Distribution of Percentage of Hospitalization by Type of Injury

Percentage Injuries Hospitalization

Figure 4: Distribution of Injuries by Trade Classification
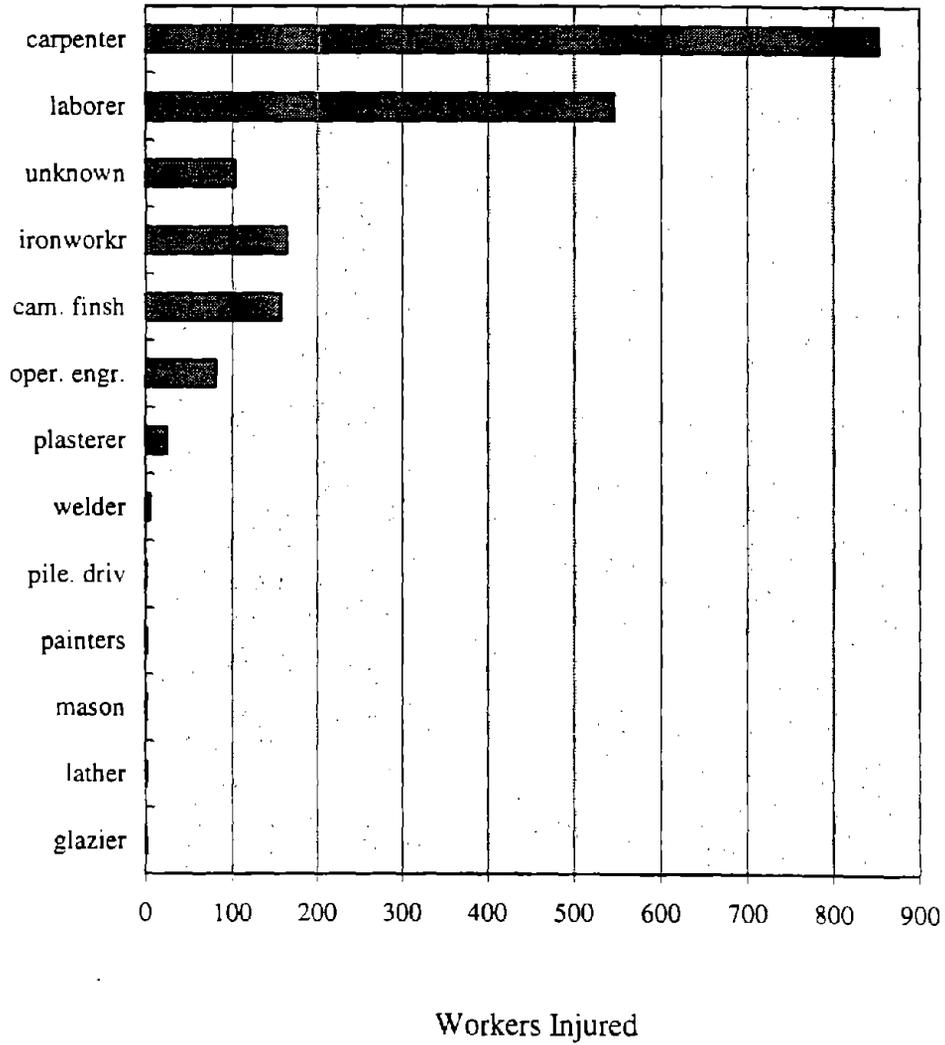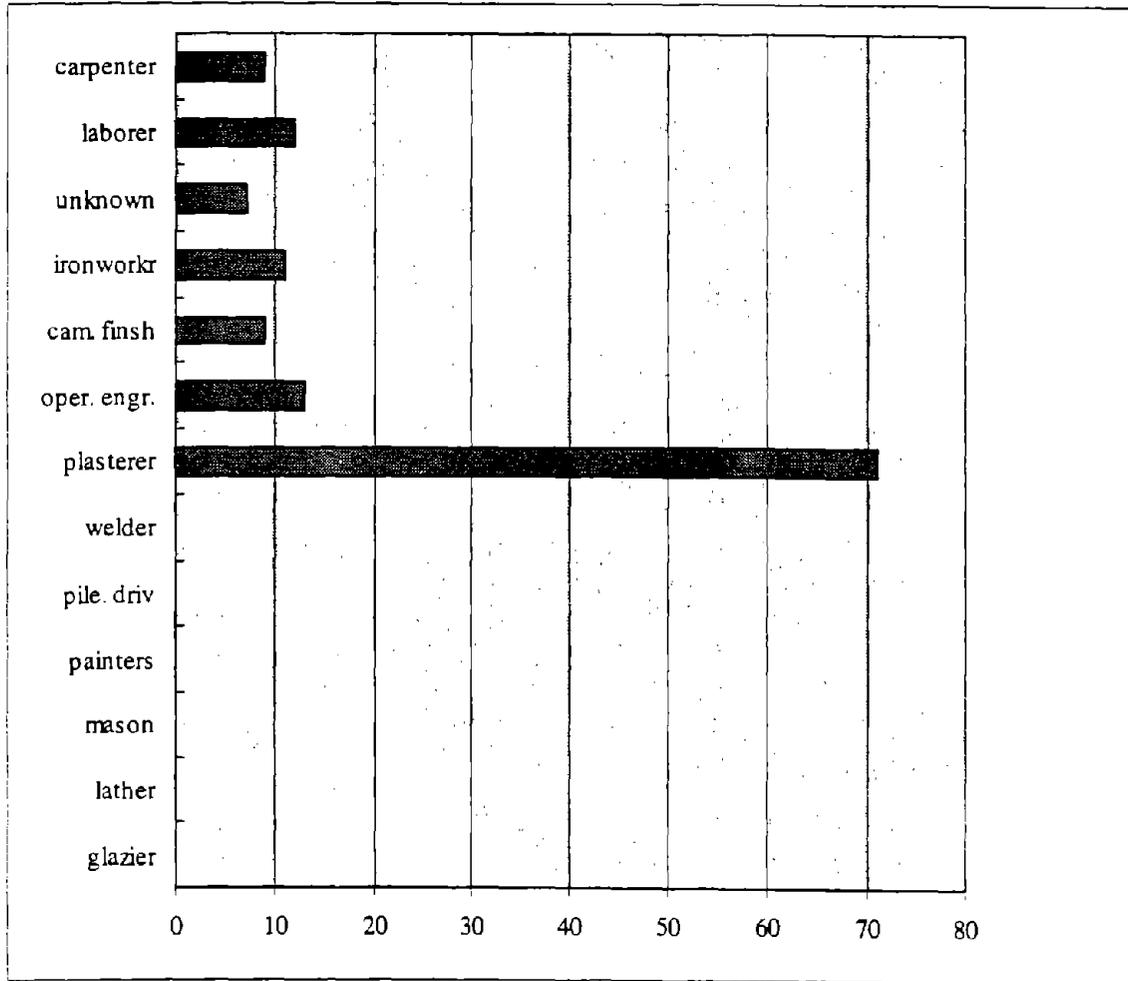(Total Number of Injuries = 1688)

Workers Injured

Figure 5: Distribution of Hospitalization by Trade Classification
(Total Number of Hospitalizations = 176)

Percent Injuries Hospitalized

Figure 6: Percentage of Workers Hospitalized by Trade Classification
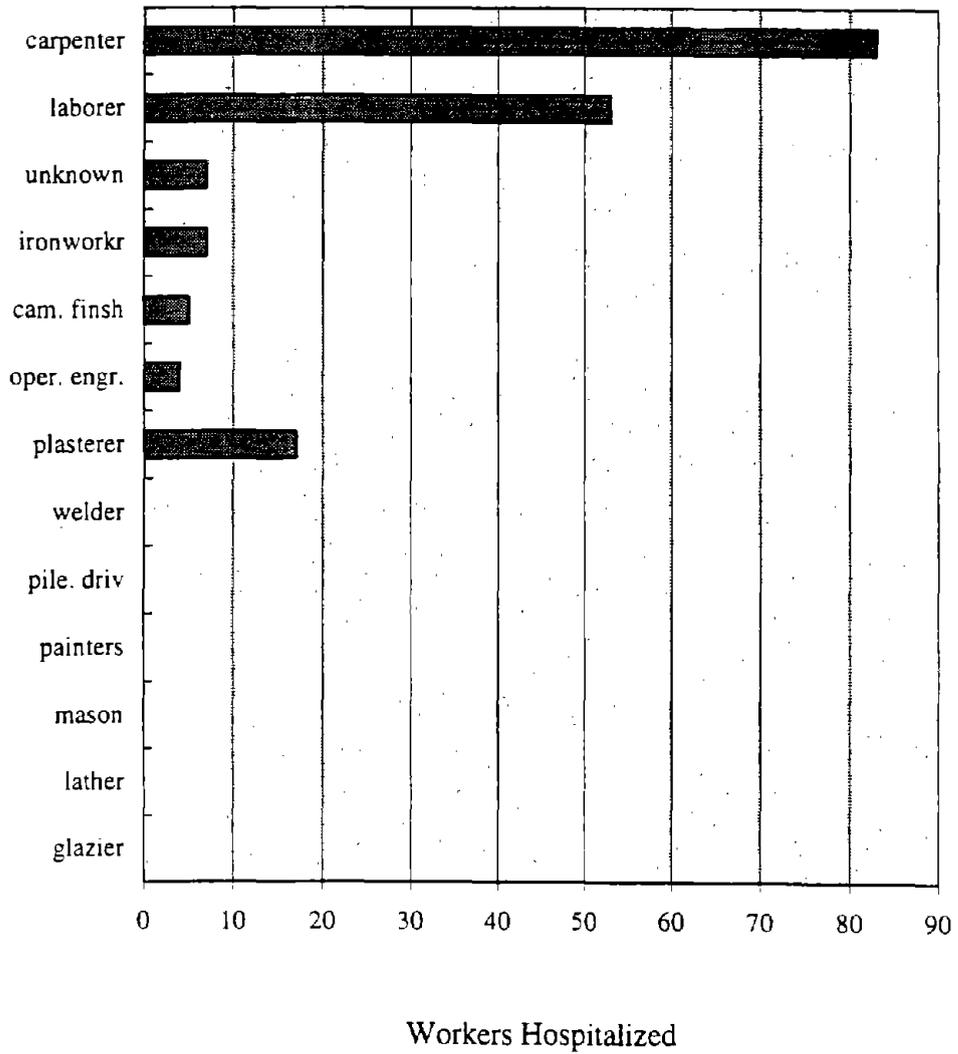

Workers Hospitalized

Figure 7: Distribution of Injuries Phase of Work (Task at time of Injury)
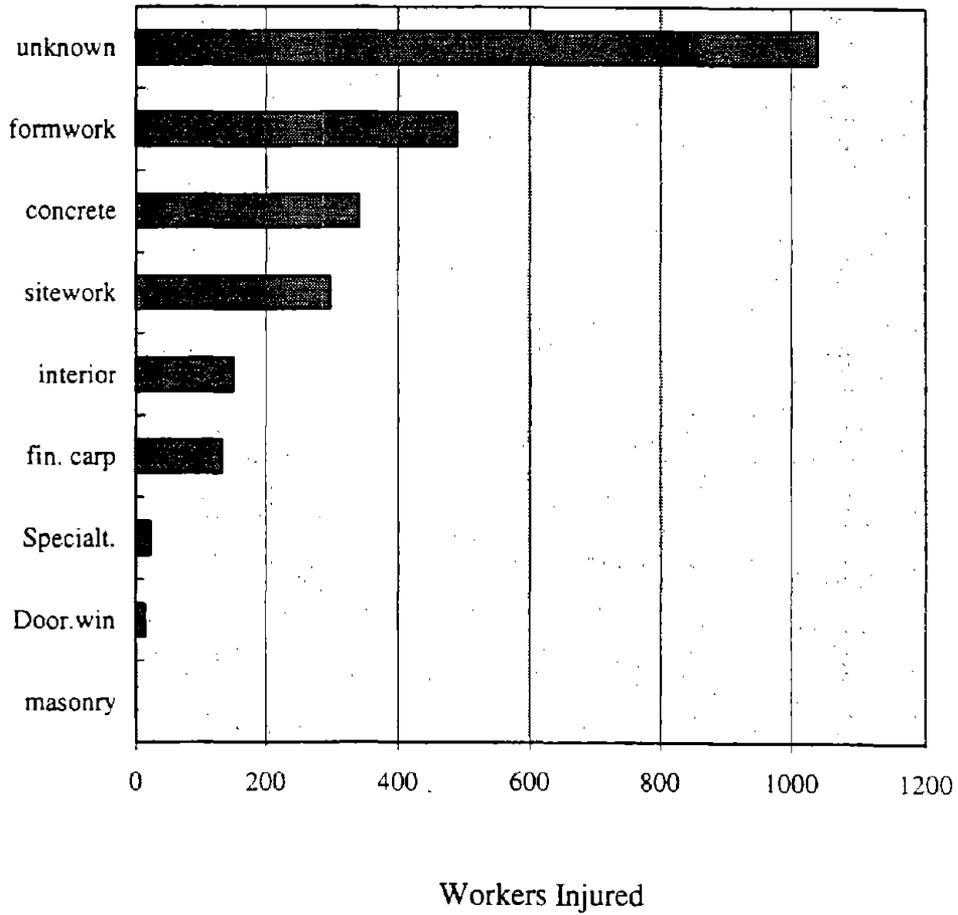(Total Number of Injuries = 1688)

Workers Injured

Figure 8: Distribution of Hospitalization by Phase of Work
(Task at time of Injury)

(Total Number of Injuries = 176)
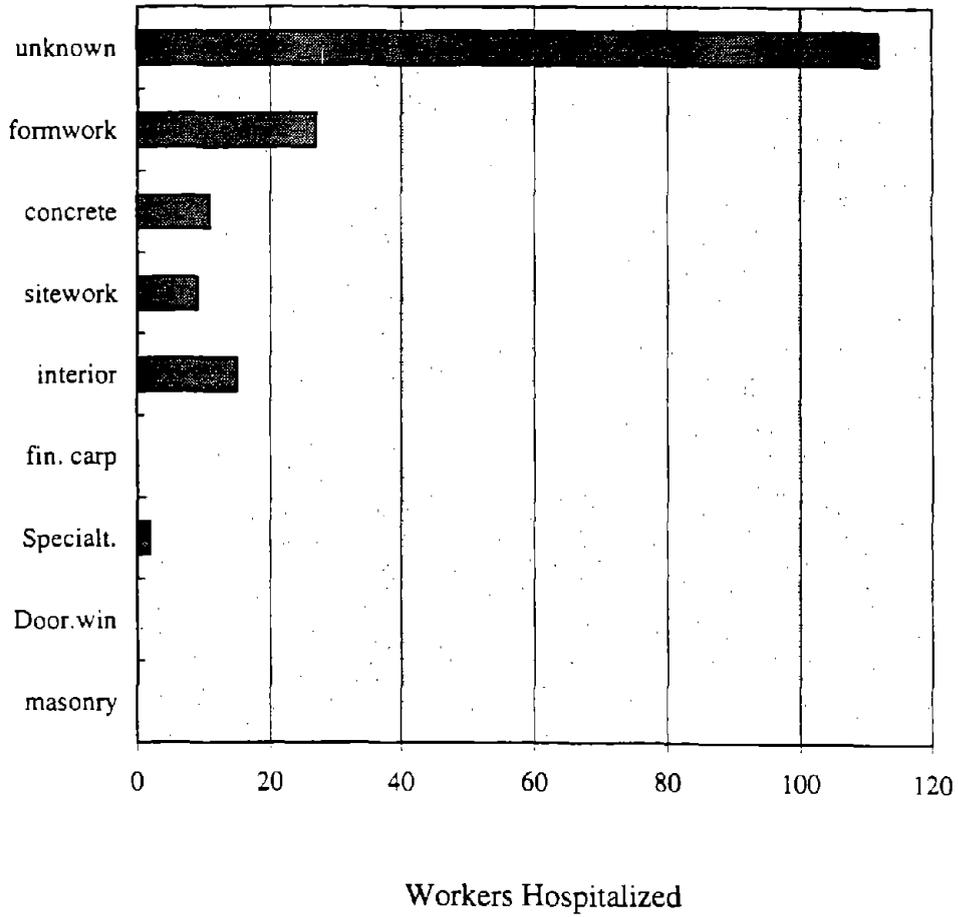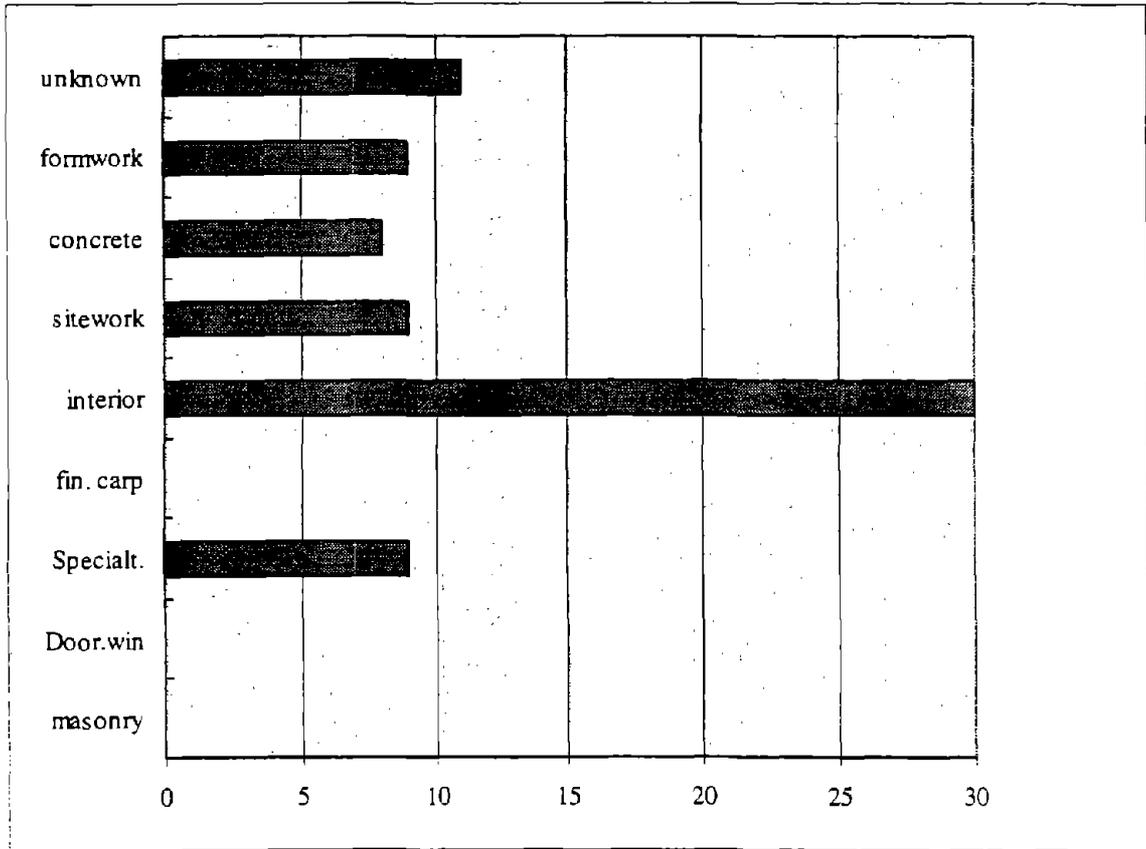

Workers Hospitalized

Figure 9: Distribution of Percentage Injuries by Phase of Work
(Task at time of Injury)

Percent Injuries Hospitalized

Table 34 gives a similar summary according to project type. Among the projects types with a substantial number of injuries, the pattern for the rate of hospitalization per injury was similar to the rate of injuries per man-hour, with construction of office space having a lower rate. The exception was that medical construction had a hospitalization rate more similar to office construction than to institutional, factory or retail space.

Table 34: Hospitalizations by Project Type

Type of Project	Total	Hospitalizations			
	Injured	Unknown	No	Yes	Percent
Office	266	1	250	15	5.7
Institution	522	3	466	53	10.2
Factory	246	5	208	33	13.7
Medical	107	0	101	6	5.6
Retail	108	1	96	11	10.3
Church	22	0	22	0	0.0
Entertainment	12	0	12	0	0.0
Garage	29	0	29	0	0.0
Restaurant	7	0	7	0	0.0
Other bldg	234	0	220	14	6.0
Non-bldg	135	0	91	44	32.6

Table 35 summarized hospitalizations by type of structure. The variation in hospitalization rates is not significant (p=.12) based on a chi-square test. Steel, steel-and-concrete, and masonry structures, which had fewer injuries per worker-year (though not significantly so), had no advantage in terms of hospitalizations. Pre-cast structures had a higher fraction of injuries requiring hospitalization, as well as a high rate over all injury rate, but this is based on only 12 injuries. Restricting attention to new construction yields similar results, except that for wood and other structures, the hospitalizations were mostly from renovation projects.

Table 35: Hospitalizations by Structure Type

Type of Project	Total	Hospitalizations			
	Injured	Unknown	No	Yes	Percent
steel+concrete	330	1	284	45	13.7
cast-in-place	253	1	232	20	7.9
steel	150	3	129	18	12.2
masonry	103	0	89	14	13.6
tilt-up	144	1	131	12	8.4
wood	104	1	95	8	7.8
pre-cast	12	0	9	3	25.0
Other	221	2	202	17	7.8
Non-bldg	371	1	331	39	10.5

Conclusions

In addition to descriptive information about the construction activities and safety related practices of commercial contractors , the major findings included: (1) the existence a large variation in injury rates between contractors, (2) an increase in injury rate per unit of labor with increasing financial size of a project, (3) a reduction in injury rates associated with supervisory personnel, at least at the lower end of the scale, and (4) lower injury rates for renovations as opposed to new construction.

The variation in injury rates between contractors and between projects may reflect unmeasured or even unmeasurable attributes of the contractor and workforce. The inverse association between supervision and injury rates was strong enough to counter a strong increase in the hazard with increasing project cost, resulting in an overall decline in injury rate with increasing cost. These are observational data, and the amount of supervision may reflect other features of a contract or project that impact on safety. The effect of managers and superintendents in the prediction model are descriptive of the population of projects as found, but would probably overstate the effect of increasing supervision in future projects by a given contractor.

Many safety practices, such as formal employee safety training and regular safety meetings were so uniform in this population that no estimate of their impact is possible. The failure to detect a measurable impact of these practices does not cast doubt on their worth. The data are simply not informative enough on these questions.

Financial incentives (and disincentives) did appear to be related to injury rates in the full model, but the strong association of incentives with both financial size and supervision greatly complicates the interpretation. Their positive association with injury rates, adjusted for project cost and supervision, casts doubt on the inefficacy, but this should be viewed as a tentative finding. If for example, financial incentives and disincentives are associated with a history of safety problems, they could yield improvements in safety, yet be associated with high injury rates in an observational study such as this.

While the hospitalization data are more descriptive in nature, they strongly suggest that falls are more likely than other types of injuries to lead to hospitalization, and that plasterers are more likely than most trades to be hospitalized if injured at all. The result for falls has obvious implications for safety, but the finding about plasterers needs to be qualified by their low incidence of injury, and the lack of knowledge about their representation in the workforce.

ACKNOWLEDGMENTS

REFERENCES

and

APPENDICES

ACKNOWLEDGEMENTS

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APPENDICES

Data Collection Forms

- Contractor Characteristics Data Form

- Project Characteristics Data Form

- Injured Worker Data Form

COMMERCIAL CONSTRUCTION SITE
INJURY DATA COLLECTION AND ENTRY FORM
(Revised 5/10/94)

CONTRACTOR CHARACTERISTICS DATA

1. Experience (# of months in business as of 12/31/93)   [_____]

*2. Size in dollars (Gross Income):   National   Washiington

                                1991 [_____]   [_____]
                                1992 [_____]   [_____]
                                1993 [_____]   [_____]

3. Professional Affiliation: [_____]
     1=Union
     2=Non-Union (merit shop)
     3=Double-breasted
     4=Unknown

*4.Number of contracts
     Total number of projects under contract in:

                                        1991 [_____]
                                        1992 [_____]
                                        1993 [_____]

     Total number of contracts completed in:

                                        1991 [_____]
                                        1992 [_____]
                                        1993 [_____]

*5. Do you perform other categories of construction work   [___]
     besides commercial construction?
          1 = yes
          2 = no
          If yes, what other categories?   [___]
          1 = Heavy, highway, paving
          2 = Industrial
          3 = Underground utilities
          4 = Marine
          5 = Other (please specify)_____

                                        Contractor Number_____

*6. Number of person months   1991   1992   1993
      Permanent salaried (home office)
      Average temporary Hourly (field)
      Permanent hourly (field supervisory)
      W-2's issued per year

[____][____][____]
[____][____][____]
[____][____][____]
[____][____][____]

7. Mandatory Drug Testing Policy?   [_____][_____][_____]
     1=Yes
     2=No

8. Dedicated Company Safety Director?   [_____][_____][_____]
     1=Yes
     2=No
          If yes, % of time   [_____][_____][_____]

9. Formal Safety Program?   [_____][_____][_____]
     1=Yes
     2=No

*10. Number of injuries requiring attention by   [_____][_____][_____]
      licensed caregiver on all projects

NOTES AND EXPLANATIONS:

Contractor Number_____

PROJECT CHARACTERISTICS DATA

*1. Project Data Number   [_____]

*2. Contracted Duration in months   *(CALENDAR DAYS)*   [_____]

3. Actual Duration in months   [_____]

4. Dates:

       Starting Date (day/month/year)   [_____]

       Completion Date (day/month/year)   [_____]

*5. Physical Size:
   Number of stories   [_____]

   Finished height of building   [_____]

   Physical Building Area in square feet   [_____]

*6. Financial size:
   Contracted Amount in dollars   [$_____]

   Actual (final) contract amount received   [$_____]

7. Scope of project:
   1= New Const.,   [_____]
   2=Remodelling/renovation

8. Type of Project: [_____]
   1=Office Building
   2=Retail Space
   3=Parking Garage
   4=Factory
   5=Entertainment Facility (Theater, etc.)
   6=Restaurant/Bar
   7=Institutional (Schools, etc.)
   8=Church
   9=Medical (Hospitals, Laboratories, etc.)
   10=Other (Please specify)_____
   99=Unknown

Contractor Number/Project Number_____/____

*9. Type of structure (frame):   [_____]
        1=cast-in-place
        2=pre-cast concrete
        3=tilt-up concrete
        4=structural steel
        5= steel & concrete combination
        6=wood/timber
        7=masonry
        8=other (please specify)_____
        99=unknown

10. Contract Delivery System   [_____]
        1=Competitive lump sum bid
        2=Negotiated lump sum
        3=Design-Build
        4=Construction Management
        5=Time & Materials
        6=Other (Please specify)_____
        99=unknown

11. Fast-Track?   [_____]
        1=Yes
        2=No

12. Partnering agreement used?   [_____]
        1=yes
        2=no

13. TQM concept implemented?   [_____]
        1=yes
        2=no

14. Employee safety training?   [_____]
        1=yes
        2=no

15. # of safety meetings per week   [_____]

16. Safety incentive program?   [_____]
        1=yes
        2=no

Contractor Number/Project Number_____/_____

17. Safety disincentive program?   [_____]
    1=yes
    2=no

*18. Number of Specialty Contractors (Subcontractors) on this   [_____]
     project

*19. Total number of General Contractor's manhours on project   [_____]

20. Number of Project Managers assigned to project   [_____]

*21. Number of field supervisory staff assigned to project

                                    Superintendent(s)   [_____]

                                    Field/Office Engineer(s) [_____]

                                              1991 1992 1993

*22. Total Number of injuries on this project to employees
     of General Contractor   [____] [____] [____]

*23. Total number of lost workdays due to injuries
     on this project   [____] [____] [____]

NOTES AND EXPLANATIONS:

Contractor Number/Project Number_____/_____

INJURED WORKER DATA

*1. Date of injury (day/month/year)   [_____]

*2. Date injured worker returned to work (day/month/year)   [_____]

3. Was injured worker hospitalized?   [_____]

        1 = yes
        2 = no

4. Age of injured worker   [_____]

5. Sex of injured worker   [_____]
           1=Male
           2=Female

6. Type on injury:

        1 = Struck against, rubbed or abraded   [___]

        2 = Struck by   [___]

        3 = Caught in, under or between   [___]

        4 = Fall on same level   [___]

        5 = Fall to different level   [___]

        6 = Overexertion or bodily reaction   [___]

        7 = Contact with temperature or pressure extremes   [___]

        8 = Contact with radiation, caustics or toxics   [___]

        9 = Contact with electric current   [___]

        10 = Stepped on object (nail, wire, etc.)   [___]

        11 = Cut by   [___]

        12 = Foreign object in eye   [___]

Contractor # /Project # /InjuredWorker #/injury#:____/____/____/____

*7. Trade classification of injured worker   [_____]
             1=carpenter
             2=cement finishers
             3=electricians
             4=glaziers
             5=lathers
             6=laborers
             7=ironworkers
             8=masons
             9=operating engrs.
             10=painters
             11=pile drivers
             12=plasterers
             13=steel erectors
             14=tile setters
             15=waterproofers
             16=welders
             17=other
             99=unknown

8. # of manhours of worker on project before injury (if available)   [_____]

*9. Category of work being performed at time of injury: [_____]
             1=sitework
             2=concrete (foundation)
             3=formwork (foundation)
             4=concrete (slab on grade)
             5=formwork (slab on grade)
             6=concrete (elevated slab)
             7=formwork (elevated slab)
             8=concrete (wall below grade)
             9=formwork (wall below grade)
             10=concrete (wall above grade)
             11=formwork (wall above grade)
             11=other rough carpentry work (please specify_____)
             12=finish carpentry
             13=other interior work (please specify_____)
             14=masonry
             15=Door, windows and glass
             16=Specialties
             17=other (please specify_____)
             18=various
             99=unknown

Contractor # /Project # /Injured Worker #/injury #_____/_____/_____/_____

10. If more than one injury to this worker, on this project,
# of manhours since previous injury   [_____]

11. Total number of workers at site at time of injury   [_____]

*12. Direct cost of injury   [_____]

NOTES AND EXPLANATIONS

Contractor # /Project # /Injured Worker #/injury #_____/_____/___/____

List of Possible Future Publications

1. Journal of Safety Research

2. Cost Engineering (The International journal of Cost Estimation, Cost/Schedule Control, and Project Management)

3. The American Professional Constructor (The Journal of the American Institute of Constructors)

4. Builder and Contractor

5. Journal of Construction Engineering and Management

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	6.

7. Author(s) Bentil, K. K., and F. M. Rivara	8. Performing Organization Rept. No.

9. Performing Organization Name and Address Department of Building Construction, College of Architecture and Urban Planning, University of Washington, Seattle, Washington	10. Project/Task/Work Unit No.
	11. Contract (C) or Grant(G) No. (C) (G) R01-OH-02743

12. Sponsoring Organization Name and Address	13. Type of Report & Period Covered
	14.

15. Supplementary Notes

16. Abstract (Limit: 200 words) The purpose of this study was to develop knowledge that can be used in preventing traumatic injuries at commercial construction sites. General contractors operating in the state of Washington and performing commercial types of construction were contacted in order to obtain information on construction site injuries occurring between 1991 and 1993, offering a total of 730 commercial projects. The overall rate of injury was 23 injuries per 10 worker years. Several strong associations were developed on analysis. Renovations tended to have a lower rate of injury than did new construction. The injury rate was strongly related to the balance between the project size and the number of supervisory personnel. Analysis suggests that the rate of injuries increases with the financial size of the project, but decreases as the number of supervisory personnel are increased from absent to moderate levels. The data cast some doubt on the value of financial incentives and disincentives, but this is qualified by a strong association of their use with other features of projects that are relevant to safety. Injuries involving cuts, blows, objects in the eye, and falls were also large contributors to both total injuries and hospitalizations, with falls accounting for a disproportionate number of hospitalizations.

17. Document Analysis   a. Descriptors

b. Identifiers/Open-Ended Terms NIOSH-Publication,   NIOSH-Grant,   Grant-Number-R01-OH-02743, End-Date-03-31-1996, Traumatic-injuries, Accident-analysis, Accident-prevention, Risk-factors, Risk-analysis, Epidemiology, Construction-industry, Construction-workers

c. COSATI Field/Group

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